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Article

A Hybrid Methodology Based on Smart Management Energy Consumption in Irrigation Systems

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Abstract: Innovative practices in irrigation systems can bring improvements in terms of economic efficiency and in the same time can reduce environmental impact. Investment in high tech technologies frequently involves additional costs, but an efficient water management can increase the lifetime of the equipment. The main objective of this article is to reduce the energy consumption by one thousand cubic meters pumped and automati

cally to increase the economic efficiency of the pumping groups. This paper develops a new operating algorithm that ensures the operation of the pumping group at safe operating intervals and in the same time identifies the equivalent pump operating points for the entire flow range and pumping height of the pumping group. This methodology is based on the principles of an Expert System to perform the optimization process of the energy consumption in pumping groups. The resulting methodology avoids the combinatorial explosion of the solutions to be analyzed and determines the point of maximum efficiency without violation of any of the system constraints under any operating condition. The proposed methodology is tested on an irrigation system that includes a pumping group with 5 pumps, showing its effectiveness in obtaining the optimal solution with a relatively low computational burden.

Keywords: energy consumption; optimization; expert system; irrigation system;

1. Introduction

The irrigation systems from crop field contain odd looking metal pipe structures on wheels stretching across the fields. These metal monsters, known as pivot irrigation systems, are used in large-scale in agriculture and have considerably improved the efficiency of the irrigation process. These irrigation systems were designed to take a large amount of the manual work out of irrigation and make it easier on the farmer to control the irrigation process in multiple locations. Over the years, the irrigation systems have gone through various improvements and many options are available today including water, hydraulic and electrically driven versions, [1].

Nowadays, the modern irrigation systems are equipped with PLC (programmable logic controllers) in the control panel for a better monitoring process status (by purchasing the device inputs via sensors, buttons, state variables of the process) and for an automated control (which involves processing of the input information and generating the required commands to automation process, according to a specific program). The most utilize electronic device for a smart management pumping units from an irrigation systems, is the frequency converter that can regulate the speed of the motors that control the pumps according to the consumption of water, so that it does not pump more water than is needed. New control technologies in irrigation systems could enhance the irrigation efficiency, stimulating water conservation and reducing the environmental impacts, [2,3].

The necessity for a more integrated and sustainable approach to control water resources in Europe is reflected in water-related policy and legislation. In the last decades, the European Union has implemented a wide range of environmental legislation. As a consequence, water, air and soil pollution has been meaningfully attenuated. Nowadays, the EU citizens enjoy some of the best water quality in the world and beyond 18% of EU territory have been appointed as protected areas, [4,5]. However, many challenges persist and these must be approached together in a structured way. These are the reasons for promoting integrated water resource management, involving all stakeholders from policy makers to water suppliers and end-users. In present, the 8th Environment Action Program (EAP) guides the European environment policy until 2030, [6]. One of the most important objectives of this program is to managing water resources in a sustainable and integrated way and to accelerate the transition to a climate-neutral, resource-efficient and regenerative economy, in the way that gives back more than it takes from the planet. The national, regional and local authorities need to introduce measures to improve the efficiency and to encourage changes in agricultural practices necessary to protect water resources and to increase the environmental quality.

For an optimal irrigation management it is always suitable, as far as possible, to have automatic irrigation control systems. A lot of advantages are referred to an efficient irrigation control system, such as saves energy, labor and water, increase the efficiency of irrigation, reduce the maintenance costs, production rises due to optimization of irrigation, [7,8].

In the literature, various studies have been carried out regarding the optimal irrigation management, each researcher having different points of view on this subject. Most of the proposed works are oriented on the controllers design that can support the levels required in the irrigation canals satisfying the water irrigation demand. But, the most important problem encountered in practice it refers to: how to serve the water demand in order to reduce the energy consumption by optimally scheduling the pumping groups.

Table 1 presents a synthesis of the solution proposed in literature depending on type of analysis (efficient use of irrigation water or reduce the energy consumption) and type of optimization method (classical or Artificial intelligence). Most of the papers formulated the analysis neglecting the energy consumption in the process of control water resources. Classical optimization methods based on linear programming [9–11], nonlinear programming [12,13], quadratic programming [14,15], and dynamic programming, [16,17] was used for an economic impact evaluation in irrigation systems. Also, the Artificial Intelligence techniques (AI), such as Genetic Algorithms, [18–20], Fuzzy techniques [21–23], Neural Networks [24] and Expert Systems, [25–27], are able to solve the problems form irrigation systems which are non-linear, complex and ill-defined. These Artificial Intelligence algorithms were designed to emulate the human decision-making process and were deployed for implementing an adaptive decision support in irrigation process.

Table 1. Synthesis of the Literature Approaches.

		Methods	
		Classical	**Artificial intelligence**
Type of study	water use	[9],[10],[11],[12],[14],[16],[17]	[18],[21],[22],[24],[25],[26],[27]
	energy consumption	[13],[15]	[19],[20],[23]

Using new technologies based on innovative tools, the farmers can cope with the challenges and requests of the future. By making the best allowable operational decisions, the efficiency will increase and in the same time the revenue rises. An optimal irrigation control implies a good coordination between each pump from the pumping groups.

This paper proposes a hybrid methodology that can control the pumping groups within irrigation system. The main objective of this paper is to reduce energy consumption at a 1000 cubic meters pumped and automatically to increase the economic efficiency of the pumping groups.

This paper aims to develop an integrated system, based on Expert System principles, that, in addition to ensuring the operation of the pumping group at safe operating intervals, to identify the equivalent pump operating points for the entire flow range and pumping height of the pumping group. Thus, indifferent of the pumping heights and flow ranges at a given time, the maximum efficiency point can be identified and managed to achieve the minimum energy consumption.

The main contributions of the paper are:

- The conceptualization of the methodology for smart management of the pumping groups from an irrigation system;
- The adaptation of the general Expert Systems principles using common encoding for the three hydraulic operating cases;
- The validation of the proposed methodology in a case study that uses a real input data from the Romanian irrigation systems;
- Discussions regarding the possible advantages and disadvantages of each hydraulic operating regime.

Considering this aspects, the researches, techniques, methods and procedures for command and control of the pumping groups from an irrigation system were developed within an Expert System (ES) in order to achieve the objective function, to minimize the energy consumption at a thousand cubic meters pumped, and in the same time taking into account a number of constraints such as maintaining constant the pressure, the cost of pumping as low as possible, the highest efficiency of the equivalent pump. This methodology aims to determine the maximum efficiency point of an irrigation system in different hydraulic regimes. Actually this maximum efficiency point represents the optimal frequency band for which the pumping cost is minimal.

The remainder of this paper is organized as follows. Section 2 describes the principles of an Expert System, synthesizing the existing approaches and providing the rationale for developing the proposed methodology for optimization process of the energy consumption in pumping groups. Section 3 presents the results of the proposed methodology into an irrigation system that includes a pumping group with 5 pumps of 160 kW and finally the paper ends with a discussion and the concluding remarks.

1.1. Irrigation systems status in EU

In Europe, there is a great variability and availability of water resources and hence a spatial variability marked in agricultural water management practices and consumption. Climate is the main factor determining water consumption in agriculture, there are regions where irrigation is the only source of water for growing crops (this is the case in summer in some Mediterranean areas), while in other regions irrigation is used as a supplement to rain-fed farming. Irrigation technology is also a major factor influencing the level of water consumption in agriculture. The agriculture sector used 30% of the total water consumption in Europe, but achieves to 70% of total water consumption in several European Southern countries. In in the countries of the European Union, in 2016 the total irrigable surface was of 18.644 million hectares, increasing by 13.4 % compared to 2003. The surface irrigated in 2016 was of 10.221 million of hectares. The biggest shares of irrigated surfaces are localized in regions of the Mediterranean countries such as Italy, Spain, Cyprus, Greece, Malta and the coast of Portugal. In Southern European countries the irrigation systems are an important and essential element in major types of agricultural production. In Northern and Central and European countries, supplementary irrigation is generally used to improve production in dry summers, [28,29]. In Figure 1 is presented the share of irrigated areas in EU countries in 2016.

