

Modelling Decision Making Procedure for Pump Electric Drives Chosen for Water Pump Stations

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Introduction

Modelling decision making procedure for water pump stations energy saving problem is described in the article. The importance of this problem lies in the electric energy saving problem actuality in Latvia, because the self sufficiency of electrical energy is less then the consumption.

Modelling of decision making procedure for electric drives choosing and other industrial electronic equipment could give good results of electric energy saving, because its saving percentage is 30 [4]. Multi criteria decision making procedure for pump electric drives choosing for water pump station are described in the article. This decision making procedure could save time of staff engineers in pump station renovation system projects, in the case of choosing the equipment.

The potential decreasing of the consumed electric energy in motor control is more than 30%, using the developed rule based multi criteria decision making method for decision making increasing energy consumption efficiency of pump aggregate if the total payment time does not exceed 5 years. The procedure is checked with a numerical example of pump station renovation calculation.

Problem statement

During the development of water pump system it is important to choose an electric motor that not only performs its direct operations but also consumes an optimal amount of power. The task of electric drive maximum productivity can be completed with the right chosen size of the motor. A motor with a less power will not provide necessary productivity, will be overheated, that can cause a brake in the system operation.

A motor with too high installed power will operate with low productivity; expenses for electric equipment and maintenance in this case are increasing. One of the basic parameters for choosing an electric motor is working temperature in comparison with the rated value.

Therefore the equation of heating balance is the following [3]:

$$\Delta p dt = C d \tau + A \tau dt, \quad (1)$$

where Δp – losses of power for a motor operating with rated loading; $\Delta p dt$ – amount of heat dissipated at time interval dt ; C – heat capacity of the motor; τ – difference of the temperatures of the motor and environment; $C d \tau$ – amount of heat that is not transferred to the environment; $A \tau dt$ – specific heat emission .

When the load does not overcome the rated power motor can operate without overheating for a long time.

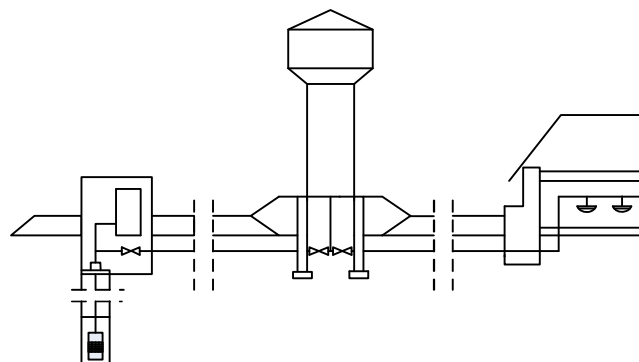


Fig. 1. Water supply system of households

The load of a water supply system is not even; its changing with time during the operation is shown in Fig.2. The figure demonstrates that the motor of the water supply system operates in a continuous duty with a changing load but without any cyclic changes; that means the case can be assumed as a normal continuous with some average loading.

As an example of energy saving a scheme of the consumed power automatic regulation could be considered – frequency converter – induction motor – centrifugal pump.

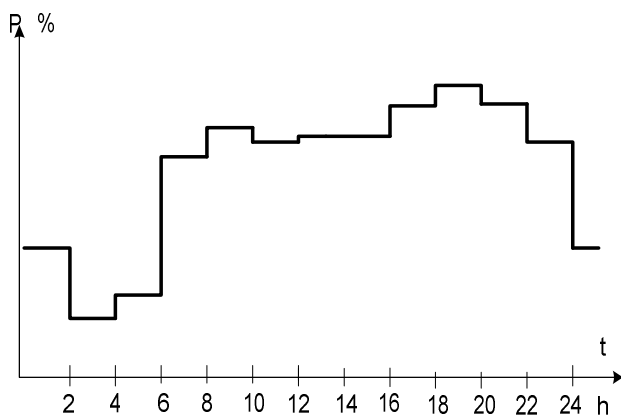


Fig. 2. Diagram of water usage from water supply system during a day.

