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OPTMIZATION OF «FUEL ELECTRIC GENERATOR – ELECTRIC MOTOR» SYSTEM IN CAD

Головні проблеми автоматизованого проектування систем «паливний електрогенератор – асинхронний електродвигун» випливають з того, що ці системи при оптимізації не можуть бути розглянуті окремо. Теоретично обґрунтоване підвищення ефективності виробництва за рахунок САПР, яка забезпечує оптимізацію параметрів обладнання за глобальною зв'язністю. Розроблено САПР «OPTIGLOC» та здійснено її виробниче випробування із позитивним техніко-економічним ефектом.

Ключові слова: *паливний електрогенератор, ковзання асинхронного електродвигуна, оптимізація в САПР, глобальна зв'язність.*

1. Introduction

There are many applications of electric driving force, where, for various reasons, the purchased asynchronous motors do not satisfy the task of designing the object as a whole. This is due to electromechanical characteristics (for example, in transport motors, escalator motors, instruments, etc.), or with non-optimal energy costs (for example, in «fuel electric generator – asynchronous electric motor» systems). This circumstance complicates existing or creates new, «atypical» constraints when optimizing such systems in CAD.

In addition, in many cases the energy indices of individual subsystems containing an electric motor can't be considered independently. Therefore, the improvement of existing and the creation of new methods and models designed to improve the efficiency of automated design of systems such as «fuel electric generator – asynchronous electric motor» is a very urgent task.

2. The object of research and its technological audit

The object of research is the process of computer-aided design of complex electrical equipment for global connectivity between the parameters of its elements [1–3].

Technological audit in CAD is a check of technological processes, methods, techniques and procedures used in the process of computer-aided design, for example, complex electrical equipment, in order to assess their performance and efficiency.

Technological audit of the research object allows to establish that the existing methods of computer-aided design of asynchronous electric motors are not able to effectively obtain the optimum parameters of the latter. This is due to the fact that their energy indicators can't be considered regardless of the corresponding indicators of electrical energy source. From this it follows that the design technology of such motors must be changed in such way that a complex aggregate of «fuel electric generator-asynchronous electric motor» type is considered as a design subject.

Another conclusion of technological audit of CAD of asynchronous electric motors is the need to change the methods, techniques and design procedures in which the theoretical and real slip of an electric motor are considered separately.

3. The aim and objectives of research

The aim of research is to reduce the time for preparing production and improving the quality of products of machine-building enterprises at the stage of computer-aided design of complex electrotechnical equipment. These indicators need to be achieved by developing and implementing methods and models to optimize global connections in CAD.

To achieve this aim, it is necessary to perform the following tasks.

1. To develop an optimization method of «fuel electric generator-asynchronous electric motor» type in CAD systems, the energy indicators of which can't be considered independently in the process of computer-aided design.

2. To develop the CAD of electrotechnical equipment «OPTIGLOC» and carry out its production test and evaluation of the technical and economic effect of its application.

4. Research of existing solutions of the problem

Asynchronous electric motors are found in the most diverse areas of engineering, transport, instrument engineering, household appliances and much more [4–6]. But, despite this, the scientific and practical improvement of the design directions for «conventional» asynchronous electric motors is a very rare process. After all, now there are stable (but very complex) calculation methods [7, 8] and, most importantly, a large line of such electric motors on sale. The latter reduces motor design to selection from the list of existing purchased motors [9, 10].

But, directions and methods of strategic development of autonomous electric equipment create requirements and conditions for new approaches for the automated design of special induction motors [11, 12]. These systems also include the «fuel electric generator-asynchronous electric motor» system, the main feature of which is the presence of restrictions on parameters that «simultaneously» belong to different subsystems of the latter [13, 14].

An example of such limitation, which has the most significant effect on virtually all motor performance, is the actual current electric slip:

$$s = (f_1 - f_2)/f_1,$$

which connects the parameters of various material substances (field and physical object) belonging to different subsystems of the «generator-motor» system: f_1 – frequency of stator magnetic field rotation; f_2 – frequency of motor rotation.