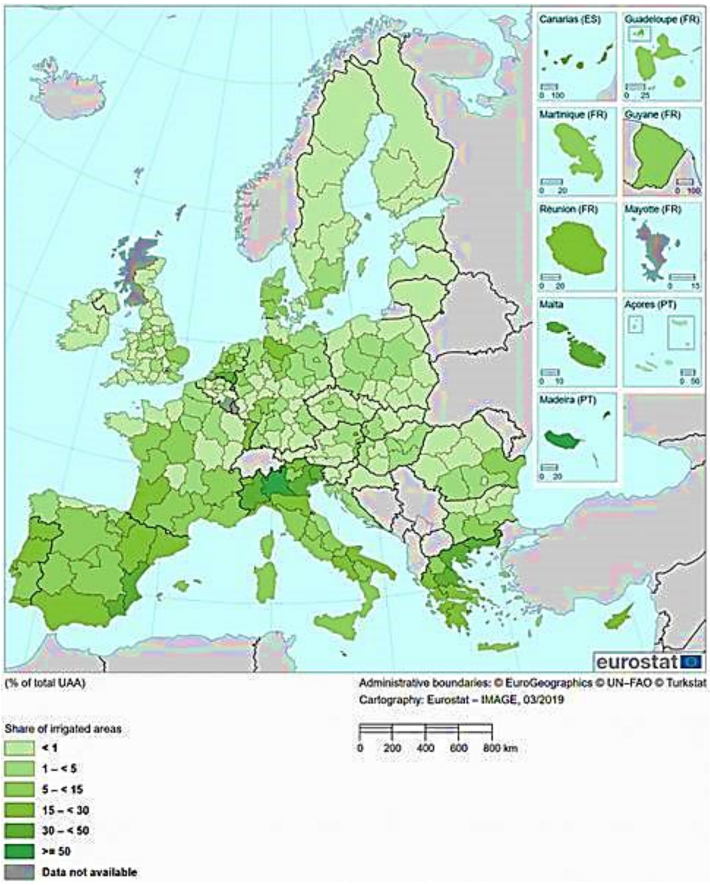

Figure 1. Share of irrigated areas in EU countries in 2016, (Source: Eurostat 2019).

The biggest shares of irrigable surfaces at country level are expectedly found in some Southern Member States: in Greece and Malta shares of 44.9% and 38.6% were recorded respectively. Cyprus, Italy and Spain followed with 34.9%, 33.9% and 31.1% respectively. Amazingly high was the irrigable surface from Netherlands, 27.0%, and Denmark, 16.8%, countries less linked to the term of irrigation. In Romania and Slovakia the shares of irrigable surface decreased by 11.2% and 4.5 % and their shares of irrigated area also decreased by 2.2% and 3.6% respectively [4,30].

Taking into consideration that the irrigation systems in Romania were built up to 1990, the principal problems that facing now the irrigation systems are as follows, low hydraulic efficiency, the high cost of electricity for the systems still based on pumping (the Danube being the main source of water) and high water tariffs. The area irrigated hold on about 22% of the agricultural surface of the country and about 34% of the arable area. It is estimated that approximately 11% of the Romanian agricultural surface is coated by economically viable or marginally viable irrigation networks. Differences occur from one region to another depending on rainfall and irrigation requirements. West, Northwest and Center involve less irrigation water, while the Southern and Southeast, areas with water problems, and enjoy greater coverage with irrigation systems, [31].

In Romania, the situation of the current irrigation systems infrastructure is characterized by a low efficiency of base and pumping stations, of about 45%, and a degree of degradation of waterproofing of canals and hydrotechnical constructions of about 75%. In this sense Romania through the National Program for Rehabilitation of the Main Irrigation Infrastructure from 2016 try to outline the strategic goals regarding the rehabilitation of the main irrigation infrastructure that will lead to an increase in the functional area from viable surface and economically viable margin for irrigation at 70% in 2020 and with 90% in the horizon 2030, [32]. The specific objective of the Program is to increase the efficiency of base (fixed and floating) and pumping stations, to eliminate water losses through infiltration from irrigation channels belonging to the public domain and to eliminate the degradation occurring in the hydrotechnical constructions. A solution to increase the pumping station efficiency could be the replacing the pumps with fixed speed (50 Hz) that are technically outdated, with some with variable speed through frequency converters that lead to a significant decrease in energy consumption, [33].

2. Materials and Methods

In Artificial Intelligence, an Expert System (ES) is a tool capable to emulate the judgment process that a human expert would employ in a decision-making process. The Expert System was made by extracting knowledge from human experts and was implemented in a computer program for knowledge processing, so that to be able to handle quantitative and qualitative data. Comparing to other conventional programs that require prescript algorithms, the Expert System allows inexact reasoning and can cope with incomplete data.

Based on its application the Expert System can be used in design and planning, control, classification or identification, diagnosis, prediction, etc. A lot of applications was resolved using the Expert Systems, such as optimal power allocation between hydropower plants of dispatchable unit, [34], fault diagnosis in power plants, [35,36], power systems control, [37], system expansion planning, [38,39], power losses evaluation, [40], power quality compensators, [41], robotic control domain, [42,43].

The authors have chosen the ES for implementing the integrated system to ensuring the operation of the pumping group at safe operating intervals, to identify the equivalent pump operating points for the entire flow range and pumping height of the pumping group, because of its specific technique is to follow the behavior that a human expert practice it in the decision-making process. The following subsections describe the basic structure of the ES and the implementation chosen by the authors for the proposed methodology.

2.1. The Expert Systems

The Expert Systems collects the human decision-making expertise and heuristics representing it in a series of rules and facts, aims to solve some difficult problems whose traditional approach would require significant human experience. The *knowledge base* and *inference rules* are models of the experience of the best specialists capable to solve the problems, [44, 45]. Thus, an ES is a computing system that emulates the decision-making ability by the human expert.

The *knowledge base* contains all the specialized knowledge provided by the human expert's experience, relevant to a particular field. The knowledge base consists of two parts: the rules basis and the basis of facts. If the rule base is the relatively static part of the knowledge base, the basis of facts is the dynamic part of the knowledge base.

The fundamental issue of the ES is the definition of methods for representing a large amount of knowledge in a form that allows its storage and efficiently use. The knowledge representation affects the development, efficiency and speed of the method proposed. Knowledge representation has been realized and developed according to the knowledge specifics, through: production rules, semantic frame, object-oriented programming, etc. The production rules are among the most commonly used methods of knowledge representation in the ES, based on a structure such as:

Condition (facts) ⇨ **Action**

this can be interpreted as follows:

IF (condition is satisfied) ⇨ **THEN** (action can be performed)

The *knowledge base* for the issue addressed in this paper totalize a series of pumping group information such as voltages, currents, frequencies, flows for each pump, and the pressure that must to be maintained constant throughout the hydraulic operation regime.

An example of a production rule associated with the problem of determination the maximum efficiency point in an irrigation system is presented in the following:

IF (requested flow is high) & (pressure is constant) ⇨ **THEN** (maximum efficiency point is recorded in the frequency band)

The *inference engine* is the logical module of the ES based on facts, takes the knowledge base rules, builds reasoning, makes associations and links, and proposes a solution to the problem. An appropriate calculation method that implements the inference engine is required for proper processing of all information's in the knowledge base. The basic concept of ES operation and the relation with users is presented in Figure 2.