Fig. 3 demonstrates the system of consumed power automatic regulation that consists of the following elements: centrifugal pump, water supply network and water pressure or water flow sensor at the control point.

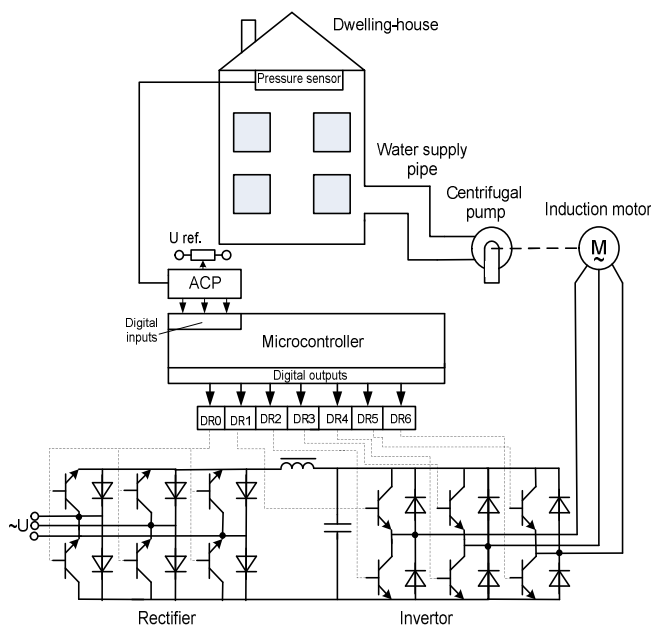


Fig. 3. A system of consumed power automatic regulation with frequency converter

The control system realizes a particular supply of water flow according to the data of the water pressure measurements. The main control element is microcontroller. The input information of it is analogue signal proportional to the pressure and a reference command signal as well [1].

To transform the analogue signal into a digital one an analogue-digital converter is supplied. The output signals of the microcontroller control the switches of the frequency converter. The inverter contains six power switches. The microcontroller realises functions of a frequency converter, for example pulse-width modulation (PWM). The frequency converter can realize control of the induction motor and centrifugal pump. The applied control

algorithm gives a possibility to change the speed of the pump drive according to the water consumption in a building. The operational speed of the induction motor is controlled in the way that the pressure at the worth point is not lower that the reference level (for example 15 m).

Electric power application for water pump operation is realised with electric drive. A structure scheme of a modern electric drive for water supply system is in fig. 4, where a semiconductor converter (PP) controls or dispenses the supplied electric power and supplies it to an electric motor (D), and then mechanical energy through a direct connection or gear (PM) is supplied to an operational machine (DM), – a pump realizing the technological process.

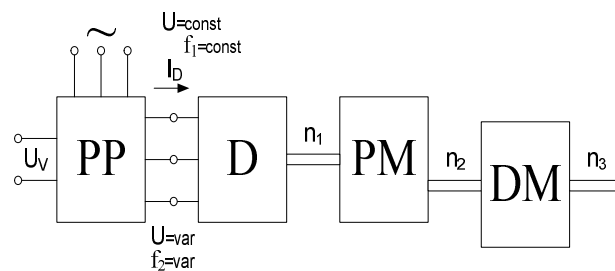


Fig. 4. Block diagram of the controlled AC drive

In Fig. 4 the following notations are used: PP – controlled power electronic converter; D – motor or electric mechanical converter; PM – gear and DM – operational machine; U_v – control voltage; U_1 and U_2 – input and output voltages; f_1 and f_2 – input and output frequencies; I_D – current of the motor; n_1 – rotational frequency of the motor; n_2 – output rotational frequency of the gear; n_3 – output rotational frequency of the operational machine.

The considered electric drive system together with the operational machine (pump, lift, transport etc.) represents a mechatronic system where a power flow and informational data or signals flow can be separated.

