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MODELING OF AN ENERGY EFFICIENT FAN INSTALLATION BASED ON AN ADJUSTABLE ELECTRIC DRIVE WITH A FUZZY LOGIC REGULATOR

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Abstract. *Centrifugal fan installations are the most common in various spheres of production, both light and heavy industry. More often, centrifugal fans are installed as unregulated electric drive installations, especially low capacity. But there are a lot of technological equipment, especially in the production sphere, where it is necessary to regulate the productivity of fans. Moreover, regulation is carried out in a fairly wide range.*

Electrical drive of centrifugal fans is usually realize on the basis of an asynchronous short -circuited engine. To adjust the supply of such fan is carried out the adjusting of the speed rotation of the engine using the frequency converter

Among the known ways of regulating the efficiency of fan installations, namely throttling, change of the angle of installation of blades, using of guiding machines, regulating of the number of rotations of the fan shaft is the most effective way.

In modern conditions, the change of the fan shaft rotation is carried out by changing the drive shaft rotation of drive engine.

In the article is considered the issue of increasing the energy efficiency of fan installations by using an adjustable electrical drive with using the regulator, built on the principles of fuzzy logic. The mathematical model of the system in the Matlab application package has been developed, computer modeling has been carried out and the benefits of the proposed approach are shown in comparing to the traditional methods of regulation.

Key words: ***fan installation, energy efficiency, adjustable electrical drive, asynchronous engine, sub- regulator, fuzzy logic controller, Matlab***

Topicality. Fan installations are widely used in ventilation system, conditioning and technological processes and occupy a significant share in the structure of energy consumption of industrial and civilian objects. Traditional methods of regulating fan productivity (throttling or use of dampers) are accompanied by significant energy losses, since their operation is carried out when using electrical drives at a fixed speed of rotation. Most unregulated electrical drives operate with significant underloading, which leads to high energy losses and reducing the capacity coefficient.

The use of adjustable electrical drives allows to optimize the fan mode.

The widespread use of powerful force controlled rectifiers, voltage converters and frequency for regulated electrical drive direct current and alternating current significantly exacerbated the problem of ensuring the required quality of electricity, especially the capacity coefficient, nonlinear voltage and current distortions, voltage stability, etc. The traditional solution to this problem with the help of expensive passive filters is not effective enough because of the difficulty setting at a fixed frequency.

Due to the high cost of converting devices for frequency control and taking into account the peculiarities of work of the fan installation, it is reasonable scheme of regulated ED can be an asynchronous drive with phase voltage control on the stator clamps. The thyristor voltage regulator system-asynchronous engine (TVR-AE) provides adjustment of the unit within certain limits, its start.The main advantages of such ED system are its simplicity, reliability, ease of automation in the general technological scheme. Taking into account what has been said, during modernizing the drives of ventilation systems of industrial premises, it is necessary to focus on equipping them with one start -up unit, a seriesly mastered domestic industry. In this case, the cost of thyristor regulators is in 2.5÷3 times lower than the cost of the corresponding frequency converters.

The use of adjustable electrical drives makes it possible to adapt the fan operation to variable conditions, providing significant energy savings. However, classic sub-regulators are not always able to provide optimal adjustment in difficult dynamic conditions. In this regard, it is advisable to use intellectual management methods, including fuzzy logic. The use of fuzzy logic allows to provide more flexible and adaptive management, which allows to take into account unpredictable changes in operating conditions and improves the stability of work of the ventilation unit. This is especially important for large production objects where changes in ventilation needs can be significant

Analysis of recent researches and publications. Despite on the measures to implementation of low -carbon energy sources around the world, the share of traditional installations that burn organic fuel remains high. One of the approaches to solving this problem is to find solutions to reduce energy consumption. There are various research projects in the field of energy efficiency that lead to various results, such as models, methodology, new data and theories. On the other hand, asynchronous motors become the main consumer of electricity due to their wide range of use. The use of adjustable electrical drives in ventilation systems, first of all, can significantly reduce the consumption of electricity by fans drive, since excessive pressure in this case is not created. In [1] it is proved that the electrical drive system is capable of reacting with high accuracy and reliability to changes in the aerodynamic parameters of the main ventilation line of mines.This will also lead to increasing of the efficiency of the electrical drive when the fan is loaded to 0.8...0.93 n.u., and the efficiency to 92.5%... 94.5% when regulated within the operating slip range of the drive fan motor rotor, which is on average 25%...40% higher in comparing to unregulated electrical drive systems.

Simulation results show that the scheme with the frequency-regulated drive (FRD) sharply reduces starting current, effectively minimizing capacity loss during engine starting [2]. It was defined in [3] that fans of mine systems have considerable potential to increasing efficiency due to introducing of frequency-regulated medium-voltage converters. But the engine feeds on the inverter from which the distorted sinusoid is obtained by the higher harmonics, which affects on the heating and accordingly increases losses. The combination of all harmonics was more harmful than each individual analyzed harmonic, among which the second harmonic had the highest contribution. [4]. In work [5] presents the control strategy developed to reduce energy consumption by DC motors by implementing smooth trajectories in the uniflow control system, using the fuzzy logical controller based on the Tsukamoto output method. The energy efficiency of the proposed controller was experimentally compared to the energy efficiency of the usual sub-controller, taking into account three traffic profiles of : parabolic, trapezoidal and S-shaped. The results show that the combination of the fuzzy controller with smooth trajectories effectively reduces energy consumption without sacrificing movement accuracy.

Fuzzy controllers reflect the experience of the expert in the installation management. Moreover, literary sources show that optimization algorithms allow you to adapt fuzzy controllers (FIS) to control different processes as a "black box" problem [6].

Purpose of the study: to determine the efficiency of the fan installation based on electrical drive with the fuzzy logic regulator (Fuzzy Logic Controller, FLC) ..

Materials and research methods. Any fan installation is characterized by an H-Q characteristic, where Q- is the fan productivity (or expenditure, supply) and H- is the pressure. The characteristic is most often given in graphical form, which reflects the functional dependence of the type *H=f(Q).* Also add additions η=*f(Q)* and *P=f(Q)* , where η- is the efficiency coefficient (efficiency)of the fan ,and P- is its power. The main energy indicators of work of the electrical drive include energy losses, efficiency coefficient (efficiency)η and capacity coefficient cosφ.

When changing the fan speed rotation from n_1 to n_2 of its characteristics (supply Q, pressure H, capacity P) change according to the law of similarity:

$$\frac{P_1}{P_2}=\left(\frac{n_1}{n_2}\right)^3 \qquad \frac{H_1}{H_2}=\left(\frac{n_1}{n_2}\right)^2, \qquad \frac{Q_1}{Q_2}=\left(\frac{n_1}{n_2}\right).$$

The economy of work of the electrical drive in any mode is characterized by the efficiency-the ratio of mechanical work performed to the amount of electricity consumed during this time:

$$\eta_ц=\frac{A_{мех}}{A_{ел}}=\frac{\int_0^{Tц} M_м(t)\omega_м(t)dt}{\int_0^{Tц} Pdt} \tag{1}$$

where $\eta_ц$- is the cycle efficiency of the electrical drive; $T_ц$ - duration of the work cycle, h; $A_{мех}$, $A_{ел}$ - useful mechanical work and consumed from the network electricity, J; - $M_м$ - moment on the shaft of the working machine, H · m;

ω-angular speed of the drive shaft of the working machine,c^{-1} ; P - capacity consumed by the electrical drive from the network, W.

If the values of the efficiency of the electricity converter $\eta_{п.ел}$ is known, the engine and mechanical conveyer $\eta_{дв}$, then efficiency of the electric drive

$$\eta = \eta_{п.ел}\ \eta_{дв}\ \eta_{мех}. \quad (2)$$

The economy of electricity consumption from the network is characterized by the capacity coefficient, which is the ratio of active power P to the full S:

$$\cos\phi = \frac{P}{S} \quad (3)$$

The European Union has been developed and entered into force the new IEC 60034-30 standard, according to which three classes of energy efficiency of single-speed three-phase asynchronous electric motors with short-circuit rotor were established.

Simulation of the adjustable electrical drive of the fan installation is carried out in the package of applications of the Matlab environment Simmulink .

Determine the parameters of the simulation model of the TVR-AE system for the asynchronous engine with the phase rotor AK-2-18-53-12MUHL4

by the following ratios:

Transmission coefficient and time constant:

$$K_{trv} = \frac{U_{f.nom}}{10} = \frac{3468,2}{10} = 346,8$$

$U_{f.nom}$ - phase rated voltage; $T_{trv} = 0.01$ - time constant ; Coefficient Ka (H · C/kg · m) integrator INT the intensity setter AJ-1:

$$K_a = \frac{K_{\max} \cdot M_{nom} - M_{nom}}{J \cdot \omega_{nom}} = \frac{2,5 \cdot 38535,64 - 38535,64}{6750 \cdot 51,9} = 0.1645$$

Where $K_{\max} = 2,5$ - the multiplicity of the starting moment, $M_{nom} = \frac{P_{nom}}{\omega_{nom}} = \frac{2000000}{51,9} = 38535,64$, Nm, nominal moment; $\omega_{nom} = 0.105 \cdot n_{nom} = 0,105 \cdot 495 = 51,9$, nominal value of the angular speed of the motor shaft;

$n_{nom} = 495$ rpm,c nominal rotation of the motor shaft; $J = 1.5 \cdot J_{em}$, the full moment of inertia of the entire system; $J_{em} = 4500$, engine inertia moment;

Transmission coefficients:

$$K_m = \frac{2 \cdot M_{\max}}{U_{f.nom}} = \frac{2 \cdot 96339,1}{6000} = 32,11$$

Where $M_{\max} = K_{M.\max} \cdot M_{ном}$; $U_{f.nom}$ - phase rated voltage;

$$K_{mc} = \frac{M_{ном}}{\omega^2} = \frac{38535,64}{51,9^2} = 14,3$$

Where M_{nom} - nominal moment; $K_{ur} = \frac{10}{\omega_{nom}} = \frac{10}{51,9} = 0,19$

Controller settings of regulators aw, bw:

$$a_w = 2 \; b_w = 2$$

Substitute the obtained parameters into the model (Fig. 1)

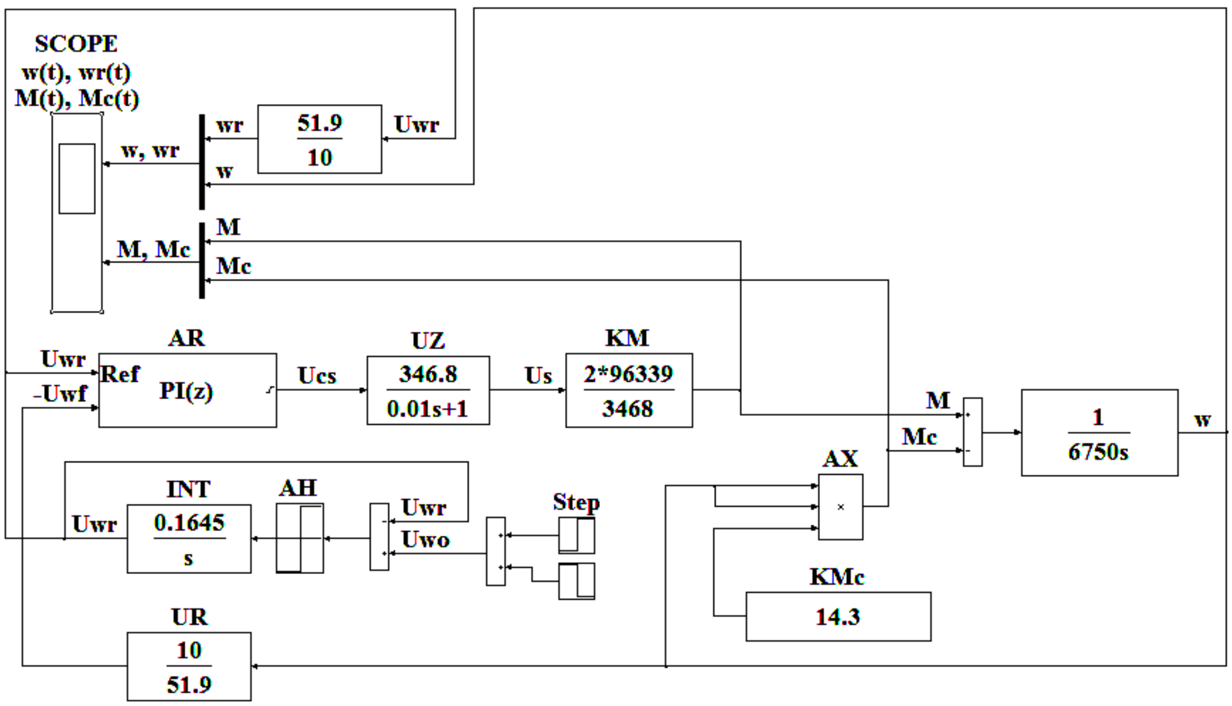

Fig. 1. The mathematical model of the electrical drive of fan installation under the TVR-AE system

The use of fuzzy logic (FL) provides an opportunity to create the system of adaptive management, in which data, purpose and restriction are quite complex or not defined, and therefore they are not amenable to an accurate mathematical description, and the necessary control action U cannot be selected by using a database of typical situations. The principle of constructing an algorithm for the formation of control actions U=(u'1,u'2,…, u'k) based on fuzzy logic (fuzzy withdrawal) is shown in Fig. 2.

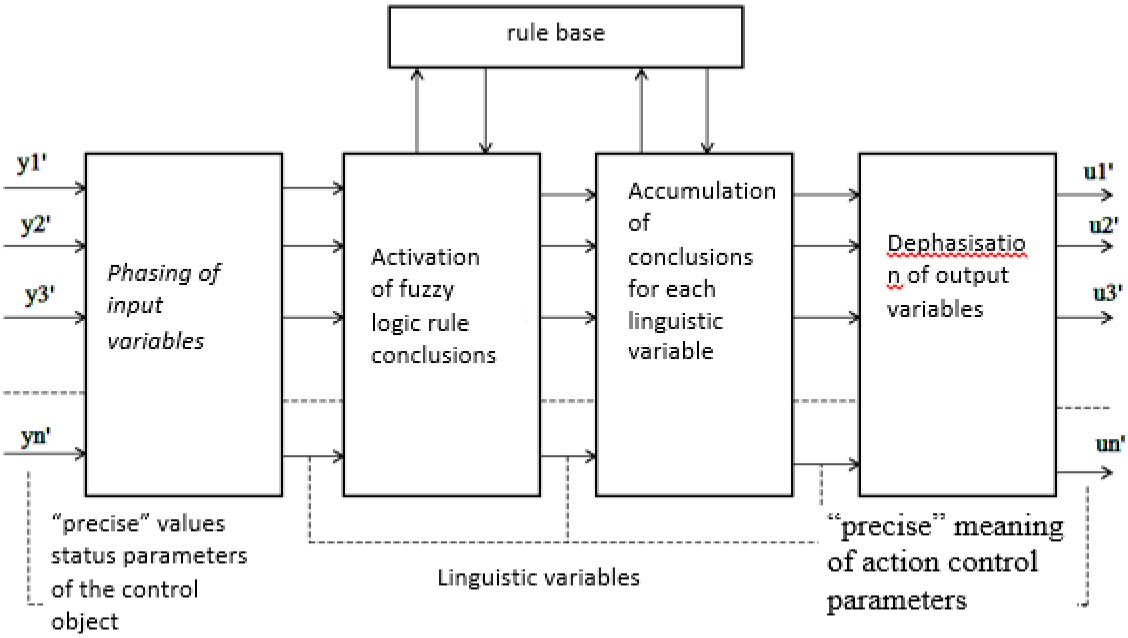

Fig. 2. The scheme of management based on fuzzy logic

The process of phasing system of fuzzy control is determined in analytical expressions for each function of belonging $\mu_S(e)$, $\mu_M(e)$, $\mu_B(e)$, three fuzzy sets S, M, B.

$$\mu(e) = \mu_S(e) \cup \mu_M(e) \cup \mu_B(e) \quad (4)$$

The range of input signal changes *e* is represented by three fuzzy sets: S - is a trapezoidal set of small values, M- is the triangular set of average values, B- is a trapezoidal set of large input signal values.

The process of defasification of the fuzzy-management system by the method of "heights" of fuzzy sets is determined by analytical expressions that reflect the coordinates (abscisses) of the centers of the severity of the areas of figures under graphs of belonging functions X_S, X_M, X_B, and intermediate values X_C of coordinates in areas of intersection of combustible fuzzy inexistence *S* i *M*, *M* i *B*..

Since the set functions of the input signal of the piecewise-linear signal, the figures under their graphs can be represented by the set of rectangles and rectangular triangles.

For piecewise-linear objects that consisting of two elementary geometric shapes, the dependence that determines the coordinate of the center of gravity looks like:

$$X_C = \frac{X_1 S_1 + X_2 S_2}{S_1 + S_2} \quad (5)$$

where X_1, S_1- respectively, the coordinate of the center of gravity and the area of the first elementary figure; X_2, S_2 - accordingly the coordinate of the center of gravity and the area of the second elementary figure.

The modern integrated Matlab computer mathematics system has a powerful device for synthesizing the fuzzy-management system using the command line operators and using SIMULINK. In addition, the MatLab system contains a special built FUZZY LOGIC TOOLBOX module, which is intended for the synthesis and analysis of fuzzy logical output systems.

To calculate the coordinates of the centers of gravity of figures under the graphs of the dependence of the function of belonging on the input signal (the process of defaisification), we make a M-file, which contains operators for the task of the range of change in the input signal, operators, which describe the form of functions of belonging and the operator, which performs defaisification using the ‘gravitational’ method (centroid).

