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CONTROL OF THE START OF HIGH-POWERED ELECTRIC DRIVES WITH THE OPTIMIZATION IN TERMS OF ENERGY EFFICIENCY

Purpose. To develop engineering solutions providing the improved energy efficiency of starters of high-powered electric drives through automatic selection of the best starting settings to increment its technical-and-economic indices.

Methodology. Developing a mathematical model to determine energy efficiency index of starting sequences which is invariant relative to the electric drive type as well as a design of the starter. Planning the experiments with the use of rotatable central composite design. Analyzing extreme experimental search engine in terms of the mathematical model.

Findings. Implementation of a subsystem has been proposed to identify the integral value of expending resources as well as a cumulative effect of a starting sequence, its duration, and energy efficiency index. A variant of hardware implementation of the extreme search engine has been proposed to control the start of high-powered electric drives.

Originality. It has been defined that the proposed structure for a start control is an invariant one relative to the electric drive type and to a starter design. Availability of the unique global maximum of energy efficiency index, resulting from the controlling action and disturbing action, has been substantiated.

Practical value. Alternatives for hardware implementation of devices to identify quantitative values of some of the components of expending resources of a starting sequence, integral cost estimate of expending resources and a cumulative start results, as well as its energy efficiency index have been formulated. A structural circuit of the extreme search engine to control start of high-powered electric drives has been designed, providing performance within a region of maximum.

Keywords: *start of high-powered electric drives, energy efficiency, extreme system*

Introduction. Starting sequences of high-powered electric drives result in significant negative influence on technical-and-economic indices of enterprises [1].

The influence is stipulated by the following basic factors: heavy energy consumption; significant deterioration of electromechanical and processing equipment; and extra economic loss of an enterprise depending upon operating trouble due to local quality degradation of a supply voltage.

Nowadays, use of special-purpose starters of the controlled electric drives is the most popular method for cost reduction connected with the equipment start [2, 3].

However, facilities of the current starters do not involve moduli for automatic determination of the best settings for starting conditions providing its improved energy efficiency as well as the reduced operating costs of an enterprise. First of all, lack of such facilities depends upon insufficient theoretical studies on energy efficiency of starting sequences and indices to evaluate it.

Literature review. Analysis of the current scientific and technical sources demonstrates considerable interest of researchers in the problems of the controlled start of high-powered electric drives. Papers [3, 4] consider operating features of

mechanisms with heavy starting conditions whose accelerating torque of resistance may exceed fundamentally the nominal one. Paper [5] analyzes energy saving potential in terms of the start control of pumping facilities.

Paper [6] examines electricity quality while using soft starters of asynchronous motors.

Paper [7] represents the results concerning development of soft starters for asynchronous motors focused on starting current limitation.

Paper [8] studies problems of dynamic identification and control of a soft start of asynchronous motors using artificial intelligence methods.

Paper [9] represents implementation of a soft start system for asynchronous motors with a control of overload level of a motor being started.

Paper [10] considers problems of a fuzzy logic apparatus to control starting sequence of electric motors.

Generally, the considered papers concern technical implementation of the soft start systems for asynchronous electric motors. Control of the starting sequence is amounted to the improved accuracy of the preset start trajectory; as a rule, it is a linear one.

Paper [11] represents an approach to the implementation of optimal systems controlling a start sequence independent of

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the started motor type. Analytical expression has been proposed for the starting sequence efficiency index taking into consideration the whole range of starting sequence influence (i.e., power consumption, the decreased useful operating life of equipment, and extra economic risks) as well as output product by the starting sequence, and its period.

Paper [12] regards influence of time distributed energy consumption processes and depreciation of a direct-current drive on the determination of an efficiency index of a starting sequence; feasibility to apply the simplified energy consumption model with the concentrated parameters has been substantiated.

Papers [13, 14] consider problems to identify the parameters of equivalent circuit to align control algorithms of energy converters in terms of the controlled start.

However, the available scientific sources do not involve comprehensive analysis of an efficiency index of a starting sequence upon a controlling action and disturbing action for electric drives of the most important types with varying design capacities and torque types. Nonavailability of such studies retards the development of new components of starting sequences providing optimization of energy efficiency of starting sequences of high-power electric drives.

Purpose is to analyze dependence of a starting efficiency index for the most important types of electric drives as well as starters with varying design capacities and torque types upon controlling action and disturbing action.

The abovementioned purpose achievement involves solution of the following problems:

- identification of the most important types of high-powered electric drives and starters used by modern industries;
- development of resource models of the most important types of electric drives;
- formulation of a plan of experiments concerning the efficiency index of a starting sequence using experiment planning theory;
- analysis of the obtained results with the formulation of optimization problem as for the control of high-powered electric drive start.

Results. In Ukraine, asynchronous and synchronous electric drives with significant (3-10MW) design capacity are popular at mining and metallurgical enterprises. Ukrainian enterprises, engaged in underground mineral mining, often use direct-current electric drives as an electric drive for hoisting devices. The global tendency for more extensive use of SRM inclusive of that with considerable unit capacity should be mentioned [15].

Gross capability as well as total energy by the mains is used as power consumption of a starting sequence. Gross capability of a power source is determined using the formula

$$S = \bar{U} \cdot \bar{I}, \quad (1)$$

where $\bar{U} \cdot \bar{I}$ are RMS of phase current and voltage of the mains. Fig. 1 demonstrates implementation variant of a subsystem to calculate power consumption of a start.

In terms of Matlab/SimPower, Models of electric motors do not take into consideration the availability of conventionally rotational loss within the devices. That is why the model is extended by **Permanent Losses** block considering action of conventionally rotational losses on the total power consumption. The numeric value of the block has been derived by

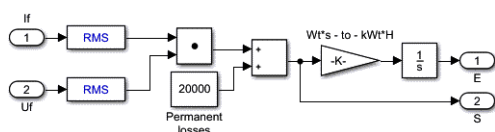


Fig. 1. Implementation of a subsystem to calculate power consumption of a start using Matlab/Simulink

means of calculations based upon the rated values of the electric motor being simulated. The model has two terminals corresponding to instantaneous electric motor voltage consumed from the mains taking into consideration conditionally rotational losses S and that E electricity consumed from the current input and measured in $\text{kWt} \cdot \text{H}$ to make further calculation of the energy cost comfortable.

According to the data by [11], equipment deterioration during a start can be determined with the help of the expression

$$W_e = I_0 \cdot \int_0^t \left(\gamma \cdot f_I(I_*(t)) + (1-\gamma) \cdot f_\omega(\omega_*(t)) \right), \quad (2)$$

where I_0 is equipment service life determined by its manufacturer; γ is the weight coefficient, $0 \leq \gamma \leq 1$; I_* , ω_* are values of current and angular velocities of electric drive respectively; f_I and f_ω are functions of the accelerated depreciation in terms of current and velocity respectively.

Fig. 2 shows a variant of a subsystem to calculate equipment deterioration. Current and angular velocity of electric drive are the factors determining the equipment deterioration.

Origination of extra economic risks of an enterprise, connected with the starting sequences of high-powered and group electric drives, depends upon the decreased level of the supply voltage within the power generation centres under the effect of starter current. Local step-down of supply voltage impacts heavily both the starting period itself and performance of technological environment on the whole which may be followed up by the emergency stop of operating schedules.

Complexity of the determination of quantitative evaluation of the decreased supply voltage is stipulated by the fact that extra economic risks of starting sequences of high-powered electric drives arise beyond the electric drive being started. First of all, the value of the extra economic risks depends upon the composition of technological environment, its current operation mode, load level of processing facilities, etc. The mentioned factors are external ones relative to the electric drive being started. Accurate determination of extra economic risk depends upon the evaluation of instantaneous state and operating schedules of the whole electric equipment which is possible if only the developed system of controlling and dispatching is available at the enterprise level.

It should be noted that numerical values of economic risk function $fe(t)$ may vary considerably depending on time of day; its numerical characteristics may be prevented from their reproduction even in terms of absolutely identical course of the starting sequence. Characteristics of economic risk function $fe(t)$ hardly depend upon the characteristics of the electric drive being started; moreover, they vary significantly when the electric drive performance is analyzed as a component of other technocenosis.

Taken as a whole, economic risk function $fe(t)$ is of the pronounced probabilistic nature; mainly, its value depends upon technological environment.

It is possible to state a priori that the value of economic risks $fe(t)$ should vary in the direction opposite to residual voltage changes on the common supply buses: a value of economic risk function $fe(t)$ decreases along with the supply voltage increase and vice versa.

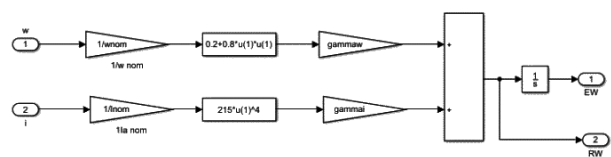


Fig. 2. Implementation of a subsystem to calculate equipment deterioration while starting (using Matlab/Simulink)

Due to the lack of experimental data, concerning the value and distribution features of economic risk function $fe(t)$, it is expedient to consider in terms of approximate evaluation that instantaneous value of extra risk function depends functionally upon the decreased voltage on the common buses of a power line, i. e.

$$fe(t) = \mu \cdot g(\Delta u(t)^*), \quad (3)$$

where μ is the proportionality factor and $\Delta u(t)^* = 1 - u(t)^*$ is relative value of voltage drop on the common buses of the mains. The necessity to use extra functional dependence $g(x)$ is caused by a nonlinear dependence of extra economic risks upon the voltage drop. A comparatively insignificant voltage drop (i. e. 10–15 %) is followed by the decrease in the efficiency of technological mechanisms; in turn, a significant voltage drop may result in their dead stop, which especially concerns those equipped by asynchronous electric drive.

Let us exemplify such a function

$$g(x) = \alpha(e^{\tau x} - 1). \quad (4)$$

Combination of expressions (3 and 4) will help to obtain the functional dependence of economic risk function $fe(t)$ upon voltage drop on the common buses of a power line

$$fe(t) = \mu \cdot \alpha \left(e^{\tau \Delta u(t)^*} - 1 \right), \quad (5)$$

where α and τ are approximation coefficients.

Quantitative evaluation of extra economic risks during electric drive start may be calculated using the expression

$$qfe = \mu \cdot \alpha \int_0^{t_s} \left(e^{\tau \Delta u(t)^*} - 1 \right) dt. \quad (6)$$

It is the important issue that power consumption and deterioration of the equipment are calculated quantitatively originating a dimensionality problem. To overcome it, all types of resource expenditures and cumulative result should be classified uniformly, which involves the use of a system of expert units. The problem aimed at the development of comparable unit system for a starting sequence expenditures may be solved using expert evaluation methods [18]. In the context of technical objects, it is expedient to apply cost estimates of different expenditure types as an expert system of comparable units since they are used as economically feasible expert evaluations.

Specific components of a resource cost vector are scaled in the cost estimate responses being summarized in the unidimensional responses of the integrated expert evaluation of the response expenditures

$$re(t) = \int_0^t \sum_{i=1}^N rqi(t) \cdot cq_i, \quad (7)$$

where N is dimensionality of resource expenditure vector; $rqi(t)$ is quantitative value of i^{th} component of the resource expenditures; and cq_i is cost estimate of i^{th} component of the resource.

After integration of the responses of the summarized expert evaluation during a starting sequence for the start termination, we obtain scalar characteristics of the starting sequence, i. e. integral expert evaluations of the resource expenditures as well as a cumulative result RE and PE , and a starting time ts .

Since the time-spaced nature of the resource consumption for a starting sequence (as it has been substantiated by paper [11]) may be ignored, it is possible to represent the starting sequence as the focused operation model [17] with concentrated $Os(RE, ts, \text{ and } PE)$ parameters.

As it has been proved by [12], the efficiency index of a starting sequence may be calculated using the simplified expression

$$kE = \text{sign}(PE - RE - FE) \cdot \frac{(PE - RE - FE)^2}{PE \cdot RE \cdot t_s^2}, \quad (8)$$

where PE , RE , and FE are summarized cost estimates of a cumulative result, resource expenditures, and extra economic risk per starting time t_s respectively.

With the help of (1–8) expressions, Matlab/Simulink has implemented all-purpose subsystem to identify the start efficiency index being invariant relative to a type of electric drive and a starting device type.

Mathematical models of electric drives, developed using SimPower library in Matlab/Simulink and added by the all-purpose subsystem identifying efficiency of a start index, form the resource models of relevant electric drives.

It is quite important for the optimization problem formulation concerning a start control to analyze dependence of a start efficiency index for different types of electric drive as well as their nominal power upon the controlling and disturbing influence.

A parameter, determining the start period and its intensity (for instance, linear scan t_U of supply voltage from zero to nominal one) is considered as a controlling influence. Resistive torque within the electric drive shaft is the disturbing influence.