Statement of the problem

The actual problem of decision making in choosing pump electric drives control in water pump station renovation is described.

The structure of water supply system is analysed in the article (Fig. 5).

Planning the project of innovation we analysed such a water supply system (Fig. 4) where the amount Y of flow of water x from environment W with the help of power system S_e (pump) is supplied to consumer S_p , after that the utilized water runs back to the environment. The informative part of this process provides a necessary data obtaining for choosing a motor correspondently to a load. A^e – set of the agents of the power system, A^p – agents of the consumers. W_{in} , $W^{(l)} x$, $W^{(l)} Y$, W_{out} – information of the system.

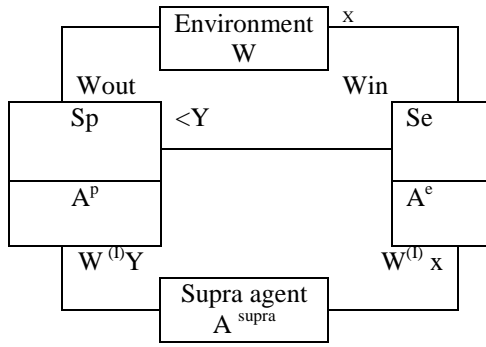


Fig. 5. The structure of water pump system

Supra agent A^{supra} provides processing of the information and initial analysis.

For the innovating of the system it is necessary to choose such a motor which meets the requirements and features of each water supply system, therefore this decision making problem is difficult to be solved in a general form but it is possible to develop electrical engineering decision support system.

Statement of the task of decision support system design

The problem of choosing controlled pump drives for water pump station could be solved, using decision support system, based on expert system, adding human interface. The controlled pump drives choosing could be formalised by expert experience and alternative evaluation for the defined system parameters and consumer's request. The using of modern information technology helps to choose the optimal drive in innovation study of pump station exploitation.

The actual problem of decision making in choosing pump electric drives control in water pump station renovation is described.

The decision making person and system collaboration gives the information based on solution decision support system. Output procedure [2] is often as rules interpretation by planning. Decisions rules are interpretation as if s_i , then p_i .

The s_i , is chosen from p_i taking into account factors f_i , in a complicated way. The output procedure could be defined in the different ways, the main idea is to define set of factors:

$$F = \{f_1, \dots, f_n\},$$

It is important to know, that the new facts can not be achieved as results of system functioning. The main aim of e system is to define relations for real situation facts.

The two existing set F subsets will be defined in the article F_0, F_1

$$F = F_0 \cup F_1, F_0 \cap F_1 = \emptyset \quad (2)$$

The subset S_1 will be named as subset of marked (known) facts, but subset F_0 – the subset of unmarked facts. The subset F_1 , sometimes could be considered as a working field of decision support system. In the beginning

of the work the system has some facts, for example: $F_1 = \{f_1, f_2, f_3\}$.

The subset F_1 fulfilment could be made by moving elements from F_0 subset. The rules interpretation could be described as $s_i \rightarrow p_i$ with facts from F_1 , if the rule is subset F_1 will be fulfilment from facts, which are true in right side of production P_i . The choosing best decision from $S_1 = \{s_1(p_1(f_1)), s_2(p_2(f_2)), s_3(p_3(f_3))\}$ is the decision maker function, the best alternative we described as $S'_1 \supset S_1$.

The structure of decision support system is analysed in the article (Fig. 6).

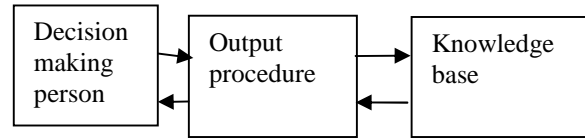


Fig. 6. The structure of production decision support system

Decision making procedure

The choosing of pump electric drives for water pump station renovation can be deviated in two parts – choosing technical solution and financial evaluation.

The technical solution could be chosen, taking into account the method of calculation of difference of expenses for electric energy in the pump drive, comparing the control of valve in pump pressure cable with frequency converter speed control.