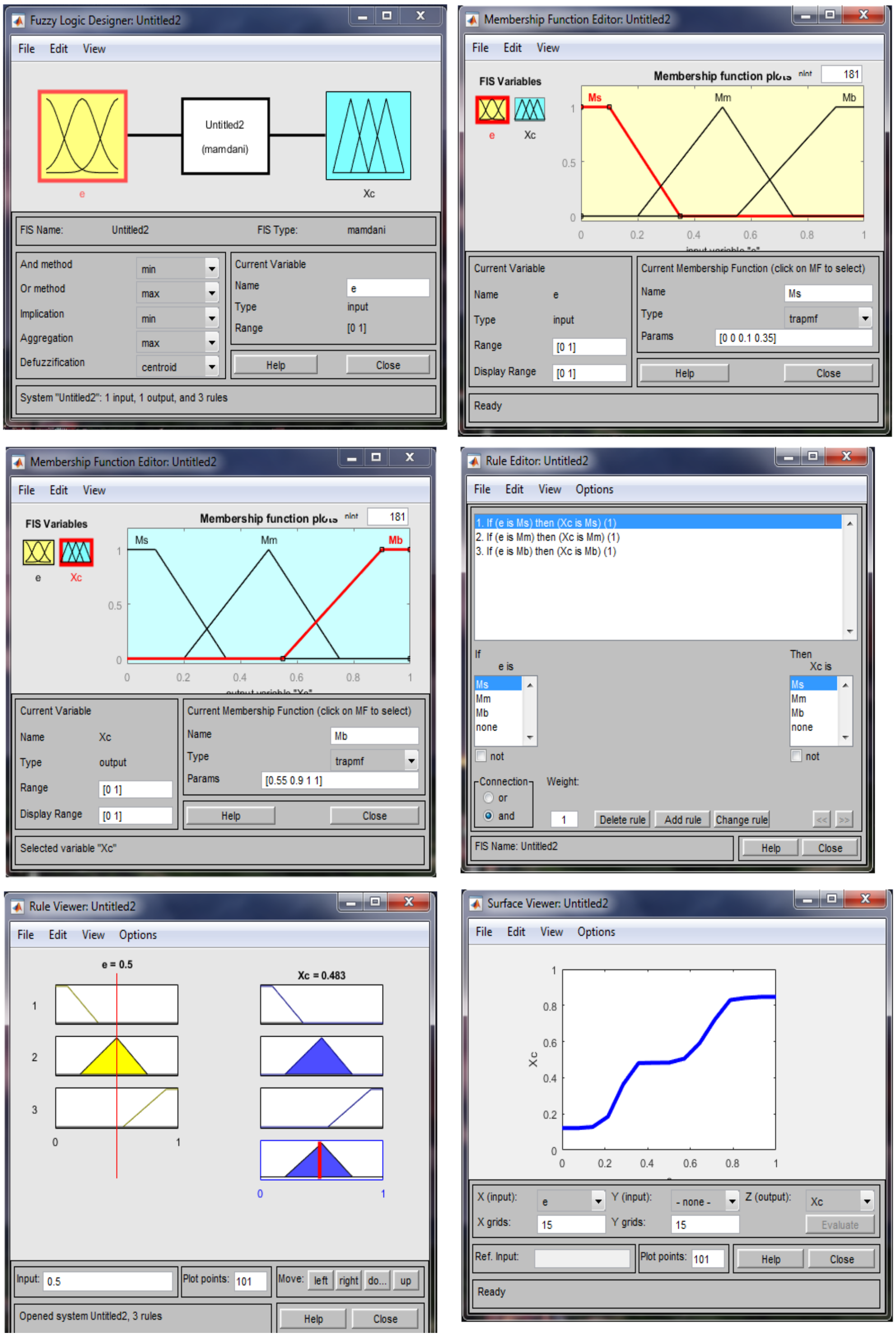

Fig. 3. The fuzzy system modeling process

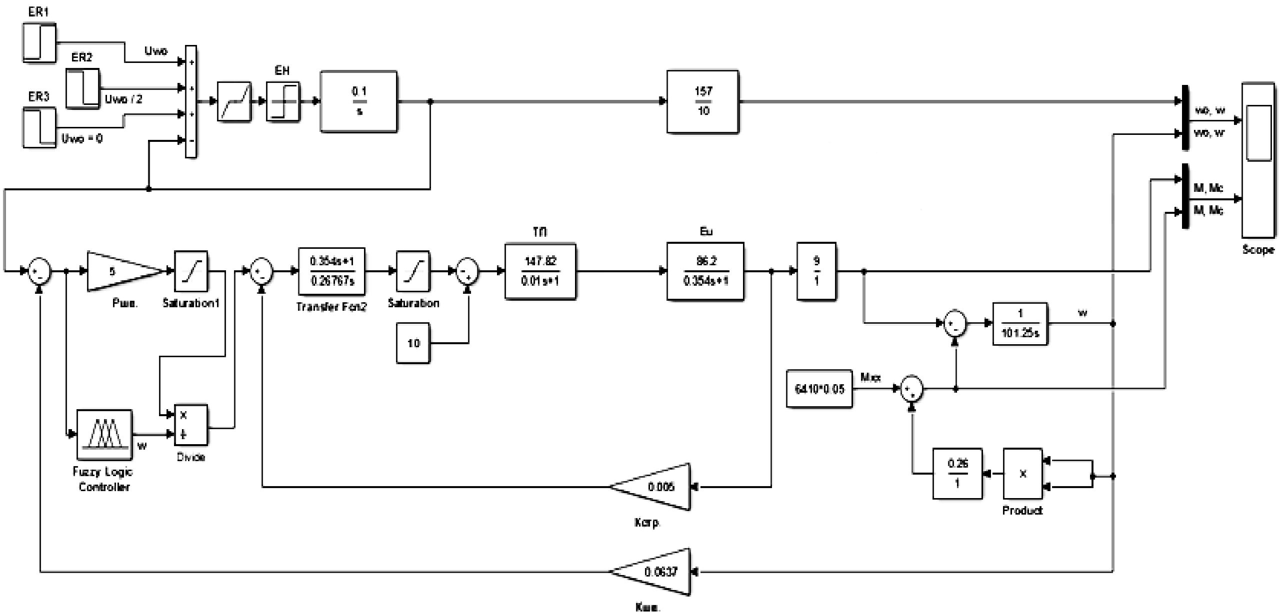

Fig. 4. The TVR-AE system with fuzzy- controller, which is located in parallel with the traditional speed regulator.

Research results and discussion. In Fig. 5 and 6 is shown the speed and loading diagrams of the adjustable electrical drive of the fan installation according to the traditional and fuzzy regulators. As the diagram figure 5 shows that the traditional regulator has reregulation in transitional modes, which is 30% at speed, which according to (1) affects on the consumption of electricity. Fuzzy regulator (Fig. 6) when changing the load accurately works out the speed modes of the electrical drive.

