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PREDICATIVE FORM OF THE ENERGY-ECONOMIC MODEL OF AN ASYNCHRONOUS MOTOR

Abstract. The article is sanctified to date issue of the day of choice of facilities of defence of asynchronous motors working in the workshop electric networks of industrial enterprises with off-grade electric power. Possibility of presentation of energyeconomic model of asynchronous engine is shown as disjunction of predicates and application to them algorithms of recognition of patterns for a decision-making. Main dignity of new model is an openness and possibility of accumulation of knowledge about the modes of operations of electromechanics equipment.

Keywords: means of protection, asynchronous motors, poor-quality electrical energy, industrial enterprises, programmable logical controller, identification and predicative model, technical and economic values, electromechanical equipment, electrical networks, non-linear objects, mathematical apparatus, data base control systems.

Introduction. The principal ways of decrease of poor-quality electricity negative impact on electric motor operation in production environment and consequently on the efficiency of production in general are as follows: application of “individual” LC-filters for protection of principal electric drives; application of “sectional” poor-quality supply voltage compensating devices on a workshop level; suppressing of supply voltage distortion in the points of its origin. Rejection of any measures is also considered acceptable despite insignificant engine lifetime reduction. Each of the aforesaid options incurs certain integration cost and expected economic effect.

The known methodology for choosing of protection equipment to secure an asynchronous motor (AM) [1] operating under the conditions of poor-quality electric energy is based on its energy-economic model. The above

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methodology implements computing algorithms involving stochastic model of linear voltage within workshop power supply network, nonlinear electro magnetic and thermal model of AM and economic model as well. Obtaining the above models involves carrying out voluminous, time-consuming industrial experiments, as well as attracting specialists from various fields of knowledge to their processing. A separate and equally challenging task is to perform computational optimization calculations for choosing the best way to protect an asynchronous motor. These features of the application of the energy-economic model are constraining factors for its widespread adoption.

The goal of this article is justification of the possibility of the above methodology implementation in production environment based on SCADA of Zenon system software installed on PC; and application of predicate models and non-relational data model-oriented recognition algorithms.

Research methods and results. Taking a decision on economic viability of the choice (or refusal) of a particular protection equipment depends on the value of several variables (input technical and economic): total harmonic distortion K_U, coefficients of specific harmonic components $K_{U(m)}(m=7)$, negative sequence ratio K_{2U}, zero-sequence index K_{20}, protection equipment cost $C_j(i=\overline{1,r})$, where r – is the number of different types of protection devices. Herewith, indexes K_U, $K_{U(m)}$, K_{2U} and K_{20} depend on objective laws of linear voltage variation within electric network and asynchronous motor operation pattern.

The characteristics of linear voltages and asynchronous motors in real time can be determined on the basis of the Zenon SCADA software system [2], placed on a personal computer (Fig. 1). Control's sensors monitor the current values of line voltages and motor parameters connected to the controller VIPA-314-6CG23. The connection between the programmable logic controller and the personal computer with the software package is implemented using the Ethernet interface. The current values of line voltages and motor parameters are displayed on the PC screen and saved for further processing. Moreover, the hardware and software of the complex make it possible to simultaneously conduct research on all the engines working in the workshop.

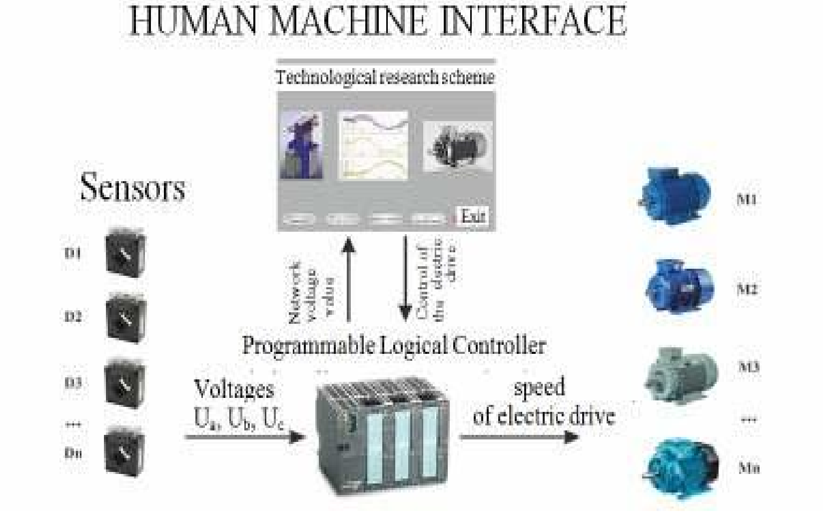

Figure 1 - Schematic structure of the system for study of electric network and induction motors

