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Investigating the Regulation System of the Synchronous Motor Excitation Mode Serving as a Reactive Power Source

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***Abstract*—**The efficient usage of the compensation abilities of the electrical drive synchronous motors used in production processes can essentially improve the technical and economic indices of the process. Reducing the flows of the reactive electrical energy due to the compensation of reactive power allows to significantly reduce the load losses of power in the electrical networks. As a result of analyzing the scientific works devoted to the issues of regulating the excitation of the synchronous motors, the need for comprehensive investigation and estimation of the excitation mode has been substantiated. By means of the obtained transmission functions, in the Simulink environment of the software package MATLAB, the transition processes of the excitation mode have been studied. As a result of obtaining and estimating the graph of the Nyquist plot and the transient process, the necessity of developing the Proportional-Integral-Derivative (PID) regulator has been justified. The transient processes of the system of the PID regulator have been investigated, and the amplitude–phase characteristics of the system have been estimated. The analysis of the obtained results has shown that the regulation indices of the developed system have been improved. The developed system can be successfully applied for regulating the excitation voltage of different-power synchronous motors, operating with a changing load, ensuring a value of the power coefficient close to 1.

***Keywords*—**Transient process, synchronous motor, excitation mode, regulator, reactive power.

I. INTRODUCTION

SYNCHRONOUS motors are widely applied to ensure the operation of different mechanisms used in the technological processes of different industrial complexes. The application of synchronous motors compared with that of induction motors is conditioned by a number of advantages. Those advantages are [1], [2]:

1. The large air gap between the stator and the rotor which increases the reliability of the motor maintenance;
2. High values of the power and efficiency factors;
3. Regardless of the load, a synchronous motor is able to give reactive power to the network which is a simple and efficient way of increasing the power coefficient. It gives an opportunity to unload the network from the reactive currents used for the consumption of the transformers of the induction motors and other devices. Due to that, the losses in the network decrease;
4. The overload capacitance of the synchronous motor from the network voltage is dependent linearly, while in case of induction motor, that dependence is quadratic. Therefore, in case of a decrease in the network voltage, it is possible to ensure the stable operation of the loaded synchronous motor which is impossible when applying an induction motor;
5. In transition modes, the overload capacitance of the synchronous motor may be increased due to the occurrence of transitional currents in the excitation winding;
6. By using an automated regulator, the excitation current of the synchronous motor is regulated smoothly which can ensure the stability of the electrical drive system at changing the operation modes.

The estimation and analysis of compensation possibilities of synchronous motors shows that their efficient application will give an opportunity to essentially improve the technical and economic indices of industrial complexes.

Taking into account the fact that synchronous motors are a source of reactive power and that their capacity has found a wide application in industrial complexes, it becomes necessary to investigate the transient processes of the motor excitation mode, considering that in case of non- regulated excitation current:

- As a result of changing the motor load, the active and reactive powers change;
- The network frequency changes.

Numerous scientific works devoted to the issues of excitation regulation of synchronous motors are known [3]-[6]. In [2]-[7], the excitation automated regulators of synchronous motors with an impact load have been studied from the standpoint of raising the dynamic stability of the motor.

In [8], an automated regulation system, ensuring the excitation in a wide range of the power coefficient is presented.

In [9], a static excitation system (SES) has been implemented in a specially designed synchronous machine installed in a testing laboratory. An imitation model of the motor excitation system has been developed for investigating the rotor voltage. To estimate the time change of the voltage, a spectral analysis was carried out, for which the Fourier transformation has been applied.

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Despite the obtained results in the area of the investigation of the automated control and improvement of the synchronous motor excitation system, there are significant problems connected with the improvement of the comprehensiveness and operational efficiency of investigations in that sphere. That is why, the comprehensive study and regulation of the synchronous motor excitation mode, which is a source of reactive power, is an urgent task.

The goal of the present work is the development and investigation of the automated regulation system of the excitation system of the electrical drive being a source of reactive power under the conditions of changing load and power.

II. The Problem Statement and the Method Substantiation

The requirements set to the excitation regulation of the synchronous motor are mainly conditioned by its operation mode. In industrial enterprises, synchronous motors can be used both to ensure the operation of the mechanisms involved in the technological process and as a source of reactive power. The synchronous motors used in industrial enterprises are mainly used in electrical drive systems with an impact and oscillating load. If the electrical drive synchronous motor is used as a source of reactive power, then, regardless of the load mode, it should give the network the required amount of reactive power which can be provided by regulating the excitation according to the corresponding law. Considering the abovementioned, in this work, the development of the regulation system of the synchronous motor excitation mode has been carried out taking into account:

- The correlations of the changes of the motor's internal angle (θ), supply voltage (U), the stator current (I) and the active power coