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# ELECTRIC DRIVE WITH FREQUENCY-REGULATED SYNCHRONOUS MOTOR WITH HIGH PRECISION DIGITAL SENSORS

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# ЕЛЕКТРОПРИВОД З ЧАСТОТНО-РЕГУЛЬОВАНИМ СИНХРОННИМ ДВИГУНОМ З ВИСОКОТОЧНИМИ ЦИФРОВИМИ ДАТЧИКАМИ

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*The article studies an electric drive with a frequency-regulated synchronous motor. The main advantages of synchronous motors in comparison with asynchronous ones are listed. The current state and the growth trends in the production of AC electric drives are considered. It is shown that two-link frequency converters have received the greatest application for wide-range regulation of rotation frequency of synchronous motors. They convert the electricity from supply network into electricity with the required voltage, current and frequency in two stages. This transformation is carried out by special devices – autonomous inverters. It has been established that the efficiency of a two-link frequency converter is quite high and about 96,5-98,5%, which is due to the efficiency of the power semiconductor devices used in the key operating mode. Modern trends in the use of voltage and current inverters are considered. It is shown that the use of new semiconductor devices made it possible to fundamentally change the topology of the power circuit and the principles of inverter control. The approach of most manufacturers to the topology of autonomous inverters in frequency converters is considered. The most advanced structures (matrix and hybrid) of AC converters, which are produced by modern industry, are considered. Based on the analysis, it is set that high-precision, reliable and noise-resistant digital sensors are widely used in DC and AC electric drive systems – absolute and incremental encoders, as well as optoelectric attached sensors for registering distances, angles of rotation or the number of turns – resolvers. They are used together with numerical control systems, drives and position determination devices. The power supply circuit for synchronous electric motors of the main drive of the rolling stand of a thick plate mill 3000 based on ALPSA VDM 7000 converters from ALSTOM (Converteam) is considered. The main task of control system of the converter network part is to regulate the voltage of the DC link. The block diagram of the control system for the rectifier and inverter parts of the VD 7000 converters is given.*

***Keywords:*** *synchronous motor, electric drive, frequency converter, autonomous inverter, sensor, current regulator, voltage regulator.*

**Introduction.** Three-phase synchronous electric motors, due to their design features and high technical and economic performance, are increasingly used in industry. Synchronous motors (SM) are used in electric drives of a variety of mechanisms with a variable load, namely, cone and hammer crushers, ball and rod mills of mining enterprises, pumping units, shears and saws for metal, continuous and reversing rolling mills, compressors, mine hoists, powerful excavators and many other mechanisms [1, 2].

The main advantages of SM in comparison with asynchronous (AM):

– SM, regardless of the load, is able to supply reactive power to the network, which is the simplest and most effective way to increase the power coefficient of the power system;

– the static overload capacity of the SM depends linearly on the supply voltage; when the voltage decreases, the operation of the loaded SM is stable, since in the SM the voltage drop in the network has less effect on the magnitude of the electromagnetic torque;

– SM has a high multiplicity of maximum torque, which allows to use SM both at a constant or smoothly changing load, and at a sharply changing load;

– a large air gap, due to which the reliability of SM is higher and heat removal is better;

– SM has a higher efficiency than AM;

Thus, SM has very valuable properties. However, they are still not widely used, since it is believed that the SM is more expensive and more difficult to operate.

**The objective.** The current state of frequency-regulated electric drives, both in terms of the implementation of their power base – power frequency converters (FC), and control and regulation tools allow to replace unregulated drives of a large range of mechanisms (for example, centrifugal and piston pumps, compressors, etc.), and also makes it technically feasible to replace the variable DC drive. In addition, it became possible to increase unit power and overload capacity, which is unattainable during the use of DC motors due to the limitation on switching conditions. This makes it possible to develop units of increased productivity.

**Research results.** Almost all leading electrical companies increase the annual output of AC drives. The production of these electric drives is predicted to grow by 20-30%. The growth of their production and the validity of the forecast are mainly due to two stable trends:

– automation of production processes using automated process control system, which involves the use of adjustable electric drives;

– the use of energy-saving technologies in various areas of production, which provide a significant economic effect.

An electric drive with a frequency-regulated synchronous motor is the most versatile and promising regulated AC electric drive in a wide range of power (from tens of watts to several tens of thousands of kilowatts) and rotation speeds (from units to 12 thousand $min^{-1}$ and higher). They are performed both with synchronous motors (SM) of traditional design (turbo and hydraulic machines) and special design (with permanent magnets, halopolar, etc.).

Two-link frequency converter (FC) (Fig. 1) (the so-called systems with double energy conversion) have received the greatest application for wide-range regulation of the rotation frequency of synchronous motors. Such devices convert the electricity of the mains into electricity with the required values of voltage, current and frequency in two stages. At the first, with the help of a rectifier, the current and voltage of the network with a frequency of 50 Hz are converted into direct current and voltage. At the second stage, direct current and voltage are converted into alternating current, but with new values of current, voltage and frequency necessary to ensure the desired mode of operation of the electric motor.

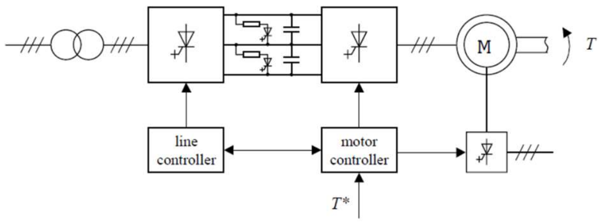


Fig. 1. Single-line power supply circuit of SM from a two-link FC

This transformation is carried out by special devices – autonomous inverters. The inverter is named autonomous because its operation is not directly connected to the power supply network. An autonomous inverter can work, for example, from a battery, and not only from a mains rectifier. Despite the imaginary cumbersomeness of such a conversion method, the efficiency of a two-link FC turns out to be quite high – 96,5-98,5%. This is due to the efficiency of the applied power semiconductor devices in the key operating mode.

The type of power semiconductor device affects the topology of the power circuit of an autonomous inverter and FC as a whole. Current inverters based on capacitor-switched SCR - thyristors are being replaced by voltage and current inverters based on fully controlled (turned on and off by control signals) GTO, IGCT and SGCT - thyristors, as well as on power insulated gate bipolar transistors – IGBT.

The use of new semiconductor devices made it possible to fundamentally change not only the topology of the power circuit of the inverter, primarily ASI, but also the principles of inverter control. For autonomous voltage inverter (AVI) and autonomous current inverter (ACI) on fully controlled «high-voltage switches», different pulse-width modulation (PWM) technologies are used: PWM with a «detector» (relay type), software PWM with selectable suppression of higher harmonics, multi-level PWM, PWM in combination with pulse-amplitude modulation, etc.

The approach of most manufacturers to the topology of autonomous inverters in FC can be reduced to the following fundamental decisions:

– implementation of ACI on a bridge circuit on SCR-thyristors (which are switched on by control signals and switched off with the help of capacitors);

– performance of ACI on fully controlled (turned on and off by control) symmetrical thyristors (GTO, SGCT);

– implementation of AVI with three voltage levels (3-level) and switching to a « star » (with a fixed zero point or a fixed neutral (Neutral-Point Clamped - NPC));

– implementation of AVI with four voltage levels (4-level);

– implementation of multi-level AVI (Multi-level).

In recent years, due to significant progress in the creation of high-speed power semiconductor devices, there has been a trend towards the creation of more advanced topologies of AC converters. These topologies primarily include matrix and hybrid structures.

The matrix structure provides the transformation of the AC source parameters (amplitude and frequency) into the voltage required to power the load, without energy accumulation in the intermediate DC link. Such converters belong to direct power transmission systems. The absence of large DC link capacitors, which occupy from 30 to 50% of the inverter's volume, allows to create small-sized converters. Also, they can operate over a wider temperature range and have a longer life because there are no electrolytic capacitors that are sensitive to high temperatures.

Speed sensors are widely used in DC and AC drive systems. The analog tachogenerators used in the past are now replacing more accurate, reliable and noise-resistant digital sensors – absolute and incremental encoders, as well as optoelectric attached sensors for recording distances, angles of rotation or speed – resolvers. These sensors are produced by foreign companies such as Heidenhine, Leine&Linde, Siemens, Hubner, Omron, Schneider Electric, Avtron, etc. They are used together with numerical control systems (CNC), drives and position detection devices [3].

Let's consider the power supply circuit for synchronous electric motors of the main drive of the rolling stand of a thick plate mill 3000 based on ALPSA VDM 7000 converters from ALSTOM (Converteam) [4, 5]. Rolls are rotated by DMMYZ 3058-16V synchronous motors from VEM motors Gmbh with a capacity of 4600 kW each.

The inverter part of the VDM 7000 converter is built on the basis of a three-level AVI. In the considered example, each converter is equipped with a rectifier / network part with the possibility of recuperating the kinetic energy of the rotating masses back to the network, the so-called Active Front-End system (AFE). In other words, the converter consists of the same modules on water-cooled GTO – thyristors for both the inverter and rectifier parts.

The main task of the network part control system of converter is to regulate the voltage of the DC link. The DC link controller calculates the task for the active component of the consumed current, fig. 2.

Slave internal current controller operates in orthogonal rotating coordinate system d/q, which is determined by the linear voltage vector. In the context of network part control, q axis means line voltage direction, d axis is orthogonal to it. The power coefficient controller controls the reactive component of the consumed current. To improve the quality of voltage vector tracking the phase-locked loop device is used (PLL). Some elements of the network part control system, such as the current consumption regulator, the PWM device and the DC link voltage regulator are similar in nature or even identical to those of the inverter part of the converter, which will be described below.

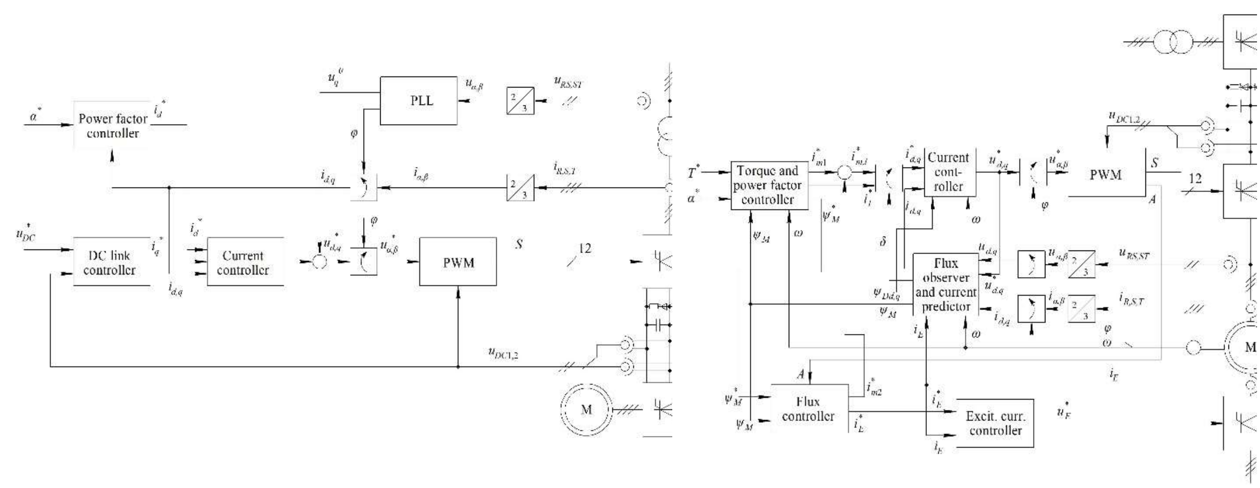


Fig. 2. Structural diagram of the control system of rectifier (a) and inverter (b) parts of converters VD 7000

*Torque and power coefficient controller.* Depending on the amount of torque $T$* required for process, the controller calculates the task for current $i_l$* using the general expression of the machine torque and the calculated flux value $\hat{\Psi}_M$ :

$$T = \frac{3}{2} z_p \left( \Psi_{s,d} i_q - \Psi_{s,q} i_d \right) = \frac{3}{2} z_p \Psi_M i_l , \qquad (1)$$

where $z_p$ – is the number of pairs of SM poles; $\Psi_M$ – is the machine flux linkage vector associated with the third orthogonal coordinate system m/l, which is used in the construction of the control system (the angle δ between the d and m axes is the SM load angle).

The value $i^*_{m1}$ is used to correct the power coefficient of the inverter. In addition, the appropriate flux linkage task value $\Psi^*_M$ is calculated depending on velocity, required torque and power factor.

*Flux and excitation current controller.* The flow of the machine is controlled in a system with feedback according to the calculated value $\hat{\Psi}_M$. PWM modulation control is also included in this block to avoid voltage saturation. The regulator generates the task for the excitation current $i_E$, which is processed by the slave excitation current regulator (excit. curr. controller). The auxiliary control signal $i^*_{m2}$ is used by the flow controller to instantly change the machine's flow when fast acceleration is required. In static mode, this additional signal is equals to zero, so the power coefficient is not degraded.

*Stator current controller of SM.* The stator current controller of SM is synthesized in a rotating orthogonal system d/q. Since the task signals from the machine torque and flux controller are connected to the m/l coordinate system m/l, an intermediate coordinate converter is used, controlled by the restored angle value $\hat{\delta}$ between the d and m axes.

*Flux observer and current predictor.* The flux observer is designed to restore coordinates that are inaccessible to direct measurement, namely the magnetic fluxes of the machine. The Kalman filter is used as an observer. The observer restores the flux value $\hat{\Psi}_M$, the flux vector of the damper winding $\hat{\Psi}_{D_{d,q}}$, and also restores the load angle $\hat{\delta}$, which is used in other modules of the control system.

All control algorithms in the converter are implemented in software using the C language in specialized controller boards equipped with TMS 320C44-60 signal processors from Texas Instruments, which implement 32-bit floating point arithmetic. If necessary, complex computational algorithms can be distributed among several controller boards. The control part and the so-called power interface boards (unlocking / locking pulse generators, thyristor status monitoring, etc.) are connected using an optical fiber, which ensures maximum data transmission speed, ideal noise immunity, as well as safety, since this makes it possible to completely galvanically isolate the controller from the converter.

**Conclusions.** The study of an electric drive with a frequency-regulated synchronous motor showed that two-link frequency converters were most widely used for wide-range control of the rotation frequency of synchronous motors. At present the Converteam company offers frequency converters of the MV7000 series based on IGBT clamping transistors with 3-level NPC topology in the power range from 4 MW to 32 MW with a voltage of 3,3 kV and 6.6 kV.

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**Руднєв Є. С., Романченко Ю. А., Брожко Р. М. Електропривод з частотно-регульованим синхронним двигуном з високоточними цифровими датчиками**

*У статті проведено дослідження електроприводу із частотно-регульованим синхронним двигуном. Перераховані основні переваги синхронних двигунів порівняно з асинхронними. Розглянуто сучасний стан та тенденції зростання виробництва електроприводів змінного струму. Показано, що найбільше застосування широкодіапазонного регулювання частоти обертання синхронних двигунів отримали дволанкові перетворювачі частоти. Вони перетворюють електроенергію мережі живлення в електроенергію з необхідними значеннями напруги, струму і частоти в два етапи. Це перетворення здійснюється спеціальними пристроями автономними інверторами. Встановлено, що ККД дволанкового перетворювача частоти досить високий – 96,5-98,5%, що обумовлено ефективністю силових напівпровідникових приладів, які застосовуються в ключовому режимі роботи. Розглянуто сучасні тенденції використання інверторів напруги та струму. Показано, що використання нових напівпровідникових приладів дозволило принципово змінити топологію силової схеми та принципи керування інвертором. Розглянуто підхід більшості виробників до топології автономних інверторів у перетворювачах частоти. Розглянуто найбільш досконалі структури (матрична та гібридна) перетворювачів змінного струму, які виробляються сучасною промисловістю. На підставі аналізу встановлено, що в системах електроприводів постійного та змінного струму широко застосовуються високоточні, надійні та завадостійкі цифрові датчики – абсолютні та інкрементальні енкодери, а також оптоелектричні датчики для реєстрації відрізків шляху, кутів повороту або числа оборотів – резольвери. Застосовують їх разом із системами числового програмного управління, приводами та пристроями визначення положення. Розглянуто схему живлення синхронних електродвигунів головного приводу прокатної кліті товстолистового стану 3000 на базі перетворювачів ALPSA VDM 7000 фірми ALSTOM (Converteam). Основним завданням системи управління мережевої частини перетворювача є регулювання напруги ланки постійного струму. Наведено структурну схему системи управління випрямної та інверторної частини перетворювачів VD 7000.*

***Ключові слова:*** *синхронний двигун, електропривод, перетворювач частоти, автономний інвертор, датчик, регулятор струму, регулятор напруги.*

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