Improvement of Energy Indicators of Asynchronous Motor under the Conditions of Asymmetric Voltage Supply

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Abstract. The article considers the problem of development of power loss minimization system in asynchronous motors with asymmetric voltage supply. The subject of the research is a continuous run of asynchronous motor based on artificial adjusting of characteristics in the area of nominal slipping with better energy indicators than at a operational segment of natural mechanical characteristics. The artificial control characteristic of a drive corresponding to power loss minimization mode is calculated in advance using the solution of extreme control concern. The paper demonstrates that under conditions of electric drive supplied by an asymmetric voltage source the one should apply a phase-by-phase control. The feedback action logic is as follows: reduction of the output voltage of thyristor converter and motor currents as a reducing of the load on the asynchronous motor shaft occurs. As a result, there appears the possibility to maintain the load angle equality of all the phases of asynchronous motor to an optimal value. This allows to solve the problem of power loss minimization in an asynchronous motor due to the load angle equality to the optimal value, and the problem of symmetrization due to the load angle equality in motor phases. The most significant result of the research is the developed automated scheme of symmetrization which is not only efficient with power source voltage asymmetry, but also with asymmetry of asynchronous motor parameters themselves. The proposed functional scheme of microprocessor control and the algorithm of control increase the possibilities of automated loss minimization system.

Keywords**:** electric drive, asynchronous motor, thyristor converter, system of control, power losses, voltage asymmetry, symmetrization.
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Îmbunătățirea performanței energetice a motoarelor asincrone la alimentarea cu tensiune asimetrică

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Rezumat. Scopul articolului constă în elaborarea unui sistem de minimizare a pierderilor de putere ale motoarelor asincrone la alimentarea cu tensiune nesimetrică. Obiectul cercetării este funcționarea continuă a unui motor asincron cu caracteristici de reglare artificială în domeniul alunecării nominale cu indicatori de energie mai buni decât în secțiunea de lucru a caracteristicilor mecanice naturale. Reglarea artificială a tracțiunii electrice, corespunzătoare modului de minimizare a pierderilor de putere, se calculează în avans, pe baza soluției problemei de control extrem. În cadrul studiului a fost realizată o descriere matematică a modurilor de operare a acționării electrice „convertizor de tensiune pe bază de tiristori - motor asincron ", în care este posibilă reducerea pierderilor de energie, se realizează o diagramă funcțională a sistemului pentru minimizarea automată a pierderilor de putere. Scopul stabilit în lucrare, în condițiile alimentării cu energie electrică de la o sursă cu tensiune asimetrică, este realizat prin utilizarea a trei canale de control și trei canale de feedback. Logica acțiunii de reacție este de a reduce tensiunea de ieșire a convertizorului pe tiristori și a curenților motorului reducând în același timp sarcina pe axul motorului asincron. Ca o consecință, este posibil să se mențină egalitatea unghiurilor de sarcină ale tuturor fazelor motorului asincron la valoarea optimă. Acest lucru ne permite să rezolvăm problema minimizării pierderilor de putere ale unui motor asincron datorită egalității unghiurilor de încărcare la valoarea optimă și problemei echilibrării datorită egalității unghiurilor de sarcină pe fazele motorului. În acest caz, unghiurile de comutare ale tiristorilor convertizorului de tensiune nu sunt în principiu simetrice.

Cuvinte-cheie: acționare electrică, motor asincron, convertizor pe tiristori, sistem de control, pierdere de putere, asimetrie de tensiune, echilibrare.

Улучшение энергетических показателей асинхронных двигателей в условиях питания несимметричным напряжением

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Аннотация. Целью статьи является разработки системы минимизации потерь мощности асинхронных двигателей при их питании несимметричным напряжением. Предметом исследования является

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продолжительная работа асинхронного двигателя на искусственных регулировочных характеристиках в области номинального скольжения с энергетическими показателями лучшими, чем на рабочем участке естественной механической характеристики. Искусственная регулировочная характеристика электропривода, соответствующая режиму минимизации потерь мощности, рассчитывается заранее, исходя из решения задачи экстремального управления. В рамках исследования выполнено математическое описание режимов работы электропривода «Тиристорный преобразователь напряжения–асинхронный двигатель», в которых возможно уменьшение потерь мощности, выполнена разработка функциональной схемы системы автоматической минимизации потерь мощности. Поставленная в работе цель, в условиях питания электропривода от источника с несимметричным напряжением, достигается применением трех каналов управления и трех каналов обратной связи. Логика действия обратной связи заключается в уменьшении выходного напряжения тиристорного преобразователя и токов двигателя при уменьшении нагрузки на валу асинхронного двигателя. Вследствие этого появляется возможность поддерживать равенство углов нагрузки всех фаз асинхронного двигателя оптимальному значению. Это позволяет решать проблему минимизации потерь мощности асинхронного двигателя за счет равенства углов нагрузки оптимальному значению и проблему симметрирования за счет равенства углов нагрузки по фазам двигателя. При этом углы включения вентилей тиристорного преобразователя напряжения принципиально не симметричны. Применение тиристорного преобразователя напряжения дает возможность реализации управляемых переходных пуско–тормозных режимов. Наиболее существенным результатом работы является разработанная автоматизированная система симметрирования, которая эффективна не только при несимметрии напряжений источника питания, но и при несимметрии параметров самого асинхронного двигателя. Предложенная функциональная схема микропроцессорного управления и алгоритм управления расширяют возможности системы автоматической минимизации потерь. Структура и сложность алгоритма управления могут претерпевать изменения в зависимости от функциональных возможностей элементов электропривода.

Ключевые слова: электропривод, асинхронный двигатель, тиристорный преобразователь, система управления, потери мощности, несимметрия напряжений, симметрирование.

Introduction

An asynchronous motor (AM) demonstrates high energy indicators in running at the rated operation. The deviations from the rated operation of the AM running as a result of decreasing the load on the shaft leads to the efficient degradation of their (indicators) energy characteristics [1, 2]. The solution of this problem leads to the interest to automated electromechanical systems, which allow to decrease the AM power losses in their underloading [1-3]. It is also known that the standardized indicators of electric energy quality do not correspond to the required ones, which determines possibilities of AM run e.g. under conditions of power supply voltages asymmetry [4-5]. The asymmetric operation modes affect negatively on the work indicators of electrical machines [6, 7]. Magnetic fields arising rotate at synchronous speed not only in the direction of rotor turning but also in the opposite direction. This leads to “parasitic” oscillations at frequency 100 hz. The extra stator heating occurs due to exceeding one or two phase AM currents of rated value [8, 9].

Theoretical and practical problems of AMs energy indicators improvement in their (ADs) incomplete loading by means of electrical drive are given a lot of attention in scientific and engineering literature [1, 10-14]. The problem mentioned above is recommended to be solved by using a thyristor voltage converters (TVCs), which permit to provide the continuous AM running based on adjusting characteristics in the area of rated slipping with less losses than at the operational segment of natural characteristic [13, 14]. Wherein the necessary adjusting characteristic is calculated on the basis of the solution of extreme control problem according to the minimal power losses criterion [1]. The researches in [10-15] solve a problem of loss decrease justification in asynchronous motors and synthesis of energy-saving control systems. However, the offered variants were developed and recommended for usage with the standardized indicators of power supply voltage quality and were completely invariant to their changes [4, 16]. The run of the automated systems of such kind under the conditions of power supply voltage asymmetry is not efficient and does not lead to the loss reduction in asynchronous motors [9, 12].

There is much less information about compensation of negative effects in AM, being supplied by an asymmetric voltage source, by means of electric drive control systems [17-19]. Most researches are limited with the development of power supply symmetrization means or with a propose to solve the mentioned problem by means of frequency converters with the AM operational moment limitation [20-24]. Along with this the synthesis and usage of the electromechanical automated system, which would permit to solve problems on losses reduction in a motor in its underloading and under the conditions of power supply asymmetry appearance – to combine this function with one of AM currents symmetrization is of greatest interest as well.

Problem statement

The goal of research is as follows – to develop a system of AM power loss minimization in supply with asymmetric voltage.

In order to achieve the goal the following tasks have to be done:

- to justify the method of loss reduction in AM by means of TVC;
- to develop a structure of losses minimization system in AM based on its element synthesis;
- to develop a circuit and algorithm of microprocessor control by the loss minimization system.

Research methods

The problem of loss minimization in reducing the load at AM shaft can be solved by a drive with a thyristor voltage converter. The continuous work based on adjusting characteristics in the area of rated slipping with less losses in AM than at the operational segment of natural characteristics is planned. The main influence is an output converter voltage, but asynchronous motor running occurs according to the appropriate mechanical adjusting characteristic.

Voltage control is performed down the rated. Adjusting characteristic is calculated beforehand on the basis of the solution of the problem of extreme control in accordance with minimal power losses. In analytical description of energy transformation processes a number of assumptions is taken into account: linearity of AM magnetic circuit; linearity of operational segment of AM's artificial mechanical characteristic; considering the first harmonic constituents of currents and voltages of the motor's stator.

This allows to obtain an analytical dependence of the control law, which corresponds to the optimal mechanical characteristic for any of known types of asynchronous motors. Four main constituents of AM losses are taken into account [26]. For the further analysis it is suitable to divide them into two groups – load loss and magnetization one.

It is known that load loss, existing in AM under the rated operation conditions, is described by two constituents [1]

$$\Delta P_{l\,n} = \Delta P_{1cl} + \Delta P_{2cl}\,, \qquad (1)$$

where ΔP_{1cl} – losses in the stator's copper due to the load current at the operational moment of load, W; ΔP_{2cl} – losses in the rotor's copper due to the load current at the operational moment of load, W.

Total magnetization losses in a motor at the operational running mode are indicated as follows

$$\Delta P_{0\,m} = \Delta P_{1c0m} + \Delta P_{sm}\,, \qquad (2)$$

where ΔP_{1c0m} – losses in the stator's copper due to magnetization current, W; ΔP_{sm} – losses in AM's steel, W.

In adjusting the AM coordinates by means of converter voltage change, load losses and magnetization losses are indicated by the relations [25]

$$\begin{aligned} \Delta P_l &= \frac{M_c}{M_n}\frac{s}{s_n}\Delta P_{l\,n}, \\ \Delta P_0 &= \frac{M_c}{M_e}\Delta P_{0\,m}, \end{aligned} \qquad (3)$$

where M_e – a moment based on the natural characteristic in slipping, which is equal to the slipping in the artificial characteristic in reduced voltage $U_1 < U_{1n}$.

If we take into account the accepted assumptions, the equality $M_e / s = M_n / s_n$, which gives the possibility to express the moment M_e value through the slipping, is right.

Then the losses are determined according to the equation

$$\Delta P = \Delta P_l + \Delta P_0 = \frac{\Delta P_{l\,n}}{M_n s_n} M_c s + \frac{\Delta P_{0\,m} s_n}{M_n} M_c \frac{1}{s}\,. \qquad (4)$$

There is some slipping, during which total losses in the motor are minimal. The problem concerning the obtaining of this optimal slipping can be solved by extremum researching of the function (4) and indicating the value *s*, with which the value ΔP possesses a minimal value. For analytical solution it is necessary to make a partial derivative with observance of slipping ΔP equal zero. This equation solutions characterize the extrumum of researched function. The condition of power loss minimum requires AM in the first (third) quadrant to run according to the adjusting characteristic with slipping

$$s_{opt} = s_n \sqrt{\frac{\Delta P_{0\,m}}{\Delta P_{l\,n}}}, \qquad (5)$$

The power loss minimum condition is observed in performance in the area of operational moments from zero to some boundary moment M_b

$$M_b = M_n \sqrt{\frac{\Delta P_{0\,m}}{\Delta P_{l\,n}}}, \qquad (6)$$

The boundary moment value corresponds to intersection of the adjusting mechanical characteristic and natural one and does not depend on the present moments of load and AM speed. Fig. 1 represents the idea about mechanical characteristics of the asynchronous motor run on.

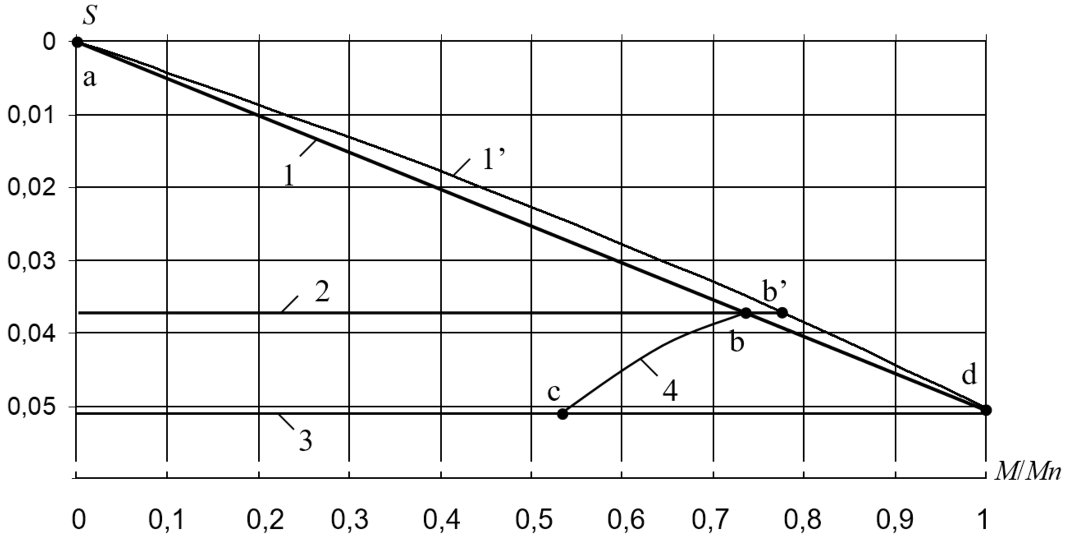

Fig. 1. Mechanical characteristics of motor 4A90L4.