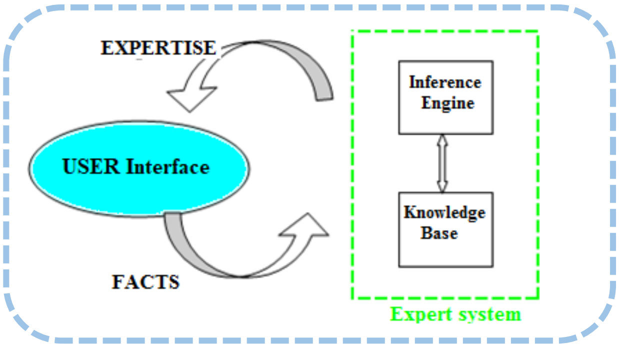

Figure 2. The basic concept of ES operation.

2.2. The proposed methodology for irrigation systems control

The problem studied in the paper is based on the principles of an ES and develops a new operating algorithm for optimization process of energy consumption in pumping groups. In Figure 3 is presented the flow chart of the integrated system for power consumption optimization and the structure of the integrated system is described in the following. Thus, the steps of the proposed methodology that aims to decrease the energy consumption of a thousand cubic meters pumped are the following:

1. Introduction of the characteristic parameters for each pump: *voltages*, *currents*, *frequencies* (*speeds*), and *flows* for each hydraulic operating mode. First off all ***Measurement and to Organize the database*** is necessary. In this step it detects the data that must to be mined, and then selecting the appropriate input attributes and output information to represent the task. The characteristic parameters for each pump are identified and organized in the database: voltages, currents, frequencies (speeds) and flows for each hydraulic operating mode. After the first step follows the ***Hydraulic operating regime identification***. The analysis was performed on a set of data with several stationary regimes, but without the technological possibility of balancing all possible hydraulic regimes of the pumping station.
2. The input data acquisition and processing and calculation of the power consumed for each pump, i, where i indicate the pump number from the pumping groups (i = 1 ... N_P, where N_P represents the total number of pumps from the pumping group) and n the number of measurements for a hydraulic operating mode. Thus, the input data subjected to the optimization process have these features recorded in a matrix [ID], having the size $N_P \times n$.

$$[ID]_{N_P \times n} = \begin{bmatrix} U_{i,1} & I_{i,1} & F_{i,1} & P_{i,1} & D_{i,1} & P_{t,1} & D_{t,1} & E_{Pe,1} & C\_p_{i,1} \\ U_{i,2} & I_{i,2} & F_{i,2} & P_{i,2} & D_{i,2} & P_{t,2} & D_{t,2} & E_{Pe,2} & C\_p_{i,2} \\ .... & .... & & & .... & & & & .... \\ U_{i,n} & I_{i,n} & F_{i,n} & P_{i,n} & D_{i,n} & P_{t,n} & D_{t,n} & E_{Pe,n} & C\_p_{i,n} \end{bmatrix}, \quad (1)$$

where N_P represents the total number of pumps integrated in the pumping group from the irrigation system; $U_{i,n}$ correspond to the voltages measured for each pump,

i, i = 1 ... N_P, in function of the number of measurements for a hydraulic operating mode, n; I_{in} indicates the currents measured for each pump, i, i = 1 ... N_P, in function of the number of measurements for a hydraulic operating mode, n; $F_{i,n}$ represents the frequencies (speeds) measured for each pump, i, i = 1 ... N_P, in function of the number of measurements for a hydraulic operating mode, n; $P_{i,n}$ indicate the instantaneous power calculated for each pump, i, i = 1 ... N_P, in function of the number of measurements for a hydraulic operating mode, n; $D_{i,n}$ correspond to the flows measured for each pump, i, i = 1 ... N_P, in function of the number of measurements for a hydraulic operating mode, n; $P_{t,n}$ represents the power on the equivalent pump in function of n; $D_{t,n}$ indicate the flow on the equivalent pump in function of n; $E_{Pe,n}$ represents the efficiency of the equivalent pump calculate in function of the number of measurements for a hydraulic operating mode, n; $C\_p_{i,n}$ correspond to the pumping cost calculated per 1000 cubic meters pumped per meters H_2O column in function of the number of measurements for a hydraulic operating mode, n.

3. *Intenal step. Frequency band for a hydraulic operating regime*. In this step the flow and the power for the equivalent pump, as well as the efficiency of the equivalent pump and the pumping cost, are determined, all parameters being included in the input data matrix. In the following are detailed the parameters calculated in the internal step:
   - Count the number of pumps switched on, to calculate the flow on the equivalent pump, $D_{t,n}$;
   - Calculate the power of the equivalent pump, $P_{t,n}$;
   - Determine the efficiency of the equivalent pump, $E_{Pe,n}$, using the following relation:

$$E_{Pe,n} = D_{t,n} \cdot H_{s,n} / (P_t \cdot M_e \cdot Df), \quad (2)$$

   where: $D_{t,n}$ indicate the total flow in function of the number of measurements for a hydraulic operating mode, n, [m³/h]; $H_{s,n}$ represents the pressure of the irrigation system in function of the number of measurements for a hydraulic operating mode, n, [bar]; P_t correspond to the total power on the irrigation system, [kW]; M_e indicate the engine efficiency, given by the catalog, 96%; D_f represent the motor drive factor (transmission factor) given data by the catalog, [0.9 – 1].
   - Calculate the pumping cost, $C\_p_{i,n}$, [kW/1000m³/mcH_2O] per 1000 cubic meters pumped per meters H_2O column, in function of the number of measurements for a hydraulic operating mode, n, with the relation:

$$C\_p_{i,n} = [P_t / (D_{t,n} / 1000)] / (H_{s,n} * 10), \quad (3)$$

4. Graphical representation of the *frequency-flow* and *frequency-power characteristics* for each pump, $F = f(D_i)$, $F = f(P_i)$. The maximum efficiency point is determined from the frequency-flow and frequency-power characteristics analysis. The characteristics representation is made for each pump for a particular hydraulic operating regime.
5. Graphical representation of the *frequency-efficiency* and *frequency- pumping cost* for the equivalent pump, $F = f(E_{Pe,n})$, $F = f(C\_p_{i,n})$. For a higher accuracy in determination the maximum efficiency point of a pumping group, the frequency-efficiency and frequency-pump cost characteristics for the equivalent pump, of a hydraulic operating regime were determined.
6. Determination of the *maximum efficiency point* of the hydraulic operating regime. In this last step a *decision matrix* which takes into account the pumping cost, the pumping group efficiency and the total flow required at a constant pressure is developed. From the decision matrix will result the optimal frequency band for which the pumping cost is minimal. The maximum efficiency point is determined for each hydraulic operating regime identified in the second step of the flow chart proposed.

The developed method is intended to be used for a larger data volume that reflects more hydraulic operating regimes by providing a variable load (variable flow from the pumping station).

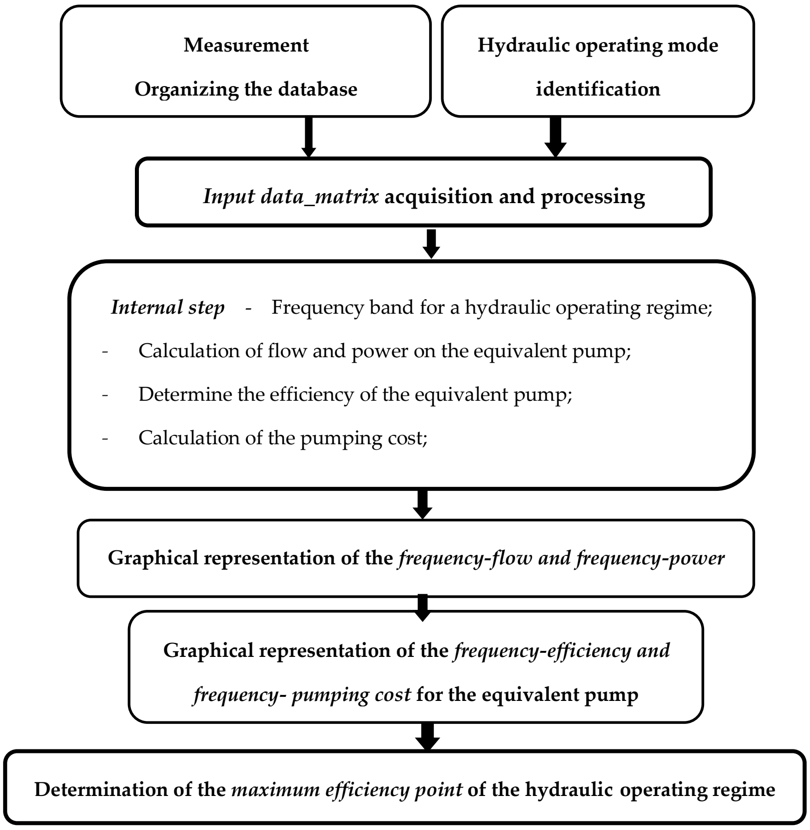

Figure 3. The flow chart of the integrated system for power consumption optimization.

3. Results

In order to show the characteristic of the proposed methodology is analyzed an irrigation system from Romania, which includes a pumping group with 5 pumps of 160 kW. The technical parameters for the vertical pumps, model (P16C 10 55 4Y), included in the pumping group are presented in Tables 2 and 3. The hybrid methodology was developed and implemented in Matlab.

Table 2. The operating characteristics of the vertical pumps from the pumping group.

Operating Characteristics of the Vertical Pumps	
Service flow rate [m³/h]	504
Service head [m]	84
Q*min* [m³/h]	104.22
Q*max* [m³/h]	800.07
Hydraulic efficiency [%]	82.6

The parameters monitored and collected for each vertical pump refers to voltages, currents, frequencies (speeds) and flows for each hydraulic operating mode. On the data measured in the irrigation system was applied the proposed methodology for different hydraulic operating mode, the case with 2 pumps in operation, with 3 pumps and 4 pumps. The case with all 5 pumps in operation wasn't possible to be analyzed because during the field measurements, the pilot station didn't use all pumps. These hydraulic regimes have been chosen on this way, because all 5 vertical pumps are identical.

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Table 3. The electric motor characteristics for vertical pumps from the pumping group.

Electric Motor Characteristics	
Nominal power [kW]	160
Rated frequency [Hz]	50
Rated voltage [V]	400
Rated current [A]	277.1
No. poles	4
Rotation speed [rotations/min]	1485
Power factor	0.87
Efficiency [%]	96.2

In the next step the input data matrix is arranged and a normalization factor is used because in the case of the flow were 4 measurements/ minute and for the voltage, current and frequency were 6 measurements/ minute. It was agreed to mediate in this way that there is one measurement per minute for all monitored parameters, which means one measurement per minute in 12 hours for a pump in operation, (60 x 12=720 measured values for each parameter per day). In the Figures 4 – 7 are represented the normalized monitored parameters just for hydraulic operating mode with 4 pumps. It is possible to see on the graphs the starting regime of pumps, all monitored parameters recording variations (red circle) until they enter the normal operating regime.

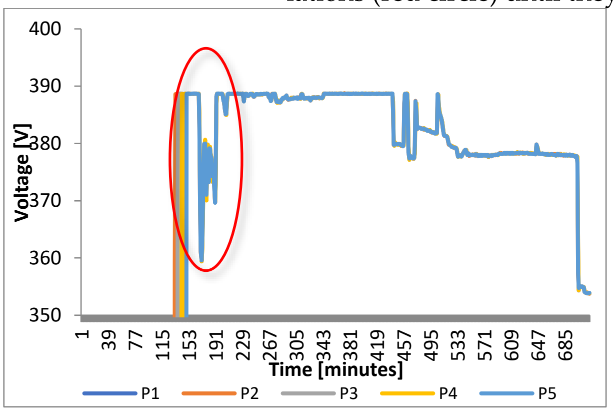

Figure 4. Voltage variations during one day.

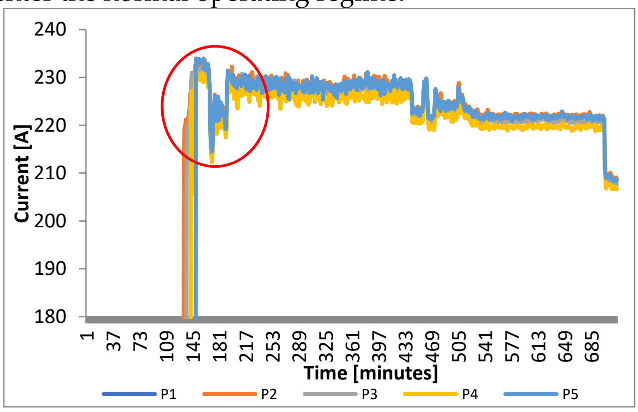

Figure 5. Current values during one day.

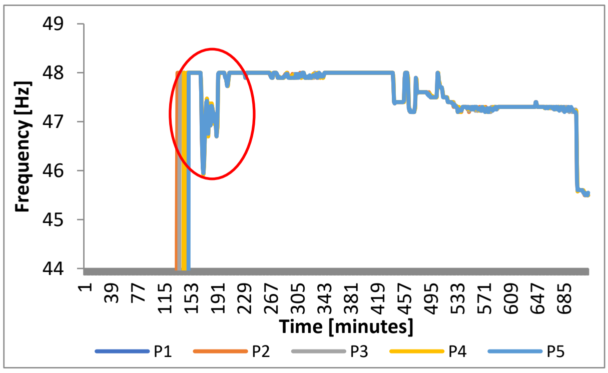

Figure 6. Frequence variations during one day.

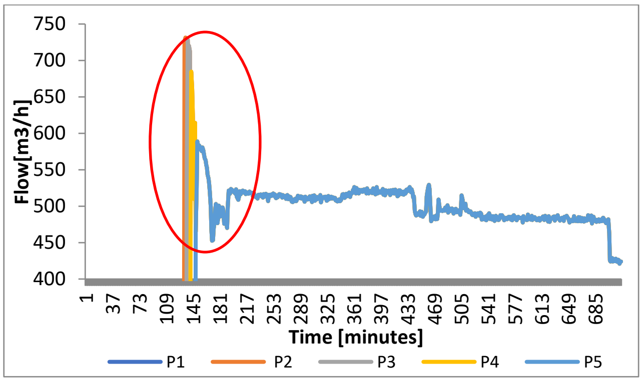

Figure 7. Flow values during one day.

Using the data included in the input data matrix and the parameter for the equivalent pump, the graphical representation of the characteristics $F=f(D_i)$, $F=f(P_i)$, $F = f(E_{Pe,n})$, $F=f(C\_p_{i,n})$, for each hydraulic operating mode, is achieved in the following subsections.