Algorithm for choosing of an induction motor

1. Continuous duty:

a. Constant loading:

$$M_{sl} \leq M_N; P_{sl} \leq P_N; \quad (3)$$

b. Cyclic loading:

$$M_E \leq M_N; P_E \leq P_N; T_c \leq T_p; \quad (4)$$

$$P_E = \sqrt{\frac{1}{T_c} \int_0^{T_c} P^2(t) dt}; \quad (5)$$

$$\text{starting } M_{pal} > M_{stmax}; \quad (6)$$

$$\text{overload } M_{maxpiel} = \lambda M_N > M_{stmax}; \quad (7)$$

where λ – factor of overload; $M_{maxpiel}$ – maximum accepted torque; M_{stmax} – maximum accepted static torque; M_E – equivalent torque; P_E – equivalent power.

The factor of overload in general case is:

$$\lambda > \frac{M_{max}}{M_{nom}}. \quad (8)$$

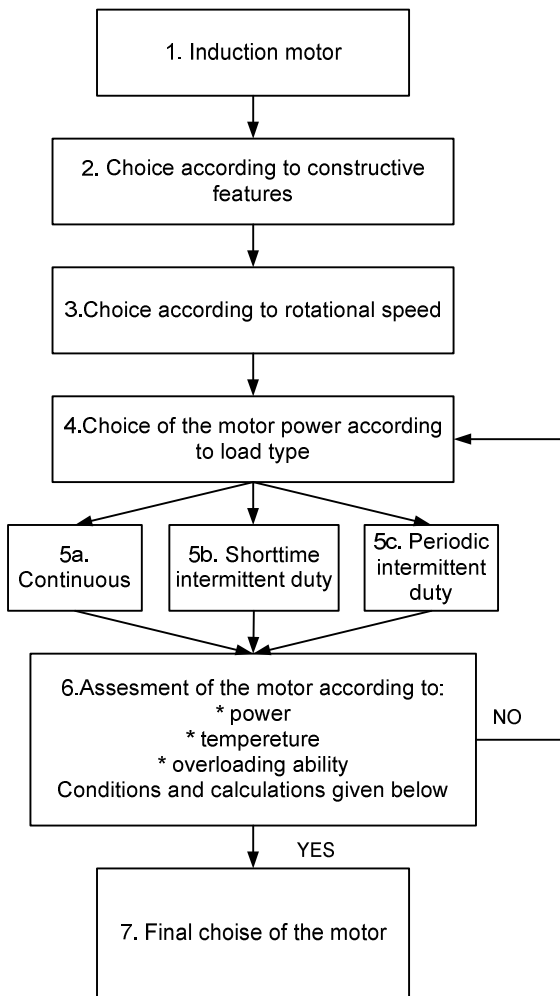


Fig. 7. Decision making procedure for pump electric drives choosing for water pump stations

2. Short-time intermittent duty ($t_{p,st} = 10, 30, 60, 90$ min):

$$M_{E,t_{p,st}} = \sqrt{\frac{\sum M_j^2 t_j}{t_{p,st}}} \leq M_{N(st)}, \quad (9)$$

$$P_{E,t_{p,st}} = \sqrt{\frac{\sum P_j^2 t_j}{t_{p,st}}} \leq P_{N(st)}, \quad (10)$$

where M_j, P_j, t_j – values at the separate cycles and duration of these cycles, starting $M_{pal} > M_{stmax}$, overloading $M_{maxpiel} = \lambda M_N > M_{stmax}$.

3. Periodic intermittent duty:

$$P_E = \sqrt{\frac{\sum_{i=1}^n P_i^2 t_i}{\sum_{i=1}^n t_i}} \quad (11)$$

where P_i, t_i – value of power in separate cycles and duration of these cycles [9]. In our case the programme

will choose way 5.a – continuous duty of the motor (Fig. 7).