Curve 1 is a linearized segment of the natural mechanical characteristic. Here is a segment of a real natural mechanical characteristic of AM 4A90L4 (characteristic 1') presented for comparison, which allows to estimate the linearization influence. Straight line 2 is an adjusting characteristic corresponding to the optimal control law as a regard to the minimal loss criterion. Characteristic 3 corresponds to the AM adjustment with rated slipping. All of the operational points of characteristic 2 correspond to the optimal mode. With the increase of moment this characteristic intersects the natural one in point b (b') corresponding to the boundary moment M_b. With the further load moment increase the mode stops being optimal. This point position and operational segment width of the optimal adjusting characteristic depends on the correlation among the losses used for magnetization and on the load at the rated mode. As follows from (6) a boundary moment for each of the asynchronous motors is only determined by own parameters of AM. In both cases in increasing or decreasing the slipping as a regard to characteristic 2, the losses in AM are enhanced. In decreasing the slipping loss increase is limited by the natural characteristic. In increasing the slipping in the lower part a conditional boundary can be formed, in which the losses are equal to the ones on the natural characteristic. This boundary corresponds to the line 4 and is called "equal losses line" [14]. An area limited with a segment a – b of the natural characteristic, axe of slipping and equal losses line 4 is an area, in which the modes with less losses than the ones (losses) with the natural characteristic in AM, can be formed. This area is used during optimal control according to the minimal loss criterion. Other characteristics embrace the less width of this area, and as to characteristic 3 it has a segment c – d, which is beyond the mentioned area. In this segment the motor runs not only in the suboptimal mode, but with the power losses exceeding the ones on the natural characteristic [25].

Technical implementation of the loss minimization mode in steady state is possible only in closed electrical drive systems. Wherein it is impractical to use the feedback proportionally to slipping (speed) since the electrical drive operation occurs in the area close to the rated slipping [26]. This imposes strict requirements to a measured value accuracy and is not always justified. The most perspective one is a method based on power factor constancy at the minimization mode. The feedback signals in this case are load angles – δ. For each of AMs in analogy with the optimal slipping there is some angle δ_{opt}, at which the power losses are minimal, it is indicated by [3].

$$\delta_{opt} = arctg\frac{Q_{1n}}{P_{1l}},$$
$$P_{1l} = \omega_0 M_b + \Delta P_{c1l}\frac{\Delta P_{0\,m}}{\Delta P_{1cl}} + \Delta P_{0\,m}, \qquad (7)$$

where Q1н, – rated reactive power AM, VAr; ΔP_{1l} – active power consumed by AM on the natural characteristic with load $M_c = M_b$, W; ΔP_{1cl} – losses in AM stator's copper with the rated load, W.

Results of research

Research of possibility to minimize the losses in AM under the conditions of power supply (PS) voltage asymmetry is of great interest. It is obvious that minimization mode of losses in AM does not lead to asymmetry. But at the same time the stator's currents symmetrization lead to efficient improvement of AM power indicators. However, the automated symmetrization systems are not invariant to load change [25]. Popular automated loss minimization systems (LMS) are suggested to be used in the power supply and AM, which parameters are symmetrical in phases. In these LMSes a single controller is used, and symmetrical control and TVC's thyristor adjustment are utilized. Under the PS voltage asymmetry conditions, it is necessary to use a separate phase-by-phase control, which requires a usage of three control channels and three feedback channels. This allows to solve the problem of power loss minimization in AM due to the load angle equality to an optimal angle δ_{opt} and to obtain the symmetrization effect due to the angle δ equality in AM phases. The functional scheme of automated system of power loss minimization in AM with the symmetrization functions is demonstrated in Fig. 2.

It includes: TVC, AM, a device forming a control signal (DFCS) in the angle δ_{opt} function; channels of control of AM phases (CCP*A*, CCP*B*, CCP*C*); channels of feedback of each phase (CFP*A*, CFP*B*, CFP*C*). The composition of each control channel contains a PI-regulator of angle δ (Rδ) and pulse-phase control system – PPCS (Fig.3, a).

Each feedback channel includes (Fig.3, b): a detector of angle δ (Dδ) measuring the current lag angle for every half of TVC voltage period and converting the angle value into the present voltage of feedback $U_{fA}(U_{fB}, U_{fC})$; a storage element (SE) keeping a feedback voltage value, a magnitude of which is renewed in a time interval *t* = 0,01 s. The minimization system operation begins with finishing the transient process of motor starting.

The principle of power supply operation with symmetrical voltage is as follows: in load reduction at AM shaft (angle δ increase) the action of feedback leads to decrease of output voltage of the thyristor converter, which in turn leads to AM's stator currents decrease.