To minimize the number of the experiments, the research has used a method of mathematical planning in terms of rotatable central composite scheduling based upon regressive analysis involving the least squares technique and statistical data processing [16].

Table 1 describes a field of the carried out experiments.

Before developing the experiment schedule, it is necessary to define the factors influencing the starting sequence efficiency relying upon the information given a priori. The factors are as follows: t_U – scanning time of supply voltage (i. e. controlling influence of the starting sequence and T_L – relative value of electric drive resistive torque (i. e. influence of the starting sequence disturbance). In the context of a static approach, mathematical model of an object or a process is represented in the form of a polynomial, i. e. truncated Taylor series in terms of which the unknown function is decomposed

$$y(x_1, \dots, x_k) = b_0 + \sum_{i=1}^k b_i \cdot x_i + \sum_{\substack{i,j=1 \\ i \neq j}}^k b_{ij} \cdot x_i \cdot x_j + \sum_{i=1}^k b_{ii} \cdot x_i^2, \quad (9)$$

where b_0 is a free term; b_i is linear effects; b_{ij} is pair interaction effects; and b_{ii} is quadratic effects.

Mathematical processing of the data will help to determine the total influence of control voltage scanning time and electric drive resistive torque on the nature of power supply change and deterioration of the equipment during a start; to determine dependence of the starting sequence efficiency index; to substantiate availability of general formal mathematical model of the starting sequence efficiency index suitable

Table 1

A complete list of experiments to analyze the efficiency of a starting sequence

Electric drive	Active load, 1600 kW	Fan load, 1600 kW	Active load, 800 kW	Fan load, 800 kW
TC-DC	1	–	2	–
FC-IM	3	4	5	6
TVR-IM	–	7	–	8
TVR-SM	–	9	–	10
SRM	11	12	–	–

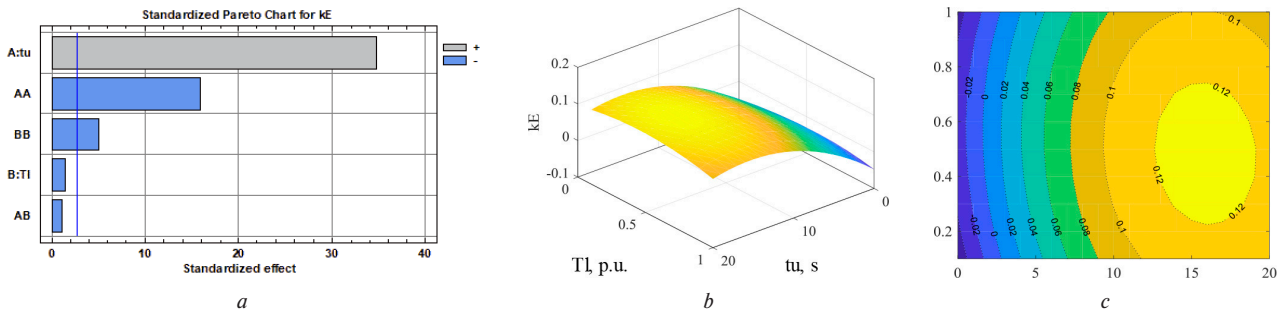


Fig. 3. Analysis of the starting sequence efficiency index:

a – Pareto chart of a regressive model of the start efficiency index; b – response surface; c – line chart of the start efficiency index for 1600 kW asynchronous motor with the fan load

for the considered types of electric drives; and identify the model type.

Response surface has been built for the start efficiency index and charts of isolines (Fig. 3).

For each experiment listed in Table 1, quadratic regression equations were obtained and regressive coefficient was determined. Pareto charts were applied to analyze the importance of certain coefficients of the regressive model.

Table 2

The generalized data of regressive analysis of the dependence of power consumption of the starting sequence

N	b_0	b_1	b_2	b_{11}	b_{12}	b_{22}	R, %
1	5698.05	589.01	71.20	18.29	78.60	4095.16	97.57
2	18 226.9	2371.48	6507.37	90.44	872.37	19378.6	85.91
3	8322.02	406.137	1698.91	6.71	78.41	476.73	99.53
4	18 174.6	2170.27	11772.3	71.80	77.48	11872.0	80.51
5	9817.05	165.026	965.137	0.568	14.45	246.61	99.98
6	7270.83	241.043	230.206	6.462	98.54	1484.54	99.79
7	8208.25	407.625	913.959	7.70	40.86	454.566	99.32
8	2275.94	287.201	590.684	10.37	43.47	1007.66	99.32
9	4905.88	682.893	1019.12	27.31	282.92	4822.16	83.60
10	4555.27	587.736	2187.78	20.20	35.68	2475.95	88.35
11	2966.82	91.7964	224.338	0.569	13.11	30.4062	99.96
12	2159.75	95.7625	124.95	1.970	22.63	345.946	99.59