Technical and economic values have some deviations conditioned by either measuring precision (for technical values) or economic situation (for costs) and are measured within certain range. This makes possible to represent energy-efficient model of IM by a sum-of-predicates form (discrete form) [3]:

$$Z_{\text{em}}\left[\vec{X},\vec{C}\right]=V_{p=1}^{q}\,\mathrm{V}_{l}^{\lambda_p}\,\mathrm{Z}_{p,l}\left[\vec{X},\vec{C}\right], \qquad (1)$$

where,

$$Z_{em}\left[\vec{X},\vec{C}\right]=2^{-n}\prod\nolimits_{j=1}^{n}\left\{1+\operatorname{sgn}\left[(X_j-X_{j\min}^{pl})(X_{j\max}^{pl}-X_j)\right]\right\}+$$
$$+2^{-r}\prod\nolimits_{j=1}^{r}\left\{1+\operatorname{sgn}\left[(C_j-C_{j\min}^{pl})(C_{j\max}^{pl}-C_j)\right]\right\},$$

V –logic operation of disjunction.

Here: q – number of loss experience categories resulting from integration of protection equipment or their clusters, λ_p – number of predicates determining p – range; n and r – number if technical and cost values respectively; $X_{j\min}^{pl}, X_{j\max}^{pl}, C_{j\min}^{pl}, C_{j\max}^{pl}$ - model constants.

Generation of predicates parameters and their consolidation in categories may be commenced in the course of teaching the model according to the criterion of minimal economic losses resulting from the availability of AM protection equipment (or their unavailability)

$$E_p \to \min, \qquad (2)$$

In this case in the course of input values sampling population recognition learning it’s requisite by setting different criteria E_p within the interval $E_{p.\max} \div E_{p.\min}$ to split factor space into two categories: M_1 if $E_S < E_p$ and M_2, if $E_S > E_p$. Provided that the criteria values changes within the range $\Delta E_p = (E_{p.\max} - E_{p.\min}) / q,$, the q splitting the categories of hypersurfaces will be received, which pursuing the methodology of analytical description by means of methods admitting splitting of the factor space into elementary subfields may be represented by predicate equation (1). Here: ΔE_p - permissible deviation of economic losses from estimated value.

Teaching the model is performed on the basis of computing experiment, structural pattern of which is shown on Fig. 2. In the course of experiment, implementation control unit (ICU) generates random sequence of input values within the prescribed limit.

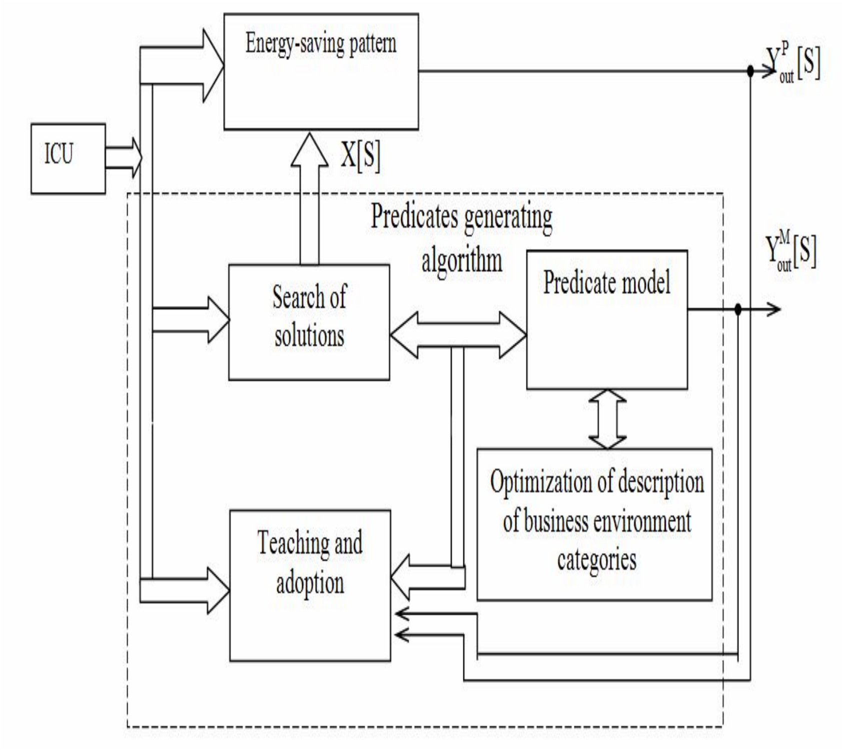

Figure 2 – Schematic structure of predicates generation model

In section “Energy Saving Pattern” calculation of economic losses incurred by application (abandoning) of protection equipment for electric drives in electric networks with poor-quality electrical energy is performed. See design formula for their determination pursuing [4-6].