As a result it is possible to keep the angles δ equality to the required value δ_{opt}.

This allows to solve the problem of loss minimization. In supply from a power source with asymmetric voltage both losses minimization in AM and currents symmetrization are accomplished due to the equality of angles δ in each of the AM phases.

Wherein the valve switching-on angles of the thyristor converter are asymmetric in principle [14].

The calculation of automated system parameters is performed on the example of asynchronous motor 4A90L4. Optimal angle δ value can be obtained from equations (6) and (7)

$$M_b = 14{,}8\sqrt{\frac{187{,}3}{364{,}7}} = 10{,}6 \text{ Nm}; \qquad (8)$$

$$P_{1l} = 157\cdot 10{,}6 + 304{,}7\frac{187{,}3}{364{,}7} + 187{,}3 = 2007{,}9 \text{ W}; \quad (9)$$

$$\delta_{opt} = arctg\frac{1680{,}1}{2007{,}1} = 39{,}9 \text{ el. deg.} \qquad (10)$$

The system of pulse-phase control is described according to the equation

$$\alpha = 0 - K_{PPCS\,\alpha}\, U_{out\,r}, \qquad (11)$$

where $K_{PPCS\,\alpha}$ – coefficient of PPCS transferring, relative units.

Wherein the PPCS transferring coefficients are indicated as follows

$$K_{PPCS\,\alpha} = \alpha_{\max} / U_{out\,r\max} = 120/10 = 12 \text{ rad/V}. \quad (12)$$

It is possible to describe the feedback channel by means of an amplifying link with the transfer coefficient

$$K_{fb} = U_{fb\max} / \delta_{\max}, \quad (13)$$

where $U_{fb\max} = 10$ V – maximal feedback voltage.

Angle $\delta_{\max}$ under typical conditions in the first quadrant does not exceed 90 el. degrees, however with the presence of sufficient voltage asymmetry of power supply its value can achieve 120 el. degrees in some phases [27]. The input signal detector voltage is indicated in accordance with condition of the set voltage equality and feedback voltage with the angle δ value, which is equal to the δ_{opt} one.

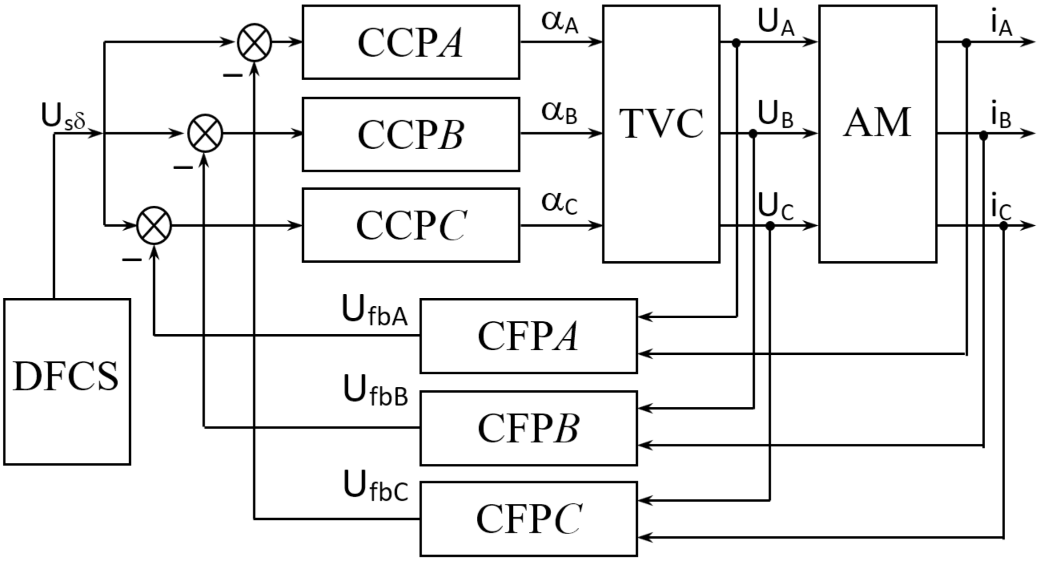

Fig.2. Functional scheme of the automated loss minimization system in AM.