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3.1. Case 1. Hydraulic operating mode with 2 pumps in operation

In Figures 8, 9, 10 and 11 are represented the characteristics $F=f(D_i)$, $F=f(P_i)$, $F = f(E_{Pe,n})$ and $F=f(C\_p_{i,n})$ for the case with 2 pumps in operation. In this case are in operation the pumps P1 and P2. From the $F=f(D_i)$ and $F=f(P_i)$ characteristics, Figs. 8 and 9 can be observed two frequency band of operation, [44 – 45.5] and [47 - 48.5] and also some sparse values that were excluded in the maximum efficiency point determination. The best degrees of efficiency and the minimal pumping costs are registered in frequency band [44 – 45.5], Figs 10 and 11.

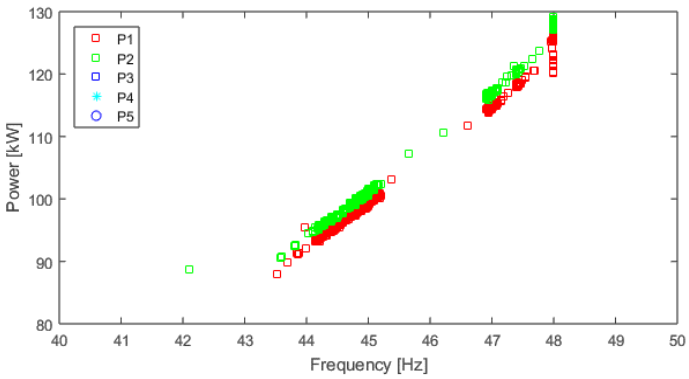

Figure 8. The characteristic $F=f(P_i)$ for the hydraulic regime with 2 pumps in operation.

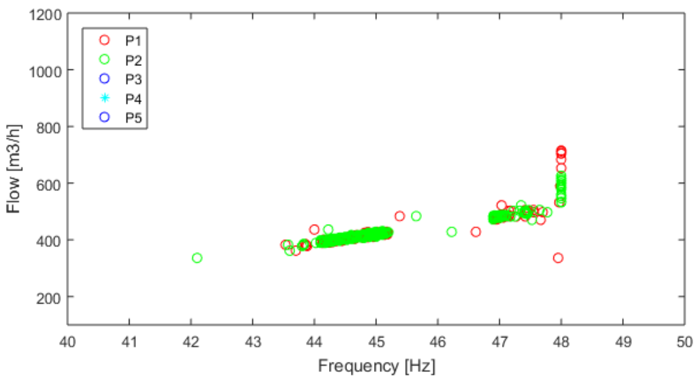

Figure 9. The characteristic $F=f(D_i)$ for the hydraulic regime with 2 pumps in operation.

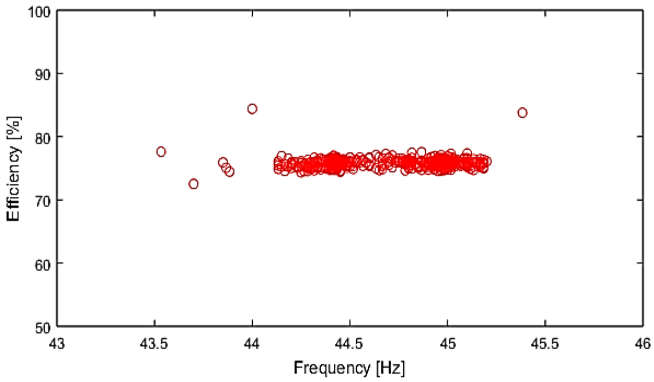

Figure 10. The characteristic $F=f(E_{Pe,n})$ for the hydraulic regime with 2 pumps in operation.

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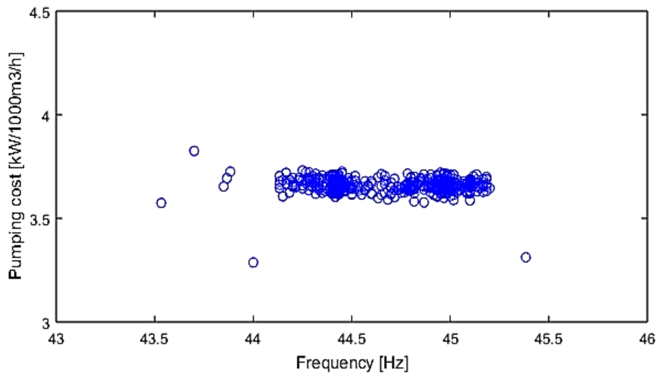

Figure 11. The characteristic *F=f(C_pi,n)* for the hydraulic regime with 2 pumps in operation.

3.2. Case 2. Hydraulic operating mode with 3 pumps in operation

In Figures 12, 13, 14 and 15 are represented the characteristics $F=f(D_i)$, $F=f(P_i)$, $F = f(E_{Pe,n})$ and $F=f(C\_p_{i,n})$ for the case with 3 pumps in operation. In this case are in operation the pumps P1, P2 and P4. From the $F=f(D_i)$ and $F=f(P_i)$, characteristics, Figures 12 and 13 can be observed a large frequency band of operation, [41.2 – 47.9] and also some sparse values that were excluded in the maximum efficiency point determination. The best degrees of efficiency and the minimal pumping costs are registered in frequency band [44.5 – 46.5], Figures 14 and 15.

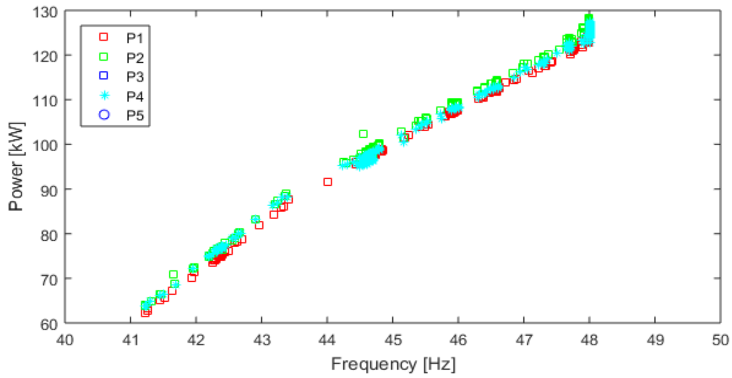

Figure 12. The characteristic $F=f(P_i)$ for the hydraulic regime with 3 pumps in operation.

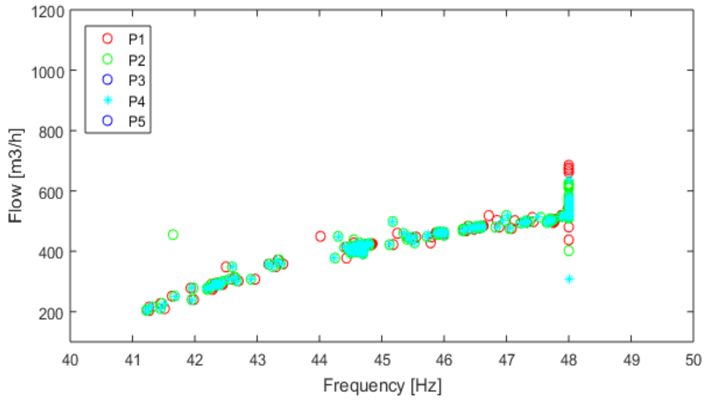

Figure 13. The characteristic *F=f(Di)* for the hydraulic regime with 3 pumps in operation.

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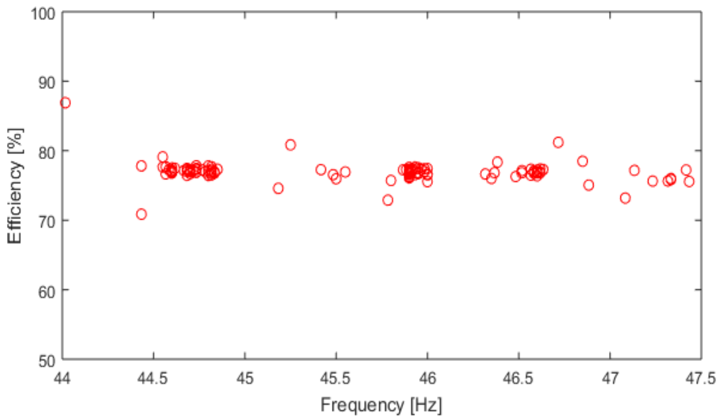

Figure 14. The characteristic $F=f(E_{Pe,n})$ for the hydraulic regime with 3 pumps in operation.