In the case of the «fuel electric generator-asynchronous motor» system with close values of the power of the subsystems, *both* these parameters, and consequently also the slip, essentially depend on the torque on the asynchronous motor (AM) shaft M: $f_1(M)$, $f_2(M)$ and $s(M)$.

In general, the term «slip» means two, essentially different from the point of view of the designer parameter. First, it is a real, *instantaneous slip* as a function of the motor load, and therefore time, and, secondly, a *nominal slip*, as a number that is taken into account in design calculations. That is why, the nominal slip for typical calculations of individual motors is either «selected from tables» or simply checked for «acceptable value», which, however, does not contribute to the creation of optimal designs [15].

On the other hand, the slip dualism creates great opportunities for CAD in the case where the design object is not a separate electric motor, but the system «generator-motor». As a rule, the powers of the elements of such systems are commensurable, and consequently the variables that enter into the slip closely interact. Under these slip conditions, thanks to the wide – *global* connectivity with many other parameters of the given system, it can be considered not as a certain limitation, but as an important intermediate objective design function.

Due to these features, slip is a stand-alone among the projected parameters, because one of its arguments – the frequency of the electric current supply – is not always available to the designer as an argument. Except in the case where the frequency is a control over the speed of motor rotation [16].

In any case, the frequency of a normally operating generator is usually subjected to constant monitoring in order to protect against various changes related to the operating conditions of the relevant electrical systems.

Protection against reduced frequency. The frequency reduction occurs as a result of a lack of generated power in the network [17].

Protection against increased frequency. The function of frequency protection is used in all cases when reliable detection of a high value of the main frequency of the power system is necessary. An increase in frequency occurs in the event of a sudden load shedding or in multiphase short circuits in the power system.

Protection by the rate of frequency change. The function of protection by the rate of frequency change allows to detect the system accidents at the initial stage. It can be used to reduce the power of generated electricity and in corrective action schemes. The function is capable of detecting both positive and negative frequency changes.

Frequency protection with time accumulation. Frequency protection with time accumulation uses system frequency measurements and time counters.

The function that is used to protect the generator generates a start signal when the frequency or voltage reaches certain limits. The frequency limit is determined by decrease of the latter in the specified frequency range, and the direct sequence voltage is within the specified voltage range.

The start signal triggers a separate event timer that counts the time of the frequency within the specified range, as well as a cumulative timer that counts the total time of the frequency within a specified range. When the timer reaches its limit values, an alarm or trip signal is generated to protect the generator from abnormal frequency conditions [18].

5. Methods of research

5.1. Calculation of parameters of complex electric equipment for global connectivity. Let's consider the case when an asynchronous motor is operated from a fuel electric generator of commensurate power.

When the torque value on the shaft M is small, the value of the rotational frequency of the stator magnetic field f_1, even when the generator is commensurable with the motor, approaches the nominal value of 50 Hz. The rotational speed of the rotor f_2 is determined by the actual slip $s(M)$ (Fig. 1). With the increase of the moment M, both frequencies decrease, and the slip $s(M)$, which is a function of these frequencies, changes insignificantly.

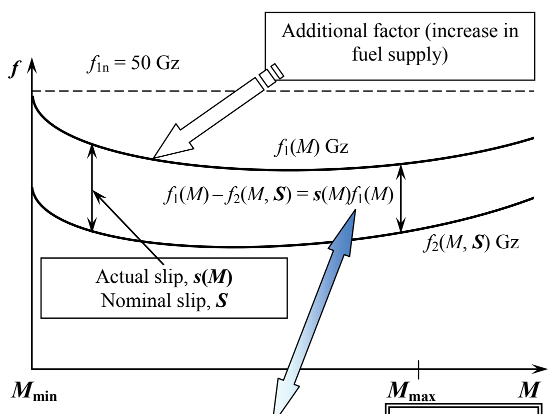

Fig. 1. Scheme for calculating the parameters of «fuel electric generator – asynchronous electric motor» system according to the actual and nominal slip

But slip is *also* a design characteristic in AM CAD. After all, the calculation of asynchronous motors also uses the «slip» parameter, which is specified or selected by the designer as a constant number (the so-called nominal slip S). Parameter S is an argument for calculating many characteristics of the motor. It also determines the actual slip of the latter $s(M)$, current $I(M, S) = I[f_1(M), f_2(M, S)]$,

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which consumes the motor from the source, and further along the chain: the actual power $P(M, S)$) and, finally, fuel consumption in the generator $Q(S)$.

From this it follows that in designing the calculated (nominal) slip value S is a number, and the actual slip s is a function of the AM operating mode. Therefore, this method of «reverse» calculation of the slip S, which is preceded by a «direct» calculation of the function $s(M)$, is realized in the paper (Fig. 1). In Fig. 1, both types of slip are indicated: actual (current) s and nominal S.

Let's note that the curves in Fig. 1 have a clearly expressed minimum. This corresponds to operation mode of the system where an «additional factor» always accelerates the power of the generator during a critical decrease in the rotational frequency of the stator magnetic field f_1.

When the motor is powered by a fuel electric generator, this additional factor is an increase in fuel consumption with an unacceptable reduction in the frequency of the source current. In this case, the value of f_1 is restored, and the fuel consumption Q in the generator is increased.

5.2. Optimization method in CAD systems of «fuel generator-asynchronous electric motor» type. The proposed scheme for calculating the parameters (Fig. 1) is the basis for the optimization method of «fuel electric generator-asynchronous electric motor» system. The sequence of operations of the method when using slip as a global connection is shown in Fig. 2.

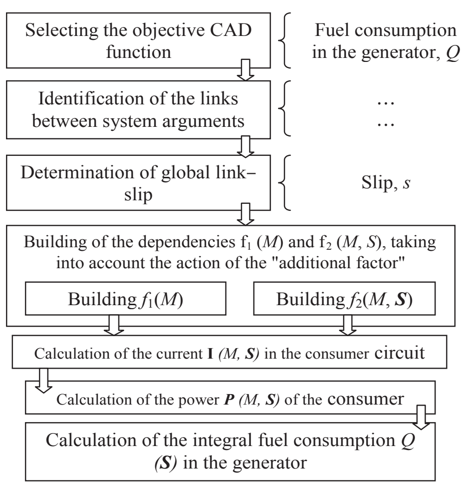

Fig. 2. Sequence of operations in calculating the slip S in the CAD of «fuel electric generator – asynchronous motor» system

First, the intermediate objective optimization function is selected, then the identification of all the links between the system arguments taken into account in CAD, and, finally, the choice of global communication.

Next, the dependences $f_1(M)$ and $f_2(M, S)$ are built and the functions $I(M,S)$ and $P(M,S)$.) are determined. Integrating the latter, the objective function – fuel consumption $Q(S)$ in the generator is obtained.

Optimization within the proposed method consists in the selection of such nominal value of S, at which the integral fuel consumption Q in the generator will be minimal. In any case, having a «direct» $Q(S)$ dependence, it is possible to solve the inverse optimization problem: the search for such nominal slip value of slip S^*, which (within the given limits) guarantees not exceeding the set fuel consumption Q^*. Such problem is essentially the optimization problem mentioned above with related arguments, since the slip S is a function of the weakly related moments $M_{\min}$ and $M_{\max}$.

6. Research results

The general structure of the developed CAD «OPTIGLOC» is shown in Fig. 3.

The structure in Fig. 3 contains blocks of input of initial data and classification of the task delivered in this data from the point of view of the design type:

– an object containing an electric motor;

– design according to the «standard» scheme with the choice of slip;

– design using the new scheme with slip determination by means of optimization calculations.

Next, the preliminary calculation of asynchronous motor «before slip» is performed, the choice or calculation of the slip and the final calculation, after which the design ends.

Among the design objects there are those that, according to one or several parameters, can be referred to as «objects of responsible use». An example of such objects can be the responsible electrical equipment, which are, in particular, unique electric motors, power lines, etc.

The first additional block is started exactly in those cases when it follows from the technical design assignment that it is necessary to create a responsible motor. By this it is understood that the latter is supposed to be used in an unfavorable environment with significant opportunities for risky threats to its operability.

The second additional unit is designed for designing electric motors intended for operation in a network that is partially inaccessible for monitoring. This gives rise to the task of providing such electric motors with an intelligent unit, which tasks are to identify faults in the network and support the decision making to eliminate them.

The experimental block of CAD «OPTIGLOC» is created for manufacturing of the prototype of the designed variant of the electric motor and its testing on the laboratory bench. The bench makes it possible to evaluate the thermal state of motor nodes by displaying and computer processing infrared radiation from its surface. It is also possible to measure the rotational speed of the shaft of an induction motor, the mechanical moment on it, the slip and the fuel consumption in a gasoline generator [19, 20].

Let's consider an example of laboratory optimization of «gasoline generator-motor» system using CAD «OPTIGLOC». «Fuel (gasoline) generator – asynchronous electric motor» system includes the purchased generator of the model «Champion GG3300» (China) and the projected electric motor.

The power of the generator operating in the «normal» mode is sufficient to support the operation of the electric motor, while the «regular» fuel consumption is 1.5 l/h or 0.23 kg/kWh.

As stated above, the load on the system is usually unstable. With its sharp growth, the frequency of the current at the output of the generator falls, which leads to an increase in its power and, as a consequence, automatic recovery of the frequency to the allowed level at the output. Accordingly, the gasoline consumption in the generator is increased.

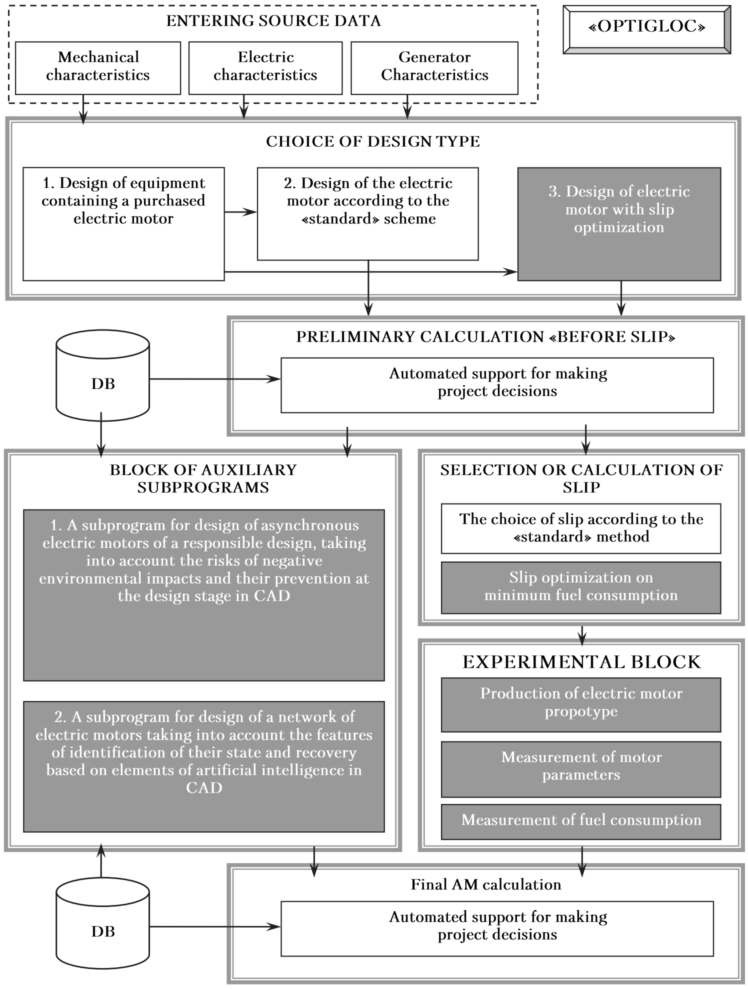

Fig. 3. Structure and main subsystems of CAD «OPTIGLOC»

The mode of fuel consumption change depends on the slip value S selected in the design of the electric motor. The experiment shows that the dependence of the fuel consumption on the slip in the project has a minimum, the search for which is the optimization task.