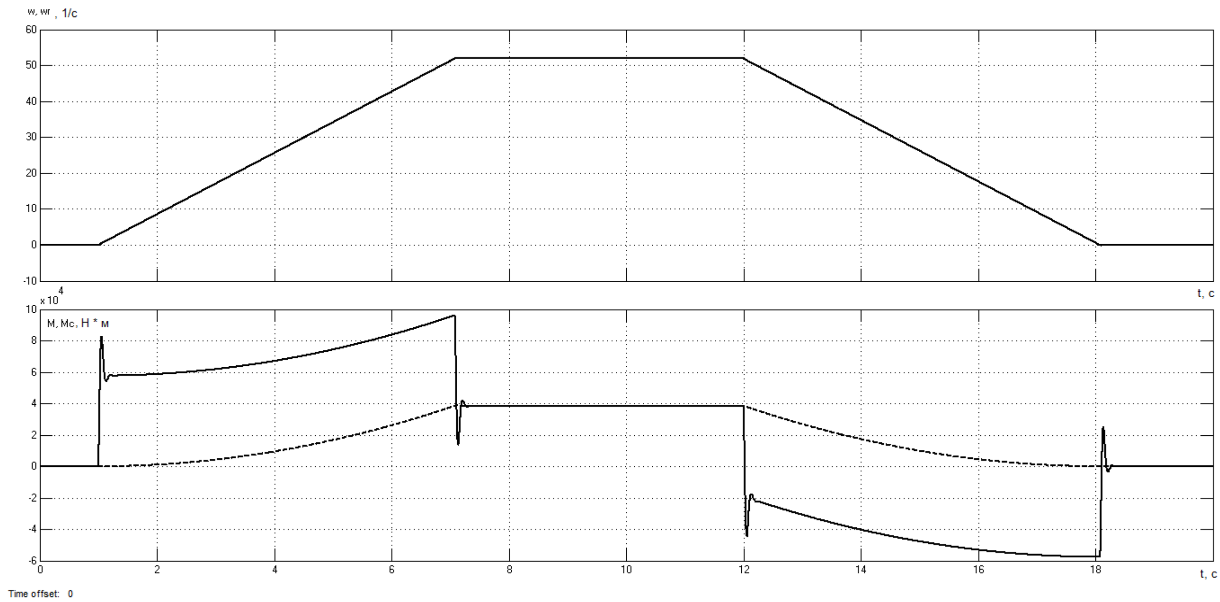

Fig. 5. Speed-loading diagram with the traditional regulator

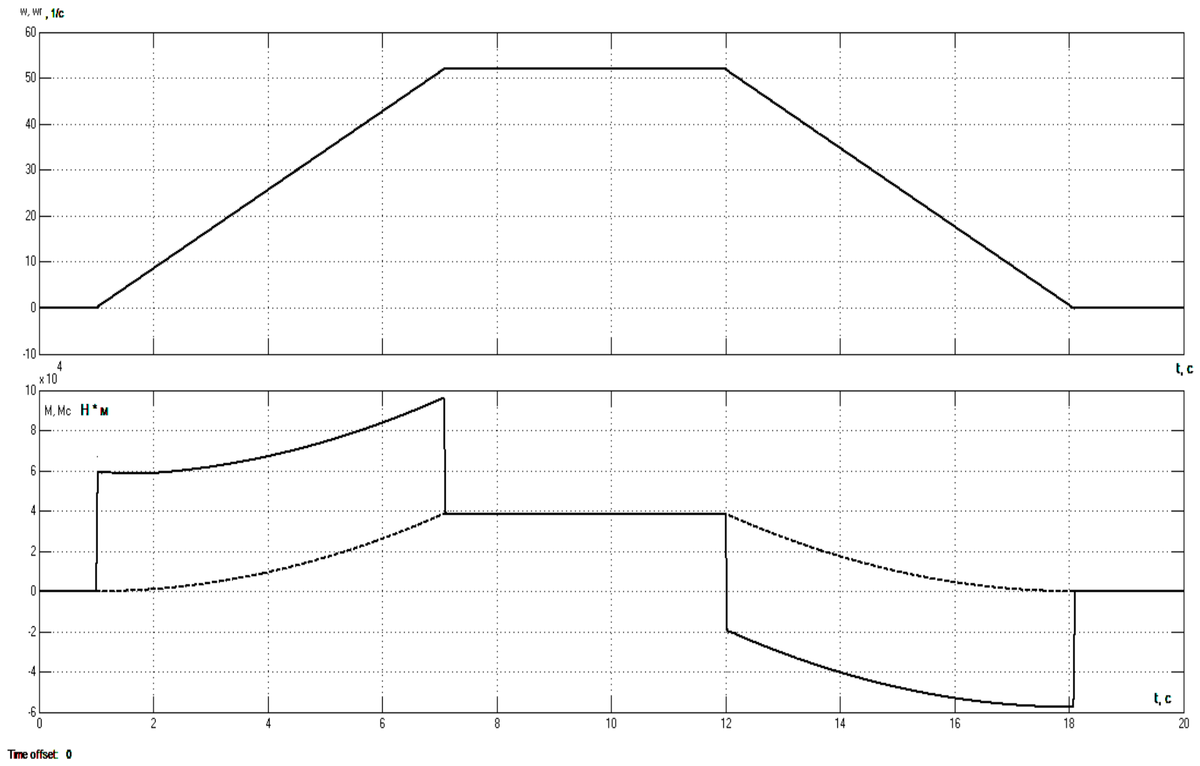

Fig. 6. High-speed loaded