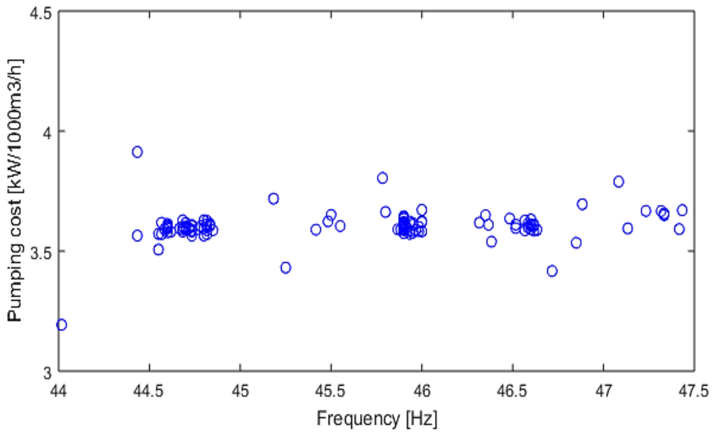

Figure 15. The characteristic $F=f(C\_p_{i,n})$ for the hydraulic regime with 3 pumps in operation.

3.3. Case 3. Hydraulic operating mode with 4 pumps in operation

In Figures 16, 17, 18 and 19 are represented the characteristics $F=f(D_i)$, $F=f(P_i)$, $F = f(E_{Pe,n})$ and $F=f(C\_p_{i,n})$ for the case with 4 pumps in operation. In this case are in operation the pumps P1, P2, P3 and P4. From the $F=f(D_i)$and $F=f(P_i)$ characteristics, Figs. 16 and 17 can be observed a finite frequency band of operation, [40.7– 41.8] and also some sparse values that were excluded in the maximum efficiency point determination. The best degrees of efficiency and the minimal pumping costs are registered in frequency band [41.3 – 41.8], Figs. 18 and 19.

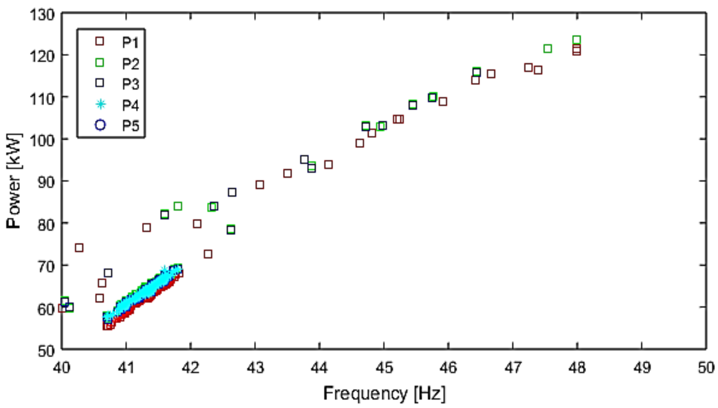

Figure 16. The characteristic $F=f(P_i)$ for the hydraulic regime with 4 pumps in operation.

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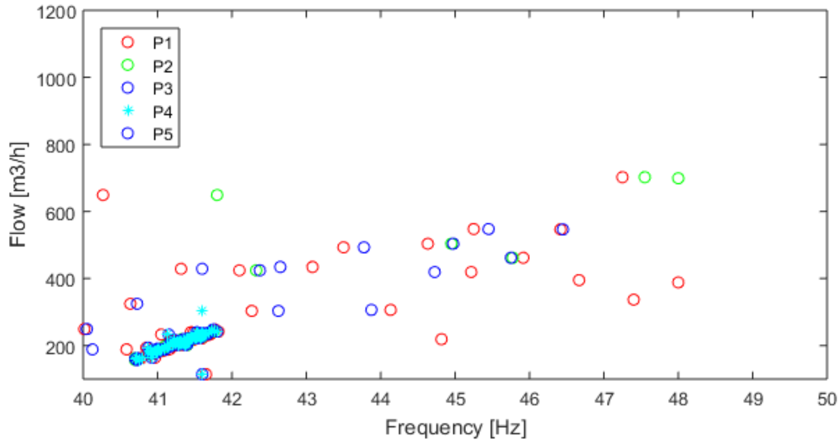

Figure 17. The characteristic *F=f(Di)* for the hydraulic regime with 4 pumps in operation.

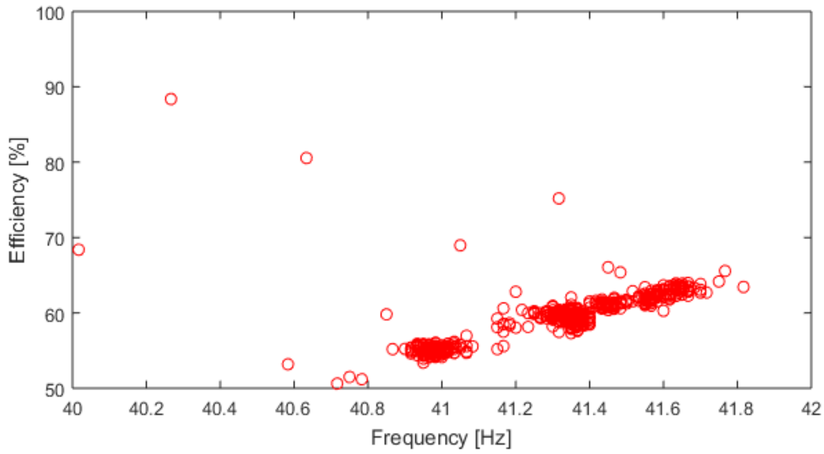

Figure 18. The characteristic *F=f(EPe,n)* for the hydraulic regime with 4 pumps in operation.

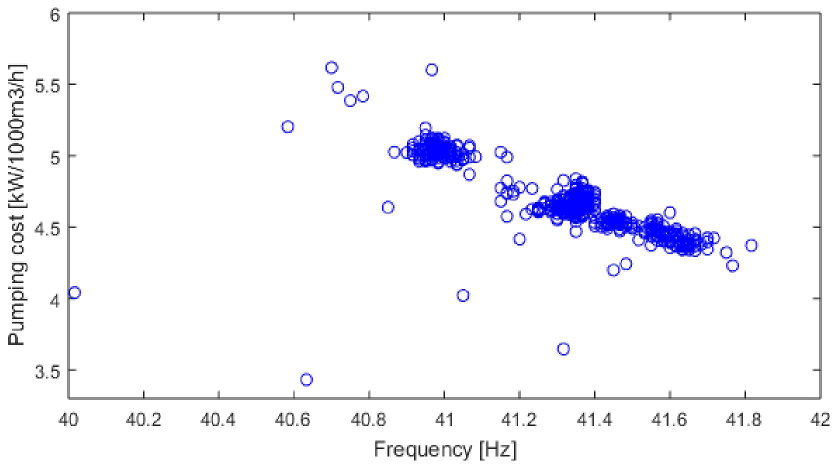

Figure 19. The characteristic *F=f(C_pi,n)* for the hydraulic regime with 4 pumps in operation.

