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THE IMPROVEMENT OF THE ELECTRIC DRIVE SYSTEM OPERATING UNDER DYNAMIC LOAD USING AN ARTIFICIAL NEURAL NETWORK

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The extensive use of electrical equipment systems operating under dynamic loads across various industrial sectors has underscored the importance of enhancing their management capabilities. This study presents a novel approach to improving the efficiency of managing electrical equipment. Specifically, we propose a new management strategy for electrical equipment that, by considering the system instability and implementing suitable adjustments through an artificial neural network, can guarantee high productivity and synchronized operation within the management system.

To develop a model for detecting instability, a database of over 2 million data points was created. Using the ANOVA algorithm, the degrees of influence of the input data on the output signal were estimated. It was revealed that the resisting moment created by the mechanism and the angular rotation speed, as well as the angular displacement of the engine shaft, have high degrees of importance. For a specific example, the training error and accuracy for different neural network algorithms were tested. The speed and accuracy of neural networks with different structures were analyzed.

The possibility of combined operation of a neurocontroller and a stability state detection classifier based on an artificial neural network was considered. A structural diagram for implementing this approach in an automated control system was proposed.

The possibilities of its application for detecting and controlling the stability of an electrification system were analyzed. It was found that despite the expansion of the possibilities of using neurocontrollers in control systems, the practical possibilities of using intelligent approaches in stability assessment problems have not been observed.

The obtained results have wide practical applicability and can be used for the development of control systems that ensure high reliability and speed of various electrification systems.

Keywords*:* artificial neural network, electrical drive, training method, neuroregulator, stability conditions.

Introduction. The automation of modern technological processes is accompanied by the use of electric drive systems, which dictates the continuous improvement of their operating modes. This makes it possible to increase the efficiency of technological equipment operation [1-6].

Electric drive systems are widely used in metallurgy, aerospace engineering, energy, transport systems, and elsewhere [7,8].

Many electrical power systems operate under the influence of randomly varying loads. Applying traditional control methods to these systems is not always appropriate or effective. The quality indicators and accuracy of an automated control system (ACS) depend on the system's ability to return to a steady state after the external influence disappears and the transient process completes. Therefore, there is a need to consider new approaches and methods proposed for controlling electrical drive systems with various technological mechanisms and motors.

Literature Review. Numerous works are devoted to electrical drive systems and their control. This section refers to works that consider intelligent control approaches and system stability assurance issues [9-12].

Article [13] proposes a model for assessing the stability of the mechanical part of a grinding mill electrical power system using machine learning. The work creates six stability assessment models. The proposed model, in uncertain operating modes, provides high accuracy and speed of instability detection. The proposed model, at an intelligent level, makes it possible to develop the capabilities of electrical power systems operating with dynamic loads [13].

The authors of [14] propose a neuro-fuzzy controller for regulating the angular position of an electromechanical device based on Boolean relations. The structure of the fuzzy system based on Boolean relations takes into account the operation of the existing sensors and actuators. For optimization of the fuzzy controller, the continuous model is transformed into a discrete-time model to include the closed-loop controller training equations.

A novel approach to adaptive control of the mechanical subsystem within an electrical power system for mechanisms operating under uncertain conditions is presented in [15]. This is accomplished by integrating a fuzzy reference model with PID controllers, leveraging the fast and precise training capabilities of a neural network. The testing of the proposed model demonstrates its effectiveness in mitigating elastic oscillations within the mechanical subsystem, while simultaneously ensuring high control speed, accuracy, adaptability, and minimal overshoot.

Of particular interest is the method for controlling the speed of a DC motor proposed by the authors of [16]. Simulation results demonstrate the effectiveness of the proposed NARMA L-2 controller, which exhibits the advantages of zero overshoot and excellent speed tracking performance.

The performed analysis demonstrates significant scientific and technical interest in research aimed at improving electrical power systems. A portion of the published work focuses on controlling oscillations that occur in the elastic components of these systems and mitigating their detrimental effects through the implementation of various controllers. Undeniably, the results achieved in this area are crucial for ensuring stable operation and preventing fault conditions within electrical power systems.

A further group of studies under review proposes models, algorithms, and methodologies for determining the stability criteria of an electrical machine, or other element, within an electrical power system. The results presented in these works are typically case-specific, and, moreover, often lack generalized solutions that explicitly address stability conditions. Our analysis indicates a substantial potential for enhancing the stability assurance of electrical power systems operating under dynamic load conditions. This potential remains largely untapped due to:

- a lack of sufficient integration between the control system design and stability analysis methods and tools;
- the absence of high-performance and accurate methods and tools for real-time detection of the system instability;
- the underutilization of intelligent techniques for detecting and classifying instances of the system instability.

Given the critical importance of precise knowledge regarding the system stability for advancements in electrical power system performance, and recognizing the significant opportunities for improving the effectiveness of stability condition consideration, the objective of the present work has been defined.

The objective of the work is to propose a control strategy for electrical power systems that, by considering the system instability and implementing appropriate control actions using an artificial neural network, will ensure high performance and a potential for seamless integration within the overall control system.

Selection of methodology. In this work, an artificial neural network model is used for stability classification. To determine the stability status of the system using the neural network, the following main problems are addressed:

- acquisition of a database;
- evaluation of the influence of the input data of the database;
- comparative analysis of neural networks trained using different methods;
- proposition of a model for detecting the stability status within the control system;
- proposition of a structural scheme for improving the control system of an electrical power system operating with a dynamic load.

Individual components and parts of the mechanical subsystem of an electrical drive system operating with a varying load can experience wear and deformation, which can result in the system entering an unstable regime. Considering the above, the work considers the stability status of the mechanical subsystem of the electrical power system.

Results. To evaluate the stability status of the mechanical subsystem using a neural network, a database (Data Base) was created. For this purpose, an algorithm developed based on the mathematical model presented in [17] (Fig. 1) was used.

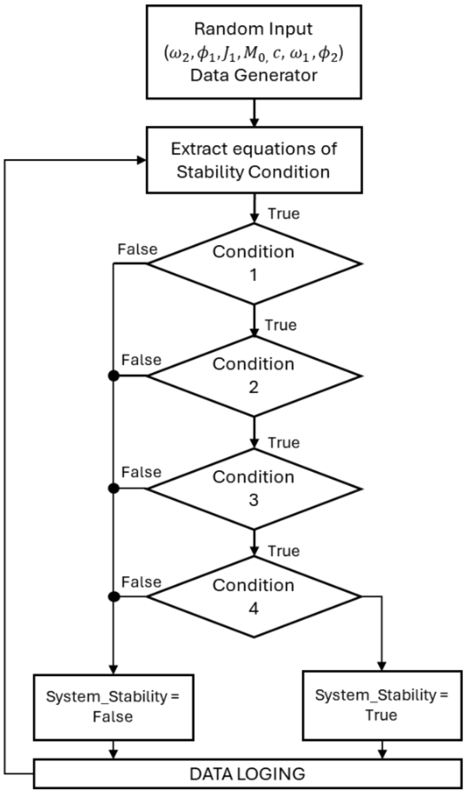

Fig. 1. A database acquisition block diagram

When creating the database, the following factors affecting the stability of the mechanical subsystem of the electrical power system were considered: the moments of inertia of the rotor of the motor and the mechanism respectively (J_1, J_2), the initial torque of the resistance of the mechanism (M_o); the rigidity of the connection between the mechanism and the motor (c); the angular displacement of the motor shaft (φ_1); the movement of the mechanism reduced to the motor shaft (φ_2); the electric rotation speed of the rotor (ω_1); the angular velocity of the actuating link of the mechanism (ω_2); the torque of the mechanism (M_o).

A database containing more than two million data points was created, consisting of 7 input features and one response.

To increase the efficiency of the database, the influence of the input data on stability conditions was evaluated.

The degree of importance of the influence of the input data on the output signal was evaluated using the ANOVA algorithm [18]. In this case, the input data are estimated by digits from 0 to infinity, and the higher the score, the more this factor will affect the performance of the system.

As shown in Table 1 the resistance torque and angular velocity of rotation created by the mechanism, as well as the angular displacement of the motor shaft, play an important role.

Table 1

Numerical results of data impact assessment

Features	ω_2	ϕ_1	J_1	M_o	c	ω_1	ϕ_2
Degree of the data impact	∞	∞	∞	677	444	39.79	6.37

The successful choice of network structure, activation function and training algorithm will improve the accuracy and performance of the artificial neural network.

First, it involves the use of various teaching methods. The neural networks trained using different methods were compared. To ensure the comparability of the results, training was performed for a network with homogeneous parameters.

The research was carried out using the TensorFlow and Keras packages using various algorithms for optimizing the network training. The following algorithms were used: Adam, RMSProp, Stochastic Gradient Descent (SGD), AdaDelta and Nadam. A total of 1,008,422 data elements were used, 30% of which were used for the network validation.

In the hidden layer, the neuron activation function was chosen by ReLU, and in the output layer by sigmoid.

The training rate was assumed to be 0.1, and only for SGD - 0.3. At a given training rate, the errors in detecting the system instability and accuracy for various training algorithms were estimated. The results are shown in Table 2.

Table 2

Results of the teaching methods

Training method	Training Loss	Training Accuracy	Validation loss	Validation accuracy
Adam	0.0156	0.999	0.0153	0.999
RMSprop	0.0356	0.9862	0. 0373	0.9831
SGD	0. 1337	0. 9791	0.1313	0. 9783
AdaDelta	0. 8833	0.4525	0. 8830	0.4511
Nadam	0. 0136	0. 9970	0. 0131	0. 9971

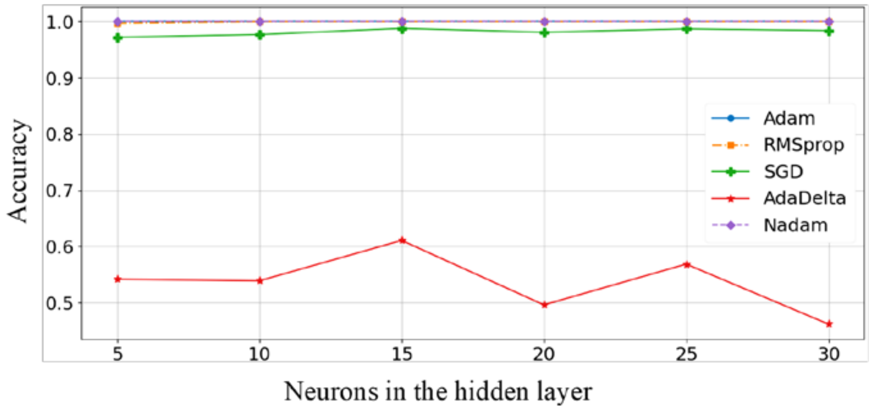

Fig. 2. The dependence of the accuracy of the validation on the number of neurons in the hidden layer

The results show that the AdaDelta optimization algorithm is unsuitable for use, because unacceptably poor results are obtained, whereas the other algorithms show acceptable results and can be used to assess the state of stability.

A change in the number of neurons in the hidden layer does not lead to any significant changes in the case of the Adam, RMSProp and Nadam algorithms, or in the case of SGD. Changing the number of neurons has a significant impact on the AdaDelta algorithm (Fig. 2), but because this algorithm provides results with low accuracy, it is unsuitable for use in this case.

The performance of neural networks with different numbers and activation functions in the hidden layer was studied using the Data Standardization algorithm (Table 3).

Table 3

Performance results for neural networks with different structures

Neuron structure	Number of neurons in the hidden layer	Activation function in the hidden layer	Data classifi-cation	Duration of training (s)	Accuracy (%)
Model 1	5	ReLU	-	557	48.8
Model 2	10	ReLU	-	652	51.1
Model 3	20	ReLU	-	712	48.9
Model 4	5	ReLU	+	168	98.2
Model 5	10	ReLU	+	248	98.3
Model 6	20	ReLU	+	388	98.1
Model 7	5	Sigmoid	+	748	97.8
Model 8	10	Sigmoid	+	882	98.3
Model 9	20	Sigmoid	+	906	98.2

The results show that the number of neurons in the hidden layer does not have a significant impact on the accuracy of the network. The use of the input data standardization algorithms has a significant impact on the network performance.

It is obvious that to improve the control system of electric drives operating with a dynamic load, it is most appropriate to use a model with one hidden layer, five neurons and a model architecture with a ReLU activation function in this layer.