Table 3

The generalized data of regressive analysis of dependence of deterioration of equipment during the starting sequence

N	b_0	b_1	b_2	b_{11}	b_{12}	b_{22}	R, %
1	9.951	0.06241	2.631	0.002	0.41	4.123	99.93
2	17.815	2.42393	10.580	0.106	1.000	7.593	96.18
3	19.033	0.62907	4.492	0.000	0.460	2.874	98.89
4	9.536	1.30259	12.162	0.061	0.650	1.473	91.52
5	16.468	0.00547	1.984	0.001	0.022	0.432	99.89
6	44.940	0.29131	1.389	0.039	0.604	9.317	99.94
7	18.697	0.64708	1.176	0.002	0.181	1.920	99.16
8	4.723	0.08546	2.778	0.003	0.287	3.977	98.11
9	4.547	0.56239	2.961	0.025	0.092	0.401	95.50
10	4.923	0.46380	0.974	0.016	0.113	0.217	97.04
11	5.179	0.00001	0.526	0.000	0.025	0.077	99.58
12	4.749	0.02334	0.016	0.0048	0.089	0.930	99.51

Table 4

The generalized data of regressive analysis of dependence of the starting sequence efficiency index

N	b_0	b_1	b_2	b_{11}	b_{12}	b_{22}	R, %
1	0.003	0.003	0.008	-8.99E-05	-0.001	-0.002	89.85
2	-0.006	0.005	0.021	-2.17E-04	-0.001	-0.027	89.79
3	0.005	0.011	0.047	-3.52E-04	-0.008	-0.015	87.31
4	-0.062	0.020	0.111	-6.23E-04	-0.001	-0.097	91.73
5	-0.068	0.024	0.143	-7.35E-04	-0.010	-0.081	88.83
6	-0.164	0.054	0.386	-2.31E-03	-0.003	-0.338	86.98
7	-0.027	0.009	0.051	-2.37E-04	-0.001	-0.039	89.9
8	-0.040	0.013	0.075	-4.29E-04	-0.002	-0.057	86.19
9	-0.019	0.007	0.034	-1.97E-04	0.000	-0.034	87.48
10	-0.029	0.009	0.056	-2.70E-04	0.001	0.040	88.93
11	0.004	0.008	0.017	-2.18E-04	-0.005	-0.008	88.63
12	-0.006	0.004	0.012	-9.90E-05	-0.001	-0.005	88.35

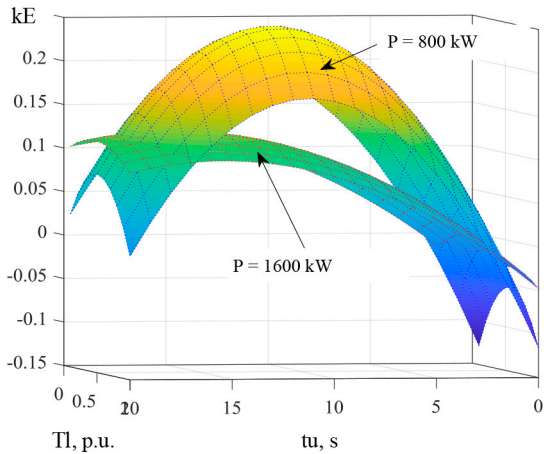


Fig. 4. Comparative analysis of $kE = f(t_u, T_L)$ dependence surfaces to start electric drives ПЧ-АД with 800 kW power and 1600 kW power and fan resistive torque

determining intensity of a starting sequence is the controlling influence of the starting sequence. Characteristics of a starter identify the engineering constraints as for the upper boundary of scanning time variation determining maximum possible period of electric drive start.

Hence, the problem of optimum control of a starting sequence has been formulated as a single-criterion one; in the general case, it is a multidimensional problem with continuous type of controlling and disturbing influence, and availability of the controlling influence restrictions.

Since response surface of a start efficiency index is of rather simple type, solving the problem of a start optimization in terms of the performance criterion may involve light optimization methods, namely, a scanning method, a half-division method or a method of golden section, and parabolic approximation method.

Applicative solution of the optimization problem of a starting sequence control is connected with a number of traditional difficulties. As it has been mentioned in paper [17] even if mathematical model of an object is quite accurate to demonstrate certain regularities as for the object parameters, use of the regularities for its extremum seeking may factor into significant errors due to the errors resulting from the determination of derivatives required to implement numerous optimization methods.

Error occurrence in the process of optimization problem solving depends upon the use of insufficiently tested mathematical models as well as inevitable influence of stochastic processes in technological equipment, probabilistic nature of measurement errors and others.

Design activities concerning the closed-loop control of high-power electric drive start should involve the fact that starting sequences take place at irregular, discrete time intervals separated by the periods of continuous service. The feature, being typical for starting sequences, initiates discrete-time operation nature of the closed-loop system controlling a starting sequences as well as the necessity to use a single-purpose database to store the required information during time intervals between the sequential starts. Significant time intervals between the sequential starts stipulate low requirements for the response time of the closed-loop system to control starting sequence.

Discrete nature of the system controlling the start sequence specifies expediency to use well-known architecture of search, step-by-step extremum engines as the foundation architecture of the closed-loop control system. Controlling systems with such architecture [16] put forward minimal demands for a priori information concerning the controlled object parameters; moreover, they are not very sensitive to the drift of the controlled object parameters and measurement noise effect. Low response (especially when it concerns a wide variation range of controlling influence) is the significant disadvantage of the step-by-step extremum engines.

Fundamental improvement of such a step-by-step extre-

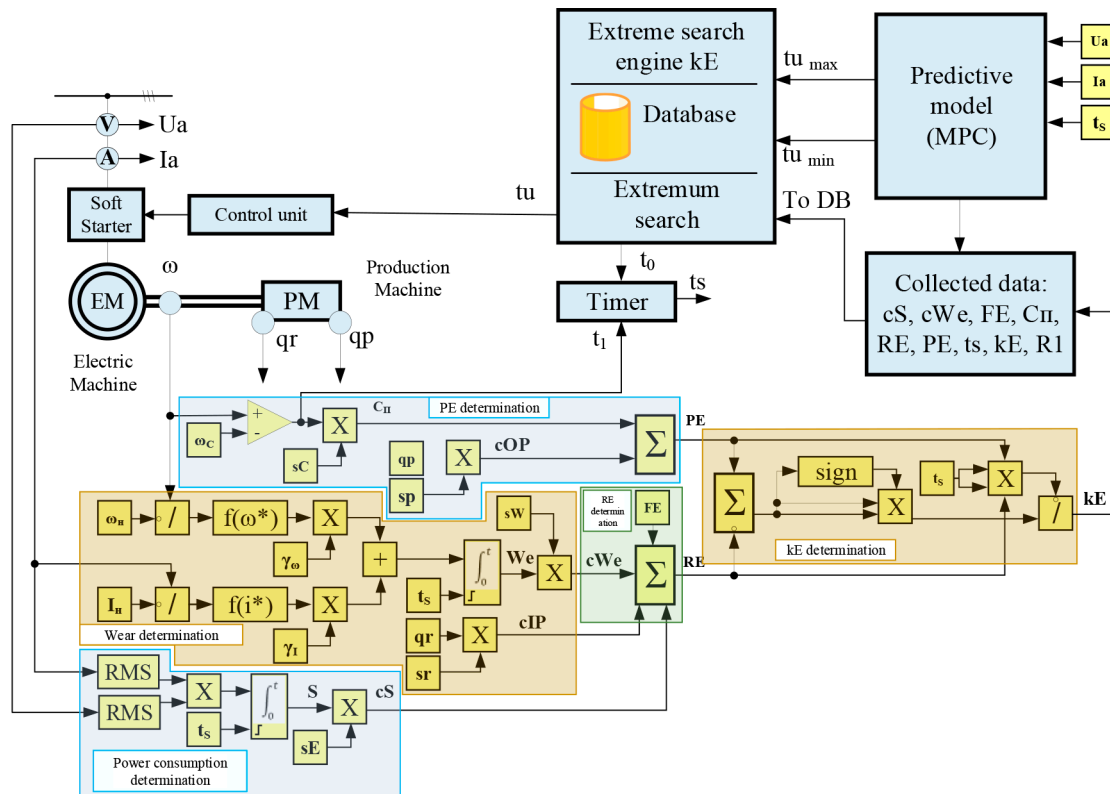


Fig. 5. Structural scheme of extremum search engine to control starting sequence of high-power electric drives in terms of its efficiency

Example of database structure to control a starting sequence in terms of its efficiency index

#	Symbol	Explanation
1	id	Start number from operation commencement
2	start	Starting time of electric drive
3	finish	Completion time of the electric drive start
4	len	Starting time of electric drive
5	ke	Efficiency index of the starting sequence
6	cS	Power consumption during the start
7	cWe	Deterioration of equipment during the start
8	FE	Extra economic risks during the start
9	RE	Integral expert evaluation of resource expenditures of the starting sequence
10	PE	Integral expert evaluation of cumulative result of the starting sequence
11	R1	Active resistance of a stator phase determined while starting

imum engine is possible in terms of the narrowed extremum search area of a starting sequence efficiency index [17]; for instance, it can be done using the control with a reference model making it possible to predict the initial condition of the efficiency index extremum.

Implementation of optimum systems to control the start of high-power electric drives is possible using the well-known structures of step-by-step extremum search engines combined with the reference model of an electric drive being started. Fig. 5 shows a variant of structural scheme of extremum search engine to control starting sequence of high-power electric drives.

Extremum search engine to control the starting sequence of high-power electric drives involves the following components: subsystem to determine power consumption during a start time and its expert evaluation cS (in terms of formula 1); subsystem to determine deterioration of equipment during a start time and its expert evaluation cWe (in terms of formula 2); subsystem to determine cumulative result of the start C_p (according to paper [17]); subsystem to determine integral expert evaluation of resource expenditures as well as cumulative result of the starting sequence RE and PE; timer TM to determine the start time; and subsystem to determine the efficiency index of the starting sequence efficiency kE (in terms of formula 3).

The represented system to control the starting sequence operates as follows. During start one, a model of electric drive prediction is adapted according to catalog data of electromechanical equipment. Methods of mathematical modeling are applied to identify the area of time variation of voltage scanning of the starter control $[t_{s_{min}}, t_{s_{max}}]$ in terms of the prediction model. Relevant signals are set to the terminals of a subsystem of extremum search of the starting sequence efficiency index; relying upon the available data, it produces a new current time value of the starter scanning $t_{s_{CON}}$. Operation algorithm of the subsystem of extremum search can consider information when the database contains no information at the initial time. After obtaining a starting permit, acceleration of a controlling motor of the electric drive initiates. During the start with the calculated scan time $t_{s_{CON}}$, proper subsystems identify quantitative and expert values of power consumption indices, indices of deterioration of the equipment, extra economic risks, indices of the formed kinetic energy, integral values of expert evaluations concerning input and output products of the starting sequence RE and PE, time of the starting sequence t_0 , and its efficiency index. At the moment when the start is over, the required data concerning certain parameters of the starting sequence are stored in the database. Relying upon the collected information on the previous starts of the electric drive, it is necessary to organize a search process of the starting sequence maximum efficiency index using both available and the tested methods to search extremum.

Table 5 contains the database required to control the starting sequence in terms of its efficiency index.

Fig. 6 demonstrates operations of a search extremum engine to control the starting sequence of asynchronous elec-

tric drive of a fan with a thyristor voltage controller obtained with the help of a program for optimum system modeling EFFLY.

The results of mathematical modeling support efficiency of the proposed structure of extremum search engine to control the starting sequence of high-power electric drives.

Conclusions. Asynchronous and synchronous electric drives, direct-current electric drive, and electric drive with SRM have been defined as the most important types of high-power electric drives being the most popular in the context of Ukrainian mining and metallurgical industries. Phase control of supply voltage and variable-frequency control are used to control the start of alternative-current electric drive.

Mathematical models have been represented to identify specific types of resource expenditures of the start; cost estimates have been proposed to be used for aggregation of certain types of resource expenditures into one class; and the efficiency index of a starting sequence has been developed to evaluate the starting sequence performance.

It has been proved that in the context of the basic types of electric drive, dependence of the efficiency index upon scanning time and resistive torque is of extremum nature, which makes it possible to formulate optimization problem of high-power electric drive start control as a one-dimensional, one-criterion problem with continuous values of controlling influence and availability of restrictions. The start efficiency index is the optimality criterion. A parameter, determining intensity of the starting sequence and its time has been selected as the controlling influence.

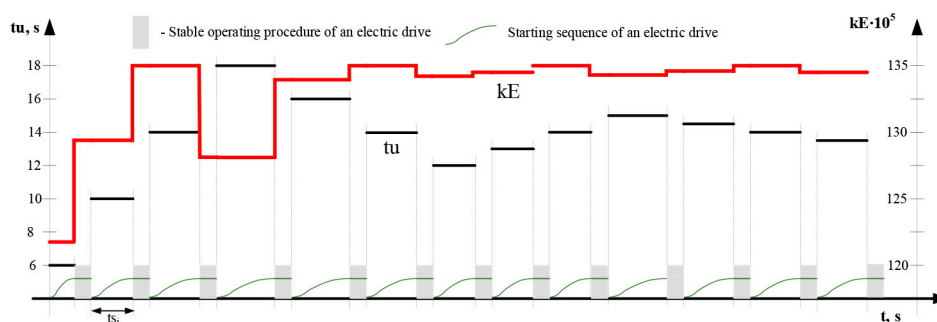


Fig. 6. Operation of a search extremum engine to control the starting sequence of high-power electric drives in terms of the starting sequence efficiency

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Керування пуском потужних електроприводів з оптимізацією за енергетичною ефективністю

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Мета. Розробка технічних рішень, що забезпечують підвищення енергетичної ефективності пускових систем потужних електроприводів за рахунок автоматичного вибору найкращих налаштувань пускового режиму, який забезпечує підвищення його техніко-економічних показників.

Методика. Побудова математичної моделі для визначення показника енергетичної ефективності пускових процесів, інваріантної щодо типу електроприводу й конструкції пускового пристрою. Планування експериментальних досліджень із застосуванням рототабельного центрального композиційного плану. Аналіз екстремальної пошукової системи на математичній моделі.

Результати. Запропонована реалізація підсистеми визначення інтегральної величини ресурсних витрат і сукупного результату процесу пуску, його тривалості й показника енергетичної ефективності. Запропоновано варіант апаратної реалізації екстремальної пошукової системи управління пуском потужних електроприводів.

Наукова новизна. Встановлено, що запропонована структура системи управління пуском є інваріантної щодо типу електроприводу та конструкції пускового пристрою. Обґрунтовано існування єдиного глобального максимуму показника енергетичної ефективності від керуючого та обурюючого впливів.

Практична значимість. Розроблені варіанти апаратної реалізації пристроїв для визначення кількісних значень окремих складових ресурсних витрат процесу пуску, інтегральних вартісних оцінок ресурсних витрат і сукупного результату пуску, а також показника його енергетичної ефективності. Розроблена структурна схема екстремальної пошукової системи управління пуском потужних електроприводів, що забезпечує роботу в області максимуму

Ключові слова: пуск потужних електроприводів, енергетична ефективність, екстремальна система

Управление пуском мощных электроприводов с оптимизацией по энергетической эффективности

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Цель. Разработка технических решений, обеспечивающих повышение энергетической эффективности пусковых систем мощных электроприводов за счет автоматического выбора наилучших настроек пускового режима, что обеспечивает повышение его технико-экономических показателей.

Методика. Построение математической модели для определения показателя энергетической эффективности пусковых процессов, инвариантной относительно типа электропривода и конструкции пускового устройства. Планирование экспериментальных исследований с применением рототабельного центрального композиционного плана. Анализ экстремальной поисковой системы на математической модели.

Результаты. Предложена реализация подсистемы определения интегральной величины ресурсных затрат и совокупного результата процесса пуска, его длительно-

сти и показателя энергетической эффективности. Предложен вариант аппаратной реализации экстремальной поисковой системы управления пуском мощных электроприводов.

Научная новизна. Установлено, что предложенная структура системы управления пуском является инвариантной относительно типа электропривода и конструкции пускового устройства. Обосновано существование единственного глобального максимума показателя энергетической эффективности от управляющего и возмущающего воздействий.

Практическая значимость. Разработаны варианты аппаратной реализации устройств для определения количественных значений отдельных составляющих ресурсных затрат процесса пуска, интегральных стоимостных оценок ресурсных затрат и совокупного результата пуска, а также показателя его энергетической эффективности. Разработана структурная схема экстремальной поисковой системы управления пуском мощных электроприводов, обеспечивающая работу в области максимума

Ключевые слова: пуск мощных электроприводов, энергетическая эффективность, экстремальная система

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