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An Algorithm for Preventing the Irregular Operation Modes of the Drive Synchronous Motor Providing the Ore Grinding

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***Abstract*—**The current scientific and engineering interest concerning the problems of preventing the emergency manifestations of drive synchronous motors, ensuring the ore grinding technological process has been justified. The analysis of the known works devoted to the abnormal operation modes of synchronous motors and possibilities of protection against them, has shown that their application is inexpedient for preventing the impermissible displays arising in the electrical drive synchronous motors ensuring the ore-grinding process. The main energy and technological factors affecting the technical condition of synchronous motors are evaluated. An algorithm for preventing the irregular operation modes of the electrical drive synchronous motor applied in the ore-grinding technological process has been developed and proposed for further application which gives an opportunity to provide smart solutions, ensuring the safe operation of the drive synchronous motor by a comprehensive consideration of the energy and technological factors.

***Keywords*—**Synchronous motor, abnormal operating mode, electric drive, algorithm, energy factor, technological factor.

I. Introduction

THE proper organization of technological processes is mainly conditioned by the smooth operation of the electrical equipment used in them and the efficiency of maintenance. The disability of the electrical drive motors providing the technological process can destruct the entire technological process, causing serious economic losses. Consideration of this issue is especially important in case of energy-intensive technological processes using powerful electrical drive motors, like in the case of ore-grinding technological process. The irregular operation of the drive synchronous motor can disrupt the normal course of the technological process, thereby contributing to changes in technical and economic indicators, as well as damage the motor.

The reasons for the occurrence of irregular operating modes of a synchronous motor and their manifestations are numerous, and, in some cases, the occurrence of irregular modes is due to the requirements and features imposed on the operation of the electrical drive motor.

Based on the abovementioned, and taking into account that the change in the operation mode of the electrical drive motor providing the ore mill operation is conditioned by the internal and external factors affecting it, which can lead to disruption of the smooth operation of the electrical drive motor, it has become necessary to consider the problem of preventing the emergency manifestations of the ore mill electrical drive synchronous motor.

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II. The State of the Problem

A great number of scientific investigations are devoted to the study of the operation modes of synchronous machines and the prevention of the irregular operation modes.

Theoretical issues on the induction starting of a synchronous motor, features of the appearance of short asynchronous modes due to external factors, as well as various issues related to the self-start of the motor were considered in [1]. Of particular interest is Dadabaev's work on the start-up modes of the pumps' drive synchronous motor [2]. To simulate the direct start-up of the synchronous motor, the Simulink/SimPowerSystems library of the MATLAB computer program has been applied.

The influence of the supply voltage drop on the operation of the synchronous motor in the state of synchronism has been estimated [3]. The static characteristics of the load angle depending on the supply voltage and excitation current for a powerful GAe-1716t/01 motor are determined. The expediency of applying the forced excitation current at voltage drops to maintain the motor in synchronous operating mode is investigated. The author of the work came to the conclusion that the choice of the correct parameters for the adjustment system allows reliable operation of the motor in the state of synchronism within the corresponding values of the excitation current and supply voltage.

A large number of industrial experiments on applying the microprocessor supply unit of the synchronous motor [4] have shown that, the correctly selected value of the forced applied excitation current at the voltage drop often allows to keep the motor in the state of synchronism. This can be done by automatic and rapid increase of the current in the excitation circuit.

In [5], a model for the study of synchronous oscillations and an algorithm for blocking the relay protection during synchronous oscillations are developed. Synchronous oscillations are modes of the power system in which there is a periodic change in its parameters (current, voltage) without breaking the synchronism. By means of the obtained mathematical model, it has become possible to obtain the imbalance coefficients that characterize the sensitivity of the blocking during oscillations. An algorithm for the vibration

blocking equipment has been developed. The analysis for the vibration blocking equipment has shown the feasibility of using a cascade of filters for sequential separation of emergency components of currents in a direct and reverse sequence. The possibility of reducing the imbalance coefficient of the reverse sequence current and increasing the blocking sensitivity in vibration mode by using an additional filter is justified [5].

Reference [6], taking into account the current value of the excitation current, has developed an algorithm for ensuring the stable operation of the motor in the case of a short pause in the power supply and a methodological recommendation for the use of automation devices and application of relay protection for its implementation.

The elimination of the induction operation mode of the synchronous motor is one of the most important and frequently used methods. System for preventing the induction mode is of great interest. It is designed to prevent possible accidents by processing the corresponding control signal through detecting the induction mode and taking into account the slip sign [7].

Works [8]-[10] are devoted to the detection of the synchronous motor faults. Despite the fact that the synchronous motor malfunctions are caused by numerous circumstances, only electromagnetic and electrical malfunctions were evaluated in the considered works. In [9], an intelligent network panel is proposed that is installed at the motor electrical drive system and the main computer. The registered data are coded and transferred to the intelligent network panel, after which they are decoded by the fault detector. Bayes classifier is used to estimate the faults.

In [10], a detector for finding the possible indistinct faults occurring in the synchronous generator has been proposed by monitoring the current components. The detection of the indistinct faults is based on the development of the indistinct output system and a rule database. The rule databases are released for specific changes.

The analysis of the known works devoted to the irregular operation modes of the synchronous motor and the possibilities of their prevention shows that some authors have carried out theoretical and experimental investigations on studying the operation modes of synchronous motors and preventing the emergencies, as well as developed methods for preventing the emergency modes [8]-[10]. There is significant experience in the sphere of developing systems for maintaining the stability of power systems and improving them. At the same time, the known works concern particular cases and the characteristic features of the considered system are not taken into account [5]-[7]. In the well-known works, the impacts of the technological factors, the possibilities of the current regulations and the occurrence of emergency situations conditioned by the mentioned impacts are not considered, thus their application for the electrical drive synchronous motors ensuring the ore-grinding technological processes is inexpedient [11]. Therefore, the works devoted to the prevention of the irregular operation modes of the drive synchronous motor providing the ore crushing is an urgent problem of scientific and technical interest [11].

The goal of the work is to develop a facility aimed at preventing the abnormal operation modes of the electrical drive synchronous motor applied in the ore-grinding technological process which will give an opportunity to prevent the possibility for the motor to appear in the emergency mode, considering the power and technological factors of the system.

III. The Main Factors Affecting the Operation Modes of the Ore Mill Drive Synchronous Motors

It is expedient to introduce the main factors, affecting the technical state of synchronous motors in two groups, one of which is conditioned by energy indicators (Fig. 1), while the other is by technological peculiarities (Fig. 2) [11], [12].

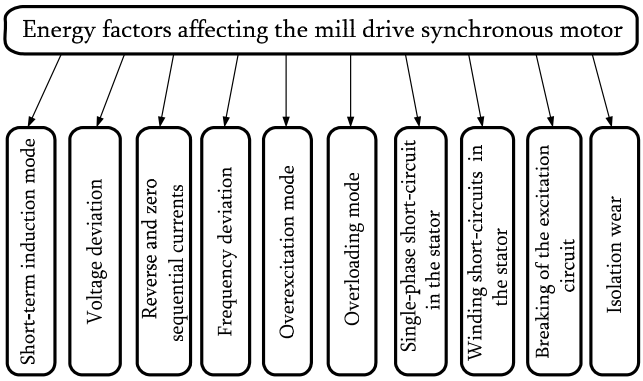

Fig. 1 The energy factors affecting the technical state of the synchronous motor

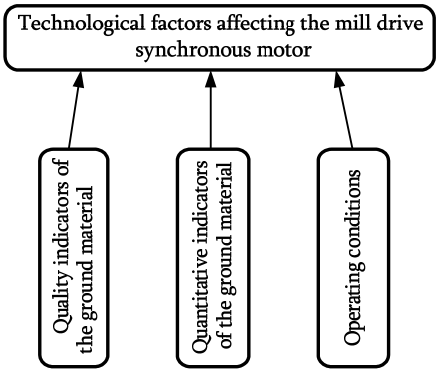

Fig. 2 The technological factors affecting the technical state of the synchronous motor

The quality indicators of the ground ore can change. Investigations have shown that even the hardness, moisture content, as well as the metrological composition of one batch of ore can change, causing changes in the technical state of the process [13], [14].

The quantitative indicators of the crushed material may vary depending on its properties, the state of the drum lining, and the degree of filling of the intra-mill load.

Changes in operating conditions are caused by energy and technological factors, and in some cases, organizational and

environmental problems.

IV. An Algorithm for Preventing Irregular Operation Modes of a Synchronous Motor

The studies have shown [1], [13], [14] that the irregular modes can appear both in induction and synchronous operation modes of the motor. Based on that, the prevention of the undesirable consequences conditioned by irregular operation modes should be implemented for both synchronous and induction modes. In Fig. 3, the block diagram of the system for protecting from irregular operation modes of the drive synchronous motor is introduced.