The analysis of the development of a model for detecting the state of instability based on an artificial neural network provides a reason to assert the expediency of its application in control systems. In modern ACS, neurocontrollers have begun to be used, and can be successfully adapted to our proposed model for detecting the state of instability. Fig. 3 shows a block diagram of the possibility of using the instability-detection model in the ACS of the electric drive.

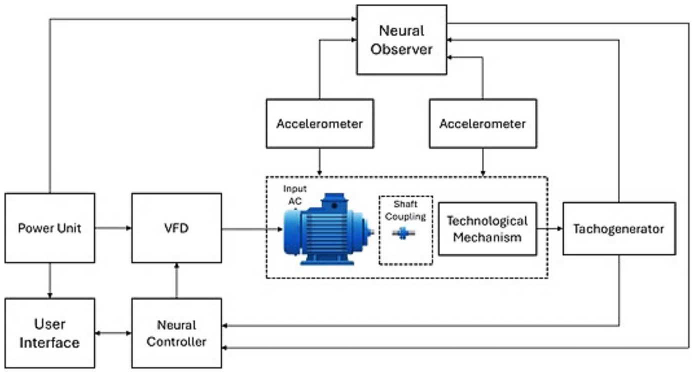

Fig.3. A block diagram of the automated control system

The automated control system comprises both a stability classifier (Neural Observer) and a neural controller (Neural Controller). Control signals are input to the system via a graphical user interface (User Interface), where the required control parameters are entered, and all the necessary information for system diagnostics is displayed. A variable frequency drive (VFD) connected to the power unit (Power Unit) converts single-phase voltage to three-phase voltage, which, in turn, supplies power to the motor. A tachogenerator is used to determine the rotational speed of the technological mechanism. Vibrations at the motor-load coupling are measured by accelerometers (Accelerometr) mounted on both the motor and the technological mechanism.

Initially, the control parameters are input. Subsequently, the neural controller determines the appropriate frequency and voltage settings for the VFD. The stability classifier then processes the signals acquired from the accelerometers and the technological mechanism. Employing the previously described algorithm, the classifier evaluates the stability status of the mechanical subsystem and transmits this information to the neural controller for further action or adjustments.

Conclusions

1. Testing a neural network model with observable structured data and a training algorithm shows that the accuracy of training increases by 1.9 times, and the training time decreases by 2.6 times with standardized input data. The results obtained allow us to assert the expediency of the standardization of input signals for the development of neural network models of electromechanical systems.

2. To detect the instability of the electric drive system, models created on the basis of an artificial neural network, with the right choice of architecture, are preferable to models based on the known classification algorithms.

3. The presented analysis provides grounds to conclude that the results obtained have a wide range of applications, in particular, they can be used to develop intelligent control systems that ensure a high reliability and high performance of various electrical drive systems.

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ԴԻՆԱՄԻԿ ԲԵՌՈՎ ԱՇԽԱՏՈՂ ԷԼԵԿՏՐԱԲԱՆԵՑՄԱՆ ՀԱՄԱԿԱՐԳԻ ԲԱՐԵԼԱՎՈՒՄԸ՝ ԱՐՀԵՍՏԱԿԱՆ ՆԵՅՐՈՆԱՅԻՆ ՑԱՆՑԻ ԿԻՐԱՌՄԱՄԲ

Վ.Դ. Հովհաննիսյան

Արդյունաբերության տարբեր ճյուղերում դինամիկ բեռով աշխատող էլեկտրաբանեցման համակարգերի լայն կիրառությունը հիմք է տալիս մշտապես արդիական դիտել դրանց կառավարման հնարավորությունների բարելավման խնդիրները: Առաջարկվում է էլեկտրաբանեցման համակարգի կառավարման արդյունավետության բարձրացման նոր մոտեցում: Մասնավորապես՝ առաջարկվել է էլեկտրաբանեցման այնպիսի

կառավարում, որը, հաշվի առնելով համակարգի անկայունությունը և իրականացնելով համապատասխան կարգավորում՝ արհեստական նեյրոնային ցանցի կիրառմամբ, կարող է ապահովել բարձր արտադրողականություն և կառավարման համակարգում համաձայնեցված աշխատելու հնարավորություն:

Անկայունության վիճակի հայտնաբերման մոդելի մշակման նպատակով ստեղծվել է 2 միլիոնը գերազանցող տվյալների բազա: ANOVA ալգորիթմի միջոցով գնահատվել են բազայի մուտքային տվյալների ազդեցության կարևորության աստիճանները ելքային ազդանշանի վրա: Բացահայտվել է, որ մեխանիզմի ստեղծած դիմադրող մոմենտը և պտտման անկյունային արագությունը, ինչպես նաև շարժիչի լիսեռի անկյունային տեղաշարժն ունեն բարձր կարևորության աստիճաններ: Կոնկրետ օրինակով փորձարկվել են նեյրոնային ցանցի տարբեր ալգորիթմների համար ուսուցման սխալը և ճշտությունը: Վերլուծվել են տարբեր կառուցվածքով նեյրոնային ցանցերի արագագործությունն ու ճշտությունը:

Դիտարկվել է նեյրոկարգավորիչի և արհեստական նեյրոնային ցանցի հենքով կայունության վիճակի հայտնաբերման դասակարգչի համատեղված աշխատելու հնարավորությունը: Առաջարկվել է ավտոմատացված կառավարման համակարգում այդ մոտեցման իրականացման կառուցվածքային սխեման:

Էլեկտրաբանեցման համակարգի կայունության հայտնաբերման ու կառավարման նպատակով վերլուծվել են դրա կիրառման հնարավորությունները: Պարզվել է, որ, չնայած կառավարման համակարգերում նեյրոկարգավորիչների օգտագործման հնարավորությունների ընդլայնմանը, չեն նկատվել ինտելեկտուալ մոտեցումների կիրառական հնարավորություններ կայունության գնահատման խնդիրներում:

Ստացված արդյունքներն ունեն կիրառական լայն հնարավորություն և կարող են օգտագործվել տարբեր էլեկտրաբանեցման համակարգերի բարձր հուսալիություն և արագագործություն ապահովող կառավարման համակարգերի մշակման համար:

Առանցքային բառեր. արհեստական նեյրոնային ցանցեր, էլեկտրաշարժիչ, ուսուցման ալգորիթմներ, նեյրոկարգավորիչ, կայունության պայմաններ:

УЛУЧШЕНИЕ СИСТЕМЫ ЭЛЕКТРОПРИВОДА С ДИНАМИЧЕСКОЙ НАГРУЗКОЙ С ИСПОЛЬЗОВАНИЕМ ИСКУССТВЕННОЙ НЕЙРОННОЙ СЕТИ

В.Д. Оганнисян

Широкое применение систем электропривода в различных отраслях промышленности, работающих с динамической нагрузкой, дает основание акцентировать внимание на проблемы улучшения возможностей их управления. В данной работе предлагается новый подход к повышению эффективности управления системами электропривода. В частности, предложено такое управление электроприводом, которое, учитывая нестабильность системы и внедряя соответствующую настройку с использованием искусственной нейронной сети, может обеспечить высокую производительность и способность работать согласованно в системе управления.

С целью разработки модели обнаружения состояния нестабильности была создана база данных, превышающая два миллиона. С помощью алгоритма ANOVA

была оценена степень важности влияния входных данных базы данных на выходной сигнал. Обнаружено, что момент сопротивления и угловая скорость вращения, создаваемые механизмом, а также угловое смещение вала двигателя имеют высокую степень важности. Для конкретного примера была протестирована ошибка обучения для различных алгоритмов нейронной сети. Проанализированы быстродействие и точность нейронных сетей с различной структурой.

Рассмотрена возможность совместной работы нейроконтроллера и классификатора определения состояния стабильности на основе искусственной нейронной сети. Предложена структурная схема реализации этого подхода в автоматизированной системе управления.

Проанализированы возможности его применения для определения стабильности системы электропривода и управления им. Обнаружено, что, несмотря на расширение возможностей использования нейроконтроллеров в системах управления, возможности применения интеллектуальных подходов в задачах оценки устойчивости не наблюдались.

Полученные результаты имеют широкий спектр применения и могут быть использованы для разработки систем управления, обеспечивающих высокую надежность и быстродействие различных систем электропривода.

Ключевые слова: искусственная нейронная сеть, электродвигатель, метод обучения, нейрорегулятор, устойчивость.