diagrams with the fuzzy logic regulator

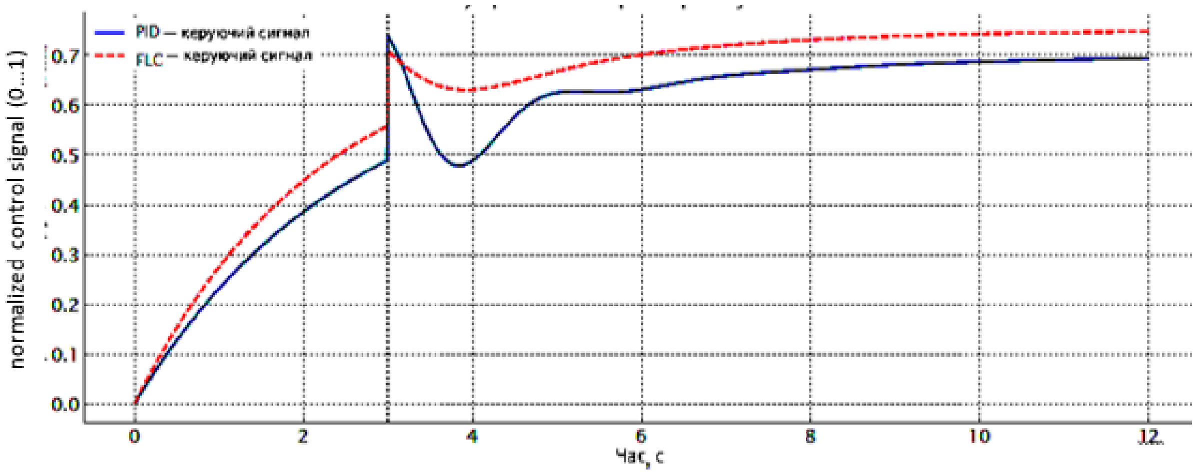

Fig. 7. The control capacity of electrical drive: 1 - Fuzzy regulator; 2 - sub-regulator