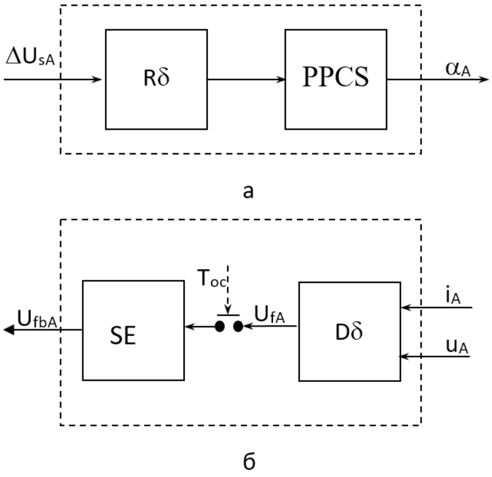

Fig.3. Functional schemes: a – control channel and b – phase A feedback channel of the loss minimization system.

$$U_{s\delta} = \delta_{opt} K_{fb}, \quad (14)$$

Each angle δ regulator is a PI-regulator, which is described by transmission function [28]

$$H_{p\delta}(p) = \frac{\frac{1}{K_M K_{TVC}} J_\Sigma}{K_{fb} 2T_E K_\delta} + \frac{\frac{1}{K_M K_{TVC}} J_\Sigma}{4T_E p K_{fb} 2T_E K_\delta} = K_p + \frac{K_i}{p}, \quad (15)$$

where K_p and K_i – coefficients of proportional and integral constituents, respectively.

For the considered motor 4A90L4 calculated values of the angles δ controllers coefficients are as follows: K_p = 0.46 and K_i = 16.2, respectively.

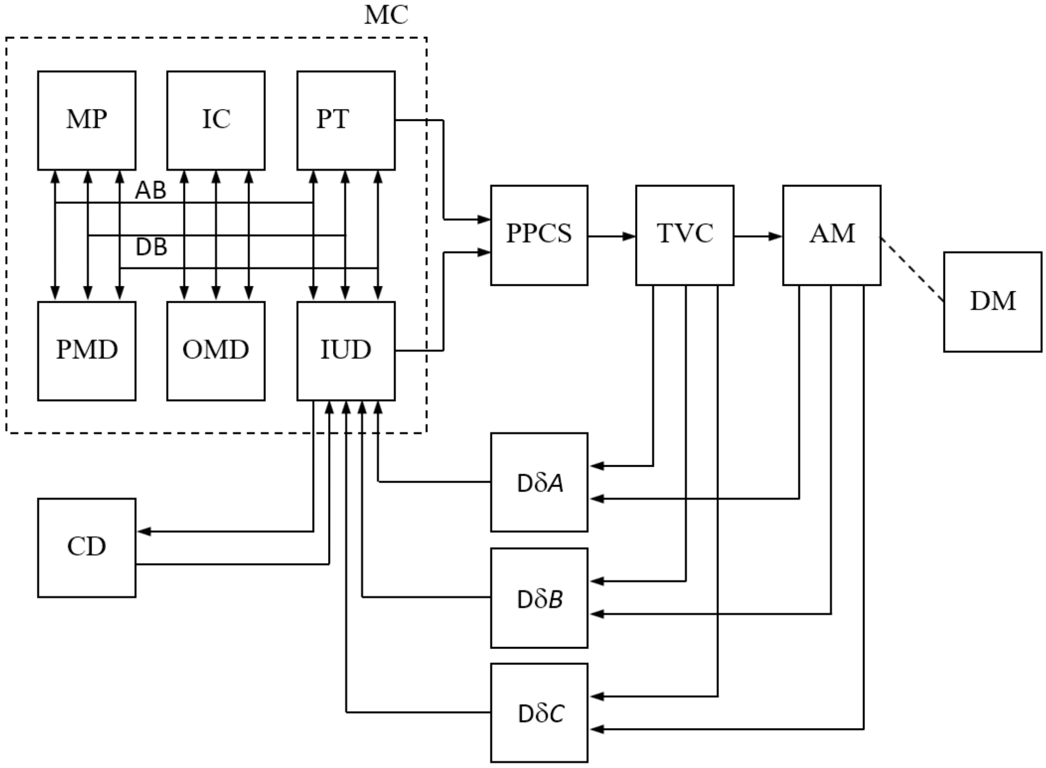

Fig. 4. Functional scheme of microprocessor control.

The functional scheme of microprocessor control of the loss minimization system is presented in Fig. 4 for general case.

The scheme demonstrates: MC – microcontroller, which includes MP – microprocessor; IC – interruption controller; PT – programmable timer; PMD – permanent memory device; OMD – operational memory device; IUD – input-output device; AB, DB, CB – address bus, data bus, control bus. In the scheme one can also see the following: PPCS – pulse-phase control system; TVC – thyristor voltage converter; AM – asynchronous motor; DM – drive mechanism; DδA, DδB, DδC – angle δ detectors of phases A, B, C, respectively; CD – control desk of the loss minimization system.

The microprocessor control system of LMS performs the base functions: calculation of the required angle δ depending on parameters of motor used, and forming the driving signal U_s based on δ_{opt} calculation; calculation of regulators parameters and performing the angle δ regulators functions, forming control signals; updating the feedback signals and keeping their values during the power supply voltage half-period; controlling the voltage of every TVC phase in the function of calculated angle δ_{opt} and the present feedback signals; control of running the loss minimization system by means of information exchange between a system and a control desk.

Algorithm of control system operation is based on the LMS run principles and demonstrated in Fig. 5.

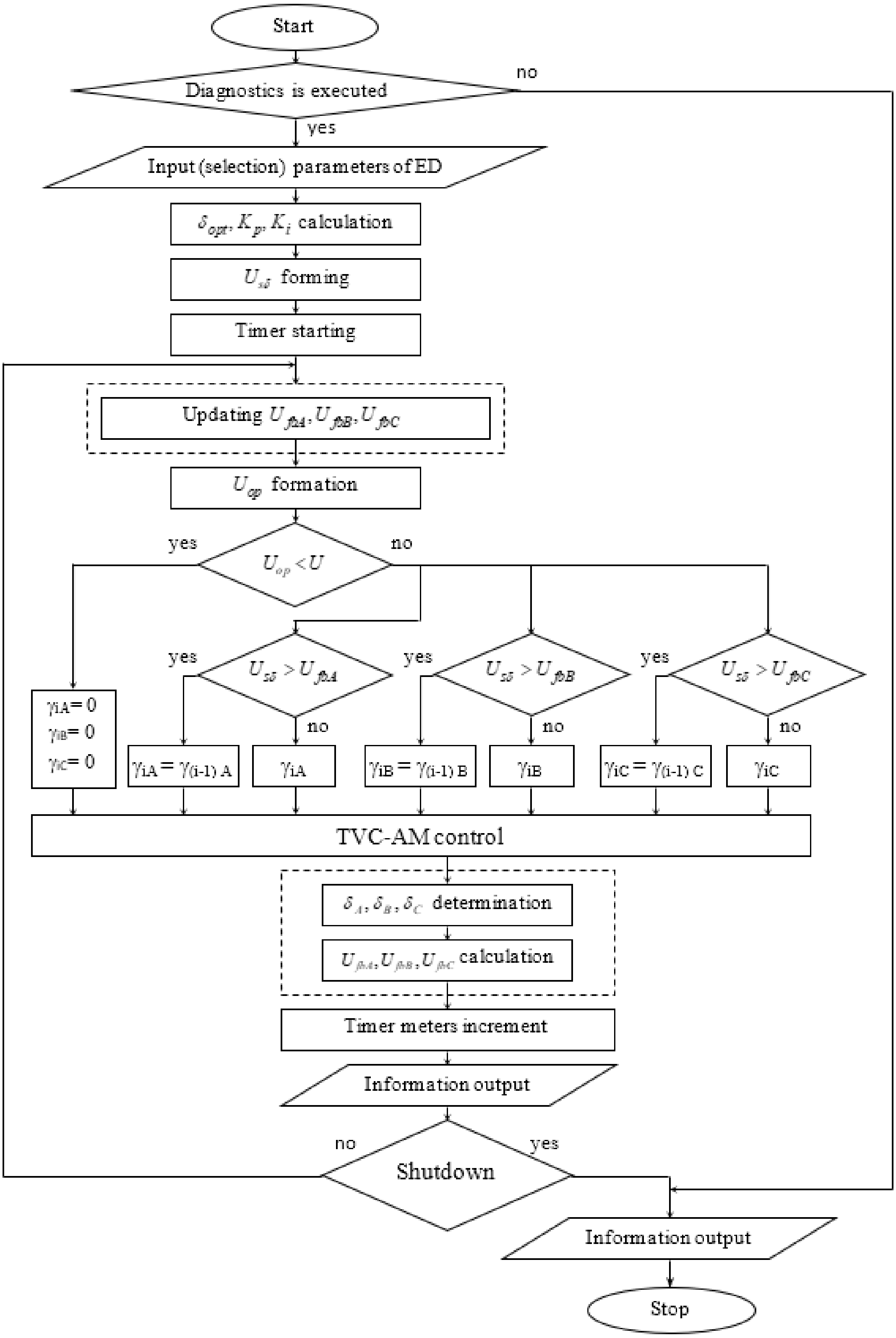

Fig. 5. LMS control algorithm.