3.4. *The maximum efficiency point determination using the decision matrix*

In the last step of the hybrid methodology proposed is developed the decision matrix which takes into account the pumping cost, the pumping group efficiency and the total flow required at a constant pressure. The optimal frequency band result from the graph analysis, when pumping cost is minimal. The maximum efficiency point is determined for

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each hydraulic operating regime. Thus, in Table 4 is shown the decision matrix, where for the optimal frequency bands are presented the efficiency band, the pumping costs and the flows band for each hydraulic operating regime. So, in Case 1, with two pumps in operation, the maximum efficiency point is recorded in optimal frequency band [44 -45.5], for Case 2, with three pumps in function, the optimal frequency band is [44.5 - 46.5] and for Case 3, with four pumps in operation, the maximum efficiency point is registered in optimal frequency band [41.3 - 41.8].

Table 4. The decision matrix for each hydraulic operating regime.

Hydraulic regime		**Flow** [m^3/h]	**Pumping cost** [kW/1000m^3/mc H_2O]	**Efficiency** [%]	**Optimal frequency band** [Hz]
Case 1	*P1 P2*	[810 - 850]	[3.64 - 3.7]	[75.3 – 76.4]	[44 - 45.5]
Case 2	*P1 P2 P4*	[1230 – 1370]	[3.53 - 3.60]	[76.7 – 77.3]	[44.5 - 46.5]
Case 3	*P1 P2 P3 P4*	[890 -930]	[4.24 – 4.5]	[61.5 – 65.3]	[41.3 - 41.8]

4. Discussion

In this paper, an integrated system for optimizing the energy consumption for 1000 cubic meters pumped in a pumping group within irrigation system is developed. The proposed methodology based on principles of Expert Systems has been successfully used to establish the maximum efficiency point for each hydraulic operating regime. Sensitivity information is embedded in the procedure through the determination the optimal frequency band for which the pumping cost is minimal. The solution process is relatively fast, as it excludes cases which violate system constraints under any operating conditions. Using the proposed methodology, with easy implementation of the Expert System principles for unsupervised learning in the decision making process, the computation time and the volume of calculation are reduced significantly by exploiting the knowledge of the characteristic parameters for each pump from the pumping group.

Based on the decision matrix results obtained from the integrated system, the human operator can modify the program from the PLC and can implement the decision matrix with a granularity that will take into account the PLC capabilities. Depending on the hydraulic regime and decision matrix, the optimum operating mode was proposed on the automation system screen (HMI, PC etc. ...) through clear messages addressed to the human operator, which will basically consist in number of pumps that should work for a minimum consumption at one thousand cubic meters pumped. After raising the level of confidence in the Expert System implemented in PLC, it will be possible to pass to automatic switching of the operating mode. The numerical results obtained for each hydraulic operating regime in the pumping group indicated that the proposed methodology is effective to achieve the minimum energy consumption.

5. Conclusions

The paper takes a new approach in smart management energy consumption in irrigation systems. Compared with the approach in which the irrigation system is oriented on the controllers design that can support the levels required in the irrigation canals satisfying the water irrigation demand, the methodology proposed by the authors considered the optimally scheduling the pumping groups in order to reduce the energy consumption. Using the flexibility of the Expert systems principles, the three cases were modeled, making the results easier to compare and evaluate, a feature that is a key factor for an optimal management in irrigation systems and for a maximum efficiency point in each hydraulic operating regime.

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References

1. Improving Pivot Irrigation Systems with Automation Direct. Available online: https://library.automationdirect.com /improving-pivot-irrigation-systems-with-automationdirect-issue-37-2017/, accessed on 28 September 2021.
2. Nikolaou, G.; Neocleous, D.; Katsoulas, N.; Kittas, C. Irrgation of Greenhouse Crops, *Journal of Horticulturae*, **2019**, doi:10.3390/horticulturae5010007, *Volume* 5, No. 7.
3. Sowah, R.A.; Armoo, S.K.; Koumadi, K.M.; Agyeman, R.; Fiawoo, S.Y. Design and Development of an Efficient and Cost-Effective Microcontroller-Based Irrigation Control System to Enhance Food Security, *Int. Journal of Electrical and Information Engineering*, **2014**, *Volume* 8, No. 8, pp. 1343-1350.
4. Agri-environmental indicator – irrigation. Available online: http://ec.europa.eu/eurostat/statistics-explained/index.php /Agri-environmental_indicator_-_irrigation, accessed on 12 September 2021.
5. Farm Level Optimal Water Management Assistant for Irrigation Under Deficit. Available online: https://www.wur.nl/ upload_mm/3/9/0/ba6fb1fe-5281-4f64-b4f9-1ce9dbd1c61f_FlowAid_Brochure.pdf, accessed on 03 September 2021.
6. Environment action programme to 2030. https://ec.europa.eu/environment/strategy/environment-action- programme-2030_en#:~:text=These%20include%20biodiversity%20loss%2C%20climate%20change%2C%20resource%20use,climate%20action%20objectives%20of%20the%20European%20Green%20Deal accessed on 15 September 2021.
7. Automatic Watering System. http://www.novedades-agricolas.com/en/irrigation/irrigation-systems/authomatic-watering-system, accessed on 01 September 2021.
8. Levidow, L.; Zaccaria, D.; Maia, R.; Vivas, E.; Todorovic, M.; Scardigno, A. Improving water-efficient irrigation: prospects and difficulties of innovative practices, *Agricultural Water Management*, **2014**, *Volume* 146, pp. 84–94.
9. Difallah ,W.; Benahmed, K.; Draoui, B.; Bounaama, F. Linear Optimization Model for Efficient Use of Irrigation Water, *Int. Journal of Agronomy*, **2017**, Article ID: 5353648, https://doi.org/10.1155/2017/5353648.
10. Singh, A.; Panda, S.N. Optimization and Simulation Modelling for Managing the Problems of Water Resources, *Water Resources Management*, **2013**, *Volume* 27, no. 9, pp. 3421–3431.
11. Lord, M.S. Linear Programming Optimizing the Resources, I*nterdisciplinary Journal of Contemporary research in business*, **2013**, *Volume* 4, pp. 701–705.
12. Azimi, V.; Salmasi, F.; Entekhabi, N.; Tabari, H.; Niaghi, A.R. Optimization Of Deficit Irrigation Using Non-Linear Programming, (Case study:Mianeh region, Iran), *Int. Journal of Agriculture and Crop Sciences*, **2013**, *Volume* 6, no. 5, pp. 252–260.
13. Bockari-Gevao, S.M.; Wan Ishak, W.I.; Azmi, Y.; Chan, C.W. Analysis of energy consumption in lowland rice-based cropping system of Malaysia, *Songklanakarin J. Sci. Technol.*, **2005**, *Volume* 27, no. 4, pp. 819-826.
14. Jiang, L.; Songa, J.; Li, M.; Shang, S.; Ma, X.; Yang, J.; Adeloyed, A. Optimization of irrigation scheduling for spring wheat based on simulation-optimization model under uncertainty, *Agricultural Water Management*, **2018**, *Volume* 208, pp. 245-260.
15. Galindo, J.; Torok, S.; Salguero, F.; De Campos, S.; Romera, J. ; Puig, V. Optimal Management of Water and Energy in Irrigation Systems: Application to the Bardenas Canal, *IFAC-PapersOnLine*, , **2017**, *Volume* 50, no. 1, pp. 6613-6618.
16. Fang, Z.X.; Voron, B.; Bocquillon, C. Dynamic Programming: A Model for an Irrigation Reservoir, *Hydrological Sciences Journal*, **1989**, *Volume* 34, no. 4, pp. 415–424.
17. Zhang, D.; Guo, P.; Liu, X.; Chen, J.; Jiang, C. Greenhouse Irrigation Optimization Decision Support System, 7th Int. Conf. on Computer and Computing Tech. in Agriculture (CCTA), Beijing, Chin, 2014, Springer, IFIP Advances in Information and Communication Technology, AICT-420 (Part II), pp.10-23.
18. Kuo, S.F.; Liu, C.W. Simulation and Optimization Model For Irrigation Planning and Management, *Hydrological Processes*, **2003**, *Volume* 17, no. 15, pp. 3141–3159.
19. De Ocampo, A.L.P.; Dadios, E.P. Energy Cost Optimization In Irrigation System Of Smart Farm By Using Genetic Algorithm, IEEE 9th Int. Conf. on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management , 2017, DOI: 10.1109/HNICEM.2017.8269497.