Generation of predicate pattern components is commenced in section “Education and Adaptation” pursuing [3]. Herewith the number of predicates of completely defined predicate pattern depends upon parameters of input variables and defined with the help of the following formula [3]:

$$K_q = \prod\nolimits_{i=1}^{n} \frac{d_i}{\Delta x_i}, \qquad (3)$$

Here $d_i; \Delta x_i$ – turndown and sample spacing of input value. See table 1 for data on input values parameters during the study of 7,5 kW AM operation under the conditions of poor-quality electrical energy. As it appears from table 1 and (3) $K_q = 1{,}664 \cdot 10^{13}$. Computation of such number of predicates within reasonable timeframes is rather difficult.

Table 1

AM input values parameters

No.	Input value	Turndown	Variation range	Note
1	Total harmonic distortion	2-15%	0,5%	
2	Specific harmonic components ratio	0 – 10%	0,5%	First 7 harmonic components
3	Reverse sequence ratio	0 – 5%	0,1%	
4	Zero sequence ratio	0 – 5%	0,1%	
5	Protection equipment cost	UAH 0-200000	UAH 2000	10 options of technical solution

To overcome the above problem called “curse of dimensionality” in the course of teaching the predicate model, the algorithm of accelerated education has been applied [7]. This algorithm allows to include untaught fields of factor space into predicative pattern once simple criteria for two predicates of a certain class are met:

$$\begin{cases} X^1_{u\min} \le X^2_{u\min} \\ X^1_{u\max} \ge X^2_{u\max}, \quad \text{при} \quad u = \overline{1,n}; u \ne 1 \end{cases}, \qquad (4)$$

where $X^1_{u\min}, X^1_{u\max}, X^2_{u\min}, X^2_{u\max}$ – parameters of the merged fields projections, u – number of factor space feature axis towards which subfields are combined.

"Predicate Model" module generates economic environment in the form of a predicate and assigns it to p-class based on defined values of technical and economic parameters and economic damages from application of protection equipment computed with energy saving pattern involved. The number of the class is defined using the following formula:

$$p = entier\left|E_p \times \Delta E_p^{-1}\right| + 1, \tag{5}$$

It is also worth noting that an adaptation algorithm has been developed for predicate model which makes possible its updating to reflect expansion of hardware park and its cost changes:

$$Z_p\left[\vec{X},\vec{C}\right] = \left[V_{i=1}^{q} \mathrm{V}_l^{L_1+\lambda_p} \mathrm{Z}_{p,l}\left[\vec{X},\vec{C}\right]\right] \Lambda \left[V_{v=1}^{L_2} \overline{\mathrm{Z}_{t,v}\left[\vec{X},\vec{C}\right]}\right], \tag{6}$$

where L_1 and L_2 – is the value obtained as a result of recognition of the first and second order controversies (respectively), $\Lambda -$ logical operation of the conjunction.

The first order controversy should be thought of as affiliation of a predicate with p class though the given predicate should be referred to t class pursuing economic losses value (as a result of technical and economic conditions) and the second order controversy should be thought of as affiliation of a predicate with t class though the given predicate should be referred to p class.

Realization of adaptation algorithm pursuing (6) leads to gradual structural complication of predicate model and difficulties in its real-world application. To overcome structural complication of the model is possible by means of application of algorithms used in "Reduction of Economic Conditions Categories Description". Reduction of categories description provides enlargement of subareas by way of their merging with the following encoding of the parameters of predicate equation which determines enlarged area [8].

Merging of subareas is commenced upon the fulfillment of equality conditions in the right and left parts of the formulas in (5). Hence, the resultant subarea has the minimal and maximum value of u-attribute determined as $X^{12}_{u\min} = \min\left\{X^1_{u\min}, X^1_{u\min}\right\}; X^{12}_{u\max} = \max\left\{X^1_{u\max}, X^2_{u\max}\right\}.$

It's obvious that in the context of enlargement of subareas the transition of predicates from one category to another and consequently resolution of the first and second order controversies is possible.

Encoding of predicate equations parameters involves determination of their numbers on feature axis in the form of some vector $\vec{B}$ and its collapse to some scalar by formula [6]:

$$K = \sum_{u=1}^{2(n+r)} b_j q^{(2(n+r)-j)}, \tag{7}$$

where b_j – collapsing vector $\vec{B}$ component, matching with j – feature axis; q - system base.