The financial evaluation choosing of pump electric drives for water pump station renovation can be realized, using decision support system.

Decision making procedure

The problem solution algorithm is modelling of water pump systems, using multi criteria model [7] by energy consumption effectiveness criteria:

- Step 1. Task formulating;
- Step 2. To formalizing set of possible decisions;
- Step 3. To define set of criteria's;
- Step 4. To define set of efficacy criteria measurement scale. Steps 3, 5;
- Step 5. Possible alternatives efficiency measurement by criteria scales. Steps 3, 4, 6;
- Step 6. Getting and sequencing information about priorities;
- Step 7. To define set of decision making rules;
- Step 8. Possible decisions ordering;
- Step 9. Ordering results analysis;
- Step 10. Sequence satisfactorily priorities? If yes Step 12, If no Step 11;
- Step 11. Non – satisfactorily reasons analysis, and definition of improvements. Steps 2, 3, 4, 5, 6;
- Step 12. Electrical drive satisfactorily problem decision? If yes Step 13, If no Step 6 or 1;
- Step 13. Finish of problem decision.

Neural network structure for decision support system

The modelling decision making procedure for water pump choosing for station renovation, taking in account energy saving problem is described in the article. Neural architectures are appealing as mechanisms for implementing intelligence for electric drive choosing problem for a number of reasons. Traditional AI programs tend to be brittle and overly sensitive to noise: rather than degrading gracefully, such programs tend to either be right or fail completely. Human intelligence is much more flexible; we are good at interpreting noisy input, such as recognizing a face in a darkened room from an odd angle or following a single conversation in a noisy party. Even where a human may not be able to solve some problem, we generally can make a reasonable guess as to its solution. Neural architectures, because they capture knowledge in a large number of fine-grained units, seem to have more potential for partially matching noisy and incomplete data. Neural architectures are also more robust because knowledge is distributed somewhat uniformly around the network. [8].

Let us consider an example of rotation distribution. Mathematical models of neural networks intelligent agents are based on the structure of perceptrons:

Set of the input data

$$X = \{x_1, x_2, \dots, x_n\}. \quad (12)$$

Weights (coefficients)

$$W = \{w1, w2, \dots, wn, wn+1\}. \quad (13)$$

Optimization function

$$F = x1*w1 + x2*w2 + \dots + xn*wn + wn+1. \quad (14)$$

Clusters

$$C = \{c1, c2, \dots, cm\}. \quad (15)$$

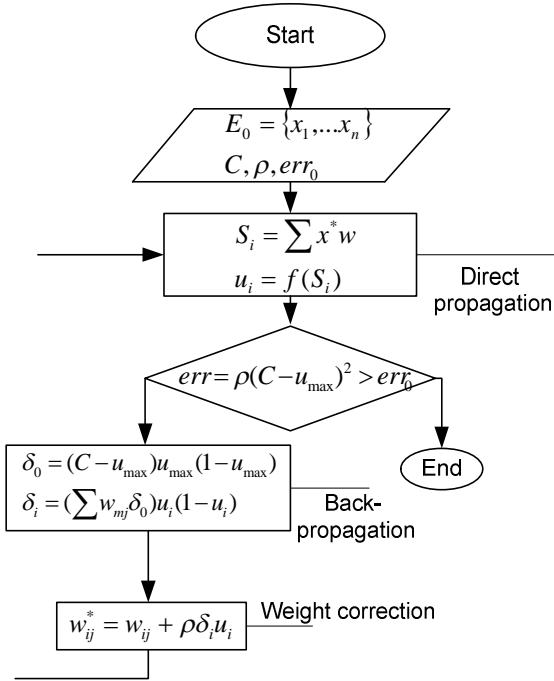


Fig. 8. Flowchat of back propagation algorithm [8]

In task of decision making for water pump choosing for station renovation incomplete data about the load of the electric motor are present, that way of neural network modelling is actual for decision making for water pump choosing.

Computer example

Example for pump electric drives choosing for water pump stations.

The “Gudrais Inženieris” software tool is designed for the users in planning and carrying out energy management and motor efficiency improvement actions. “Gudrais Inženieris” provides the electrical energy and Eur savings obtainable through selection and use of an Energy Efficient or Premium Efficiency motor in three scenarios: new purchase, repair versus replace, and replacement of existing operable motors.

“Gudrais Inženieris” supports motor management functions at commercial and institutional facilities, water supply and wastewater treatment systems, irrigation districts, and medium-sized and large industrial facilities. Designed for utility auditors, energy managers, and plant or consulting engineers, “Gudrais Inženieris” supports motor and motor systems improvement planning through identifying the most efficient action for a given repair or

motor purchase decision. “Gudrais Inženieris” can be used to compute the energy and demand savings.

Motor Catalog Data. The motor performance database includes the following information, when available, for each motor (Fig. 9): using the specified search criteria motor’s power, voltage, speed, enclosure type, weight, current, phases, efficiency with predefined load and other known parameters are displayed. For each motor the operation diagram is calculated and shown in separate window.

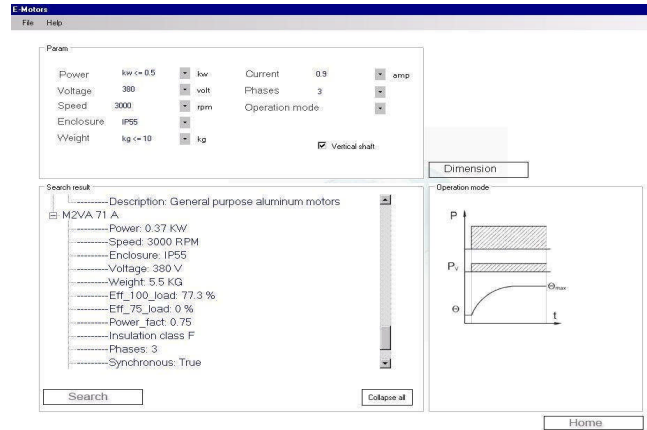


Fig. 9. Software “Gudrais inženieris”

When selecting the best available motor for the given parameters the software uses the following procedure (Fig.10). First, if the speed is constant, synchronous or reluctance motors are selected when the speed equals constant regardless the value of the torque. If the speed is slightly reduced when the load torque increases, DC shunt or separately excited are used. If the speed is changing with load the induction motor is selected. Second, the needed type of voltage is determined, for systems running on battery power the DC is predefined selection, in other cases AC systems will be a better solution. Third, the size of the motor narrows the selection even more allowing to choose single-phase or poly-phase motor will be used for the given task. Taking in the account all this information, the software queries the database and selects motors with predefined parameters and presents them in a table, sorted by the power efficiency.

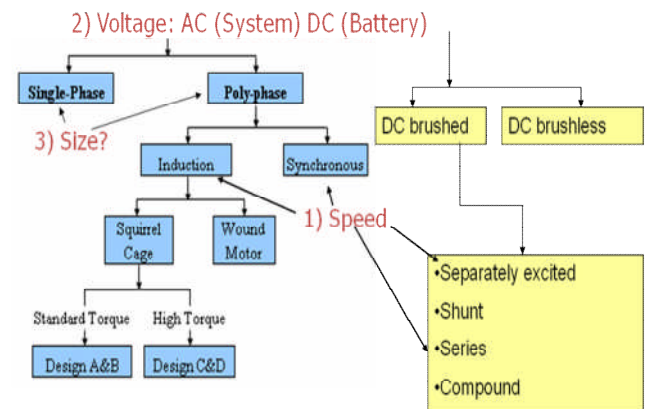


Fig.10. Fragment of Motor Selection Algorithm

Software “Gudrais inženieris” could give such results: Motor Selection, Motor Savings Analysis, Life Cycle, Best Available. The Energy Conservation Summary Report indicates the Energy Action date, title, type of action (motor replacement, rewind, systems improvement or process operating hours change); and the annual energy savings (kWh/year), instantaneous demand, reduction (kW), and annual savings.