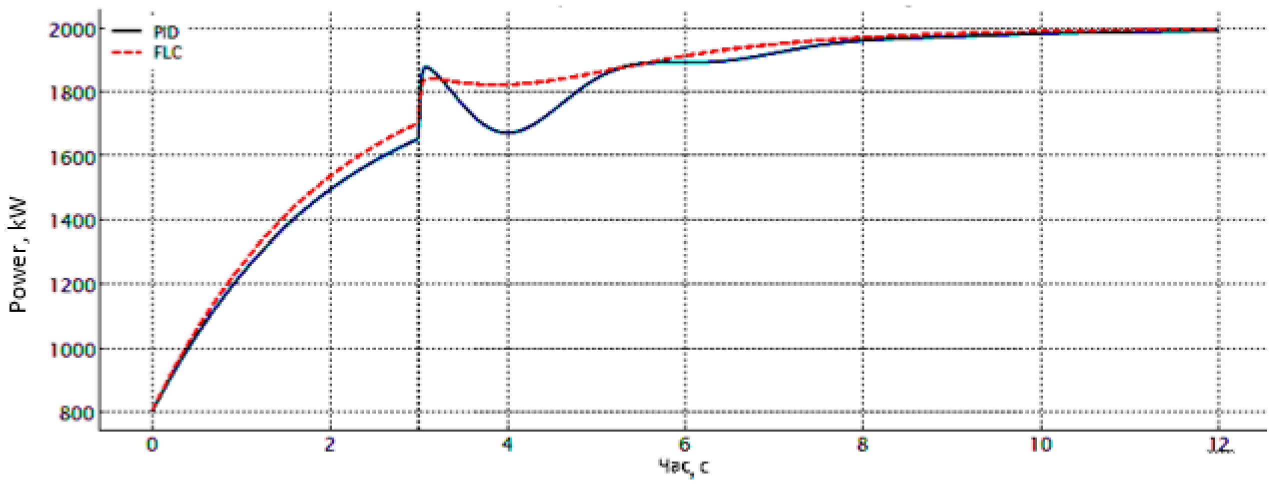

Fig. 8. Teams work: 1 - Fuzzy regulator; 2 - sub- regulator

When changing the speed of the fan, its power will change accordingly the action of the regulators should be directed to compensation for this load. In figure 7 is shown the reaction of the perturbation regulators, the sub- regulator has a sharp effect and then the oscillatory process, and FLC - performs a smoother and stable correction, changing the angle of opening of thyristors thereby changing the voltage that is fed to the motor and thus changing its capacity. In Fig. 8 is shown transitional processes with the FLC regulator have less value of the duration of regulation and less regulation than the sub-regulators, and this affects not only on the energy efficiency, but also the quality of the technological process.

Conclusions and prospects.

As the results of the numerical experiment show the use of the fuzzy logic controller in the controlled drive system on the basis of the thyristor voltage regulator allows to improve the quality of the process of regulation in dynamic modes due to better speed-opration and accuracy of working out of commands in comparison with sub- regulator, which will also increase its energy efficiency and technological parameters.

The use of the developed system will be the most efficient where the fan installation operates in dynamic mode and high capacity, such as in the mining industry.

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МОДЕЛЮВАННЯ ЕНЕРГОЕФЕКТИВНОЇ ВЕНТИЛЯТОРНОЇ УСТАНОВКИ НА ОСНОВІ РЕГУЛЬОВАНОГО ЕЛЕКТРОПРИВОДА З РЕГУЛЯТОРОМ НЕЧІТКОЇ ЛОГІКИ

П.Б. Клендій, М.М. Федірко, В.Г. Камишлов, В.Г. Подобайло, О.П. Дудар

Анотація. *Вентиляторні установки відцентрового типу є найбільш розповсюдженими у різних галузях виробництва, як легкої, так і важкої промисловості. Частіш за все, відцентрові вентилятори встановлюються як установки з нерегульованим електроприводом, особливо малої потужності. Але є багато технологічного устаткування, особливо у виробничій сфері, де необхідно регулювати продуктивність вентиляторів. Причому регулювання здійснюється у доволі широких межах.*

Електропривод відцентрових вентиляторів звичайно реалізовано на базі асинхронного короткозамкненого двигуна. Для регулювання подачі такого вентилятора здійснюється регулювання швидкості обертання двигуна за допомогою перетворювача частоти

Серед відомих способів регулювання продуктивності вентиляторних установок, а саме дроселювання, зміна кута встановлення лопатей, використання направляючих апаратів, регулювання числа обертів валу вентилятора є самим ефективним способом.

У сучасних умовах зміна обертів валу вентилятора здійснюється зміною обертів валу привідного двигуна

У статті розглянуто питання підвищення енергоефективності вентиляторних установок шляхом застосування регульованого електропривода з використанням регулятора, побудованого на принципах нечіткої логіки. Розроблено математичну модель системи в пакеті прикладних програм Matlab, *проведено комп'ютерне моделювання та показано переваги запропонованого підходу в порівнянні з традиційними методами регулювання.*

Ключові слова: ***вентиляторна установка, енергоефективність, регульований електропривод, асинхронний електродвигун, ПІД - регулятор, контролер нечіткої логіки, Matlab***