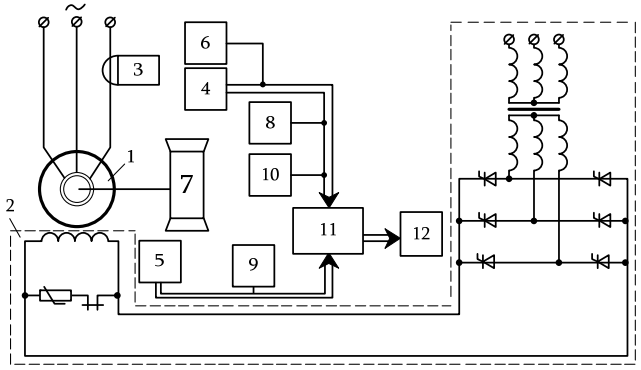

Fig. 3 The block diagram of the system for protecting from the irregular operation modes of the mill drive synchronous motor: 1- the motor, 2-the thyristor transformer, 3- the current meter, 4 – the strain gage transducer of the motor rotating torque, 5 –the motor speed sensor, 6 – the voltmeter, 7 – the mill, 8 – the drum speed sensor of the mill, 9 – the transducer of the mill filling degree, 10 – the transducer of the mill pulp density, 11 – the control subsystem of the electrical drive synchronous motor, 12 – the subsystem for preventing the emergency situation.

The system introduced in Fig. 3 operates in the following way: By the strain gage transducer of the motor rotating torque, the motor speed sensor, the voltmeter, the noncontact amperometer, the strain gage transducer of the ore mill rotating torque, the drum speed sensor, the transducer of the mill filling degree, and the transducer of the mill pulp density are respectively measured the motor torque (M_D), the synchronous speed of rotation (ω_D), the supply voltage of the motor (U), the stator current (I), the angular velocity of the motor rotation (ω_A), the filling degree of the mill (K), the volume density of the pulp (δ), the excitation current (I_f) with a $t_1, t_1+\Delta_t, t_1+2\Delta_t, t_1+3\Delta_t, ..., t_n$ periodicity.

The measurement results are transmitted to the control subsystem of the electrical drive synchronous motor. The latter, according to the algorithm described in [13], notifies about the state of the system and when a situation close to critical is detected, the emergency prevention subsystem is activated (Fig. 4); the algorithm of which is presented below.

1. The fact of the motor's being in the synchronous or induction mode is determined by the operation mode differentiation unit. For that, the value obtained through the control subsystem of the electrical drive synchronous motor for the *s* slide is checked.

   If
   - $s = 0$, the motor operates in the synchronous mode,
   - $0 < s \le 0{,}05$, the motor enters into the induction mode,
   - $-0{,}05 < s < 1$, the motor operates in the deep induction mode.
2. For improving the operation of the motor working in the irregular synchronous mode, the adequate signal and information are transmitted to the regulator of improving the operation modes [14].

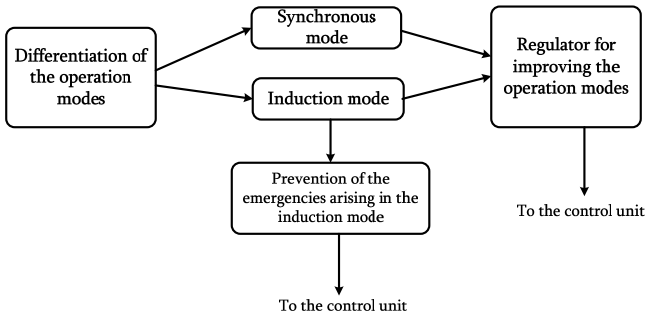

Fig. 4 The structure of the subsystem for preventing the emergency situations

3. For preventing the emergency situation of the ore mill electric drive motor operating in an irregular induction mode, the adequate signal and information are transmitted to the block for preventing the emergencies occurring in the induction mode. The following operations are implemented in that block.
   - Comparison of the motor's supply voltage and the critical voltage. If $U < U_K$, the ore mill loading is checked and, in case of satisfying the condition $M_A / M_{Amax} > 0{,}25$, a signal is sent to the control unit on the increase of the supply voltage and the mill discharge,
   - Determining the duration of the synchronous motor operation in the induction mode and its transmission to the control unit,
   - In case of the smooth start-up of the synchronous motor, as well as a need for reverse, blocking and stoppage, a signal is transmitted to the installation of the smooth start-up of the control system.

IV. Conclusion

An algorithm for preventing the irregular operation modes of the drive synchronous motor is proposed, which gives an opportunity to improve the operation modes of the synchronous motor in case of detecting situations close to critical by considering the energy and technological indicators of the process. The proposed algorithm can be successfully used to put forward smart solutions, ensuring the safe operation of the electrical drive synchronous motor of the ore mill.

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