Operation of system starts from a signal from the control desk or in automatic way on completing the transient process connected with AM speed change. After signaling about the beginning of a run the MP performs LMS control, diagnosing all its elements. If a kind of malfunction is detected, the information is sent to the control desk, and the system is automatically switched out. A control desk operator permits a repeated switching-on after detecting the reasons of malfunction and troubleshooting. If the control is successfully performed the operator should enter from the control desk the drive parameters (or select them from database) necessary for calculation of the angle δ_{opt} and angles δ regulator parameters by microprocessor. Generally, this operation is required and carried out during the first start of control system. In the course of the next system start and under the condition of invariability of power unit of drive elements this is executed in automatic way without operator’s action. On calculating the optimal control angle the forming of the preset signal $U_{s\delta}$ voltage is carried out. The start of timer counters, which are necessary for counting time intervals, occurs. The feedback signals, which are formed by the angle δ detectors, are updated for a time equal to power supply voltage half-period. This implies a pause equal t = 0.01 s. in the beginning of a voltage regulation process. After this time interval finished detectors determine the information of the present angle δ values, according to which the feedback $U_{fb}A$, $U_{fb}B$, $U_{fb}C$ voltages are formed. These values are memorized in the storage elements and kept during the next time interval t = 0,01 s. The necessity to transit to the main run characteristic (in PS voltage asymmetry and the load moments, which are more than a boundary ones) was justified before. To do this the forming of reference voltage was implemented in the operation algorithm. The reference voltage U_{op} value is compared with a set voltage $U_{s\delta}$. If the condition $U_{op} < U_{s\delta}$ is observed, the dead pause values of TVC phases in synchronizing with the load current equal zero. After this the banning on volt-age adjustment and AM transition to the main characteristic continues. If the condition is not observed, the LMS running limitation is not required.

The subsequent algorithm procedure of control system operation is the verification of the following conditions: $U_{s\delta} > U_{fbA}$, $U_{s\delta} > U_{fbB}$ and $U_{s\delta} > U_{fbC}$. If the set voltage $U_{s\delta}$ exceeds the present feedback voltage, the control voltage is zero. This corresponds to the fact that the PPCS dead pause γ_i value does not change and corresponds to the previous step $\gamma_{(i-1)}$ value, which is right for each phase. If the condition $U_{s\delta} > U_{fb}$ in any phase is not observed, then the control signals, which determine the present values of PPCS dead pause γ_i, are formed. After forming the PPCS control pulses, corresponding to the dead pauses γ in each phase, the voltage adjustment of TVC, AM and drive mechanism is performed. Timer counters increment and presentation of information about the present values of LMS parameters to the control desk is carried out.

Time countdown is performed by timers before LMS run completion. LMS run interruption can be performed by an operator, diagnostic of system or one of drive protection devices [27]. On completing the drive running the information of the system parameters is presented to CD. If the system run is not completed, the cycle is repeated wherein the feedback voltages in the storage elements are updated not after each timer counter increment, but in *t* = 0.01 s.

The structure and control algorithm complexity can be changed depending on the functional capabilities of TVC-AM drive elements [8, 9]. For example, ensuring the electric drive parameter control in each time moment corresponding to the timer counter increment, the adaptive angles δ controllers should be used. In this case the controller parameters are not fixed, but calculated by the microprocessor after each timer counter increment. As mentioned above, this allows to increase the LMS operation speed. Depending on the offered microprocessor system run algorithm, one can choose the necessary control system hardware, which is not difficult, if the modern level of development and variety of the microprocessor means are taken into account [10-14]. Basic requirements, which MC loss minimization system should meet, are the presence of necessary integrated peripheral devices and principal possibility to perform an algorithm of the mentioned complexity. In addition the electrical drive TVC-AM along with the modes of symmetrization and power loss minimization is to provide commonly accepted functions of AM smooth descent and braking [9, 10].

Conclusions

1. Artificial adjusting characteristic of a drive corresponding to the power loss minimization mode is calculated in advance based on the solution of an extreme controlling problem.

2. Engineering implementation of the loss minimization mode in steady state is possible only in closed electrical drive circuits. It is not reasonable to use a slipping feedback since the electrical drive operation occurs in the area close to a rated slipping.

3. The structure of automated loss minimization system with the simultaneous symmetrization functions in supply from an asymmetrical voltage source is offered. Separated phase-by-phase control that implies the usage of three channels of control and three channels of feedback is implemented in the system.
4. The problem of AM power loss minimization is solved due to preservation of the load angles δ equality to the optimal value. In supply from the asymmetric voltage source both the simultaneous AM power loss minimization and simultaneous current symmetrization are achieved due to the angles equality in each phase of asynchronous motor. Wherein the valves switching-on angles of the thyristor voltage converter are asymmetrical basically.
5. The developed automated symmetrization system is efficient due to design peculiarities not only in power supply voltages asymmetry, but also with the asymmetry of asynchronous motor parameters themselves.
6. The offered functional scheme of microprocessor control and control algorithm increases the capabilities of automated loss minimization system. The structure and control algorithm complexity can be changed depending on the functional drive element capabilities.

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