Conclusions

Decision making problem for pump electric drives control choosing for water pump stations innovation, by long term energy saving are analyzed in the article. For this problem solving the development of decision making procedure for decision support system, taking into account structure of the technical problem, the user requirements of water supply, the costs of control system installation and other parameters are used. The rule based method, based on analysis of technical effectiveness and costs of tree alternative decision in five middle and long term period. Decision making procedure example for pump electric drives choosing for water pump stations are described in the article. The solution of energy saving problem in water pump station could achieve a potential decreasing of the consumed electric energy in motor control that could be more than 30%.

References

1. **Ribickis L., Galkina A.** Elektroenerģijas taupīgas lietošanas metodes. – Rīga. – 1998. – 109 p.
2. **Kunicina N., Levchenkovs A., Gorobetz M., Uteshev I.** Intelligent Agents Networks for Power Processes Control in Mechatronics Systems // Proceedings of International conference and workshop ECAD/ECAE'06, Stuttgart, Germany. – 2006. – P. 1–13.
3. **Общая электротехника** (Под. ред. **В. Панюшина**). – Москва: Высшая школа, 1970. – 568 p.
4. **Energy Saving Calculator for Pump Drives.** – ABB Industry OY, Finland, 1996.
5. **Latvian energy in figures.** – Latvian Investment and Development Agency. – 2006. – 43 p.
6. **Galkina A., Ribickis L., Kunicina N., Čaiko Y.** Development Decision support system for pump electrodrives system for pump electrodrives control choosing for water pump stations // Scientific proceedings of Riga Technical University, Power engineering. – 2007. – 31–36 p.
7. **Fishburn P., Fishburn P. C.** Decision and Value Theory. – New York: Wiley, 1964. – 451 p.
8. **Luger G.** Artificial intelligence. – London: Addison Winsly, 2004. – 903 p.
9. **Leonard W.** Control of Electrical Drives. – Springer. – 2001. – 460 p.

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Е. Чайко, А. Жиравецкая, Н. Куницына, А. Галкина, Л. Рыбицкий. Моделирование процедуры принятия решений выбора двигателей для станций водоснабжения // *Электроника и электротехника*. – Каунас: Технология, 2008. – № 2(82). – С. 59–64.

В статье рассматривается проблема принятия решений выбора двигателей для станций водоснабжения в случае их реновации, путем анализа потребления электроэнергии в долгосрочном периоде. Для решения этой проблемы в статье предлагается использовать разработанную процедуру для системы принятия решений, принимая во внимание структуру технической проблемы, требования пользователей системы водоснабжения, стоимость установки системы контроля и другие параметры. Рассматривается экспериментальный пример моделирования процедуры принятия решений выбора двигателей для станций водоснабжения. III 9, библи. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

Y. Čaiko, A. Žiravecka, N. Kunicina, A. Galkina, L. Ribickis. Siurblių, skirtų vandentiekio stotims, variklių parinkimo sprendimo procedūros modeliavimas // *Elektronika ir elektrotechnika*. – Kaunas: Technologija, 2008. – Nr. 2(82). – P. 59–64.

Nagrinėjama elektros variklio, skirto renovuojamai vandentiekio stočiai, parinkimo problema. Analizė atliekama remiantis ilgalaikėmis energijos sąnaudomis. Šiai problemai spręsti siūloma naudoti sukurtoją procedūrą, skirtą sprendimų priėmimo sistemai. Procedūroje atsižvelgiama į techninės problemos struktūrą, vandentiekio sistemos vartotojų poreikius, valdymo sistemos įrengimo išlaidas ir kitus parametrus. Nagrinėjamas eksperimentinis sprendimų priėmimo, parenkant variklius vandentiekio stočiai, procedūros modeliavimo pavyzdys. III. 9, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).