20. Moradi-Jalal, M.; Rodin, S.I.; Marino, M.A. Use of Genetic Algorithm in Optimization of Irrigation Pumping Stations, *Journal of Irrigation and Drainage Engineering*, , **2004**, *Volume* 130, no.5, https://doi.org/10.1061/(ASCE)0733-9437(2004)130:5(357).
21. Gao, L.; Zhang, M.; Chen, G. An intelligent irrigation system based on wireless sensor network and fuzzy control, *Journal of Networks*, **2013**, *Volume* 8, no. 5, pp. 1080–1087.
22. Mohapatraa, A.G.; Lenka, S. K. Neural Network Pattern Classification and Weather Dependent Fuzzy Logic Model for Irrigation Control in WSN Based Precision Agriculture, *Procedia Computer Science*, **2016**, *Volume* 78, pp. 499-506.
23. Marinescu, T.; Arghira, N.; Hossu, D.; Fagarasan, I.; Stamatescu, I.; Stamatescu, G.; Calofir, V.; Iliescu, S. Advanced control strategies for irrigation systems, 9th IEEE Int. Conf. on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, 2017, DOI: 10.1109/IDAACS.2017.8095206.
24. Capraro, F.; Patino, D.; Tosetti, S.; Schugurensky, C. Neural Network-Based Irrigation Control for Precision Agriculture, IEEE Int. Conf. on Networking, Sensing and Control, Sanya, China, 2008, DOI: 10.1109/ICNSC.2008.4525240.
25. Srinivasan, R.; Engel, B.A.; Paudyal, G.N. Expert System For Irrigation Management, *Agricultural Systems*, **1991**, Elsevier, *Volume* 36, no. 3, pp. 297-314.
26. Mohan, S.; Arumugam, N. Expert System Applications In Irrigation Management: An Overview, *Computers and Electronics in Agriculture*, **1997**, Elsevier, *Volume* 17, no. 3, pp. 263-280.
27. Adeyemi, O.; Grove, I.; Peets, S.; Norton, T. Advanced Monitoring and Management Systems for Improving Sustainability in Precision Irrigation, *Sustainability*, **2017**, *Volume* 9, DOI: 10.3390/su9030353.
28. Giannakis, E.; Bruggeman, A.; Djuma, H.; Kozyra, J.; Hammer, J. Water pricing and irrigation across Europe: opportunities and constraints for adopting irrigation scheduling decision support systems, *Water Science & Technology Water Supply*, **2016**, *Volume* 16, no. 1, pp. 245-252.
29. Wastewater. The Untapped Resource, The United Nations World Water Development Report, 2017, Available online: http://unesdoc.unesco.org/images/0024/002475/247553e.pdf accessed on 28 August 2021
30. Intrigliolo, D. Water And Energy Advanced Management For Irrigation. The Future of Smart Irrigation Management in Europe, WEAM4i Policy Brief, 2014, Available online: www.weam4i.eu accessed on 10 September 2021
31. Năstase, G.; Şerban, A.; Năstase, A.F.; Dragomir, G.; Brezeanu, A.I.; Iordan, N.F. Hydropower development in Romania. A review from its beginnings to the present, *Renewable and Sustainable Energy Reviews*, **2017**, *Volume* 80, pp. 297-312.
32. National Program for Rehabilitation of the Main Irrigation Infrastructure in Romania, http://www.madr.ro/docs/agricultura/programul-national-reabilitare-irigatii-update.pdf, 2016.
33. Agriculture in Romania 2017, Flanders Investment & Trade Market Survey, Available online: https://www.flandersinvestmentandtrade.com/export/sites/trade/files/market_studies/2017_Agriculture_Romania.pdf accessed on 05 September 2021
34. Grigoraş, Gh.; Scarlatache, Fl.; Comănescu, D.; Neagu, B. Expert System for Optimal Power Allocation in Hydropower Dispatchable Units, Joint International Conference OPTIM - ACEMP 2017, Optimization of Electrical & Electronic Equipment - Aegean Conference on Electrical Machines and Power Electronics, , Brasov, Romania, pp. 605 – 610, May 25-27, 2017.
35. Mayadevi, N.; Vinodchandra, S.S.; Ushakumari, S. A Review on Expert System Applications in Power Plants, *Int.Journal of Electrical and Computer Engineering* (IJECE), **2014**, *Volume* 4, no. 1, pp. 116-126.
36. Faisal, M.; Mohamed, A.; Shareef, H.; Hussain, A. Power Quality Diagnosis Using Time Frequency Analysis And Rule Based Techniques, *Expert Systems with Applications*, **2011**, *Volume* 38, no. 10, pp. 12592-12598.
37. Niebur, D. Expert Systems for Power System Control in Western Europe, Proceedings 5th IEEE Int. Symposium on Intelligent Control, pp. 34-40, DOI: 10.1109/ISIC.1990.128593, 1990.
38. Gajbhiye, R.K.; Naik, D.; Dambhare, S.; Soman, S.A. An Expert System Approach for Multi-Year Short-Term Transmission System Expansion Planning: An Indian Experience, *IEEE Transactions On Power Systems*, **2008**, *Volume* 23, no. 1, pp. 226-237.
39. HeungJae Lee, L.; ChaNyeon, K.; WonKun, Y. Application of an Expert System for Planning of Primary Restorative System, *Int. Journal of Application or Innovation in Engineering & Management* (IJAIEM), **2016**, *Volume* 5, no. 5, pp. 301-305.
40. León, C.; Biscarri, F.; Monedero, I.; Guerrero, J.I.; Biscarri, J.; Millán, R. Integrated expert system applied to the analysis of non-technical losses in power utilities, *Expert Systems with Applications*, **2011**, *Volume* 38, pp. 10274–10285.
41. Liberado, E.V.; Marafão, F.P.; Simões, M.G.; De Souza, W.A.; Pomilio, J.A. Novel expert system for defining power quality compensators, *Expert Systems with Applications*, **2015**, *Volume* 42, pp. 3562–3570.
42. Gua, J.S.; De Silva, C.W. Development And Implementation Of A Real-Time Open-Architecture Control System For Industrial Robot Systems, *Engineering Applications of Artificial Intelligence*, **2004**, *Volume* 17, no 5, pp. 469-483.
43. Devedžić, V. REX: Robotics expert systems building tool, *Engineering Applications of Artificial Intelligence*, **1989**, *Volume* 2, no. 4, pp. 286-299.
44. Cârţină, Gh.; Grigoraş, Gh. Artificial Intelligence Techniques in Electroenergetics, House Publishing SETIS, Iasi, Romania, 2004.
45. Garbea, R.; Scarlatache, Fl.; Grigoras, Gh.; Neagu, B. "Integration of Data Mining Techniques in SCADA System for Optimal Operation of Hydropower Plants," 2021 13th Int. Conf. on Electronics, Computers and Artificial Intelligence (ECAI), 2021, pp. 1-6, DOI: 10.1109/ECAI52376.2021.9515045.