Next, the calculation of asynchronous motor «before slip» is performed, the choice or calculation of the slip and the final calculation, after which the design ends.

It is theoretically and practically proved, with the help of computer experiment and production tests, the possibility of improving design efficiency and the quality of electrical products production is confirmed. Its basis is the use of CAD, which provides an effective optimization of the parameters of complex electrical equipment for global connectivity – by slip.

In Odessa, LLC «Specialized Energetic Enterprise «Energo-KOM» (Ukraine), a CAD test of electrical equipment «OPTIGLOC» is conducted, which is based on the proposed models and methods. As the object of computer-aided design, «diesel generator – asynchronous induction motor» system is used. As a result of the tests it is found that the use of the CAD «OPTIGLOC» allows to reduce the specific fuel consumption in the generator by 5.3 %. At the same time, the service life of the system and the stability of its technical tasks do not change, and the design time is reduced by an average of 13.7 %.

7. SWOT analysis of research results

Strengths. The main positive effect of the object of research on its internal factors is the opportunity created by it for using two autonomous concepts of «slip». The first, calculated, is the number that characterizes the design of an asynchronous motor, and the second is the actual one, as a variable characterizing the current electromechanical mode of its operation. In comparison with analogues, the proposed approach allows to optimize the motor mass, reducing the time costs for its design.

Weaknesses. The main negative impact of the research object on its internal factors is the need to constantly use experimental support, take the design process in the CAD of electrical equipment beyond purely computer laboratories. This leads to a certain increase in energy costs and the cost of additional manpower.

Opportunities. Opportunities for further research in this area are related both to the development of the theoretical framework (for example, methods for optimization of complex systems) and to the improvement of methods and tools for improving the efficiency of computer-aided design.

With the further introduction of a new method for calculating asynchronous electric motors, additional possibilities are expected, first of all, to expand the capabilities and applications of power systems with autonomous power.

Threats. As in any CAD, built on predictive models, threats to its effectiveness derive from the «design damnation». This circumstance consists in the fundamental impossibility of an accurate prediction of the project's compliance with the technical task for the projected object before this object is manufactured and tested.

8. Conclusions

1. A method of optimization in CAD systems of the type «fuel electric generator-asynchronous electric motor» is developed, the energy indices of which can't be considered independently in the process of computer-aided design. The method is based on the fact that the relative proximity of the generator and electric motor powers, on the one hand, makes it necessary to simultaneously take into account the parameters of both subsystems during the optimal design of the latter. On the other hand, it allows to perform such design more efficiently. Increasing the design efficiency is created by using as an objective optimization function the nominal slip of an induction motor. Calculation of the nominal slip relies on the experimental measurement of the actual slip, which, in turn, is related to the objective function – the fuel consumption in the generator.

2. In Odessa, LLC «Specialized Energetic Enterprise «Energo-KOM» (Ukraine), a CAD test of electrical equipment «OPTIGLOC» is conducted, which is based

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on the proposed models and methods. As a result of the tests it is found that the use of the CAD »OPTIGLOC» allows to reduce the specific fuel consumption in the generator by 5.3 %. At the same time, the service life of the system and the stability of its technical tasks do not change, and the design time is reduced by an average of 13.7 %.

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ОПТИМИЗАЦИЯ СИСТЕМ «ТОПЛИВНЫЙ ЭЛЕКТРОГЕНЕРАТОР – АСИНХРОННЫЙ ЭЛЕКТРОДВИГАТЕЛЬ» В САПР

Главные проблемы автоматизированного проектирования систем «топливный электрогенератор – асинхронный электродвигатель» вытекают из того, что эти системы при оптимизации не могут быть рассмотрены отдельно. Теоретически обосновано повышение эффективности производства за счет САПР, которая обеспечивает оптимизацию параметров оборудования по глобальной связности. Разработана САПР «OPTIGLOC» и осуществлено ее производственное испытание с положительным технико-экономическим эффектом.

Ключевые слова: топливный электрогенератор, скольжение асинхронного электродвигателя, оптимизация в САПР, глобальная связность.

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