Moving from encoding figures K_γ to vector $\overrightarrow{B_\gamma}$ is done by the formula $b_{j\gamma} = \mathrm{mod}(\left[K_\gamma / q^{(2(n+r)-j)}\right], q), j = \overline{1,(n+r)}$.

Determination of the best technical option of AM protection according to predicate model is based on algorithm of recognition static optimization in "Solutions Search" unit as follows. For current technical values $Z_{em}\left[\vec{X}, \vec{C}\right]$ is computed starting from the first category of economic p=1, which is an equivalent of minimal value of economic losses. If $Z_{1l}\left[\vec{X}, \vec{C}\right] = 0$ for all $l = \overline{1, \lambda_1},$, then the second category of economic conditions should be analyzed, etc. This procedure is performed unless some p=c and $l = Z_{cg}\left[\vec{X}, \vec{C}\right] = 1$. Then according to the values of the chosen predicate constants financial expenditures and consequently the chosen technical option of protection are determined.

In [9] mentions that predicate equations (1) may be represented by relational data model. It helps describe the processes of teaching, adaptation, minimization and search of the optimum solutions based on single mathematical apparatus α – algebra.

Taking into consideration that relational model is supported by Data base control system this approach towards determination of optimum protection equipment for AM with regard to its operation under poor-quality electricity conditions is easy to implement in production environment.

Conclusions and acknowledgments. The analyzed approach towards determination of optimum option of protection of electrical equipment operating under conditions of poor-quality electricity networks is possible to implement in production environment. The proposed algorithms make it possible to derive mathematical models of electrical units under research in the form of logical sum of predicates standing for specific economic losses. Based on predicate models it's easy to find a range of optimal solutions for different conditions of electric devices operation. Obtained solutions may be saved on data store electronic component. For practical application of the obtained results it's enough to estimate the quality of electric energy on specific enterprise and engine`s health and afterwards, by means of data base control system, to choose the most economically reasonable protection equipment.

REFERENCES

1. Kachan U.G., Dyachenko V.V., Kuznetsov V.V. Means of efficient use of electrical energy, Monograph ,Zaporizhia,2016. – 156 p.

2. Boiko O.A. About the possibility of interaction of zenon SCADA system with external software. Altera. URL: http://www.svaltera.ua/press-center/articles/8773.php, 2014. – p. 28.

3. Kuznetsov V.V. Recognition algorithm in the tasks of increasing energy efficiency of asynchronous motors operating in low-quality electricity / V.V. Kuznetsov, A.V. Nikolenko, V. P. Ivashenko, N. M. Triputen Bulletin of the National Technical University "Kharkov Polytechnic Institute" Kharkov. 2017. Release 27 (1249).-P. 95-98.

4. Kuznetsov, V., Nikolenko, A. (2015). Models of operating asynchronous engines at poor-quality electricity, EasternEuropean Journal of Enterprise Technologies. vol 1, no 8(73) (2015): Energy-saving technologies and equipment. Pages: 37 - 42. DOI: 10.15587/1729-4061.2015.36755.

5. Romashykhin Iurii, Rudenko Nikita, Kuznetsov Vitaliy (2017). The possibilities of the energy method for identifying the parameters of induction motor. Proceedings of the International Conference on Modern Electrical and Energy Systems, MEES 2017. Pages: 128 – 131.
DOI: 10.1109/MEES.2017.8248869/

6. M. Zagirnyak, D. Rod'kin, Iu. Romashykhin, Zh. Romashykhina, A. Nikolenko, V. Kuznetsov, “Refined calculation of induction motor equivalent circuit nonlinear parameters by an energy method”, Eastern-European Journal

of Enterprise Technologies, Vol. 3, No. 5(87), pp. 4–10, 2017. DOI: 10.15587/1729-4061.2017.104146.

7. Triputen, N. M. Methods and results of computational studies of the predicate model identification algorithm / N. M. Triputen, A.S. Koba // Mining electromechanics and automatics.-2000.-№64.-p.106-108.

8. Triputen N.M., Noskin D.V. Investigation of the predicate model adaptation algorithm // Informacion technology. Bezpeka and links: Materials of All-Ukrainian Science - Practical Conferences. Dnipropetrovsk: State Higher Educational Institution "National Mining University".2011.- P.9-11.

9. Triputen, N. M., Beshta D.O. α algebra in the problems of control of technological processes // Scientific herald of the National Mining Academy of Ukraine. – 2001. –№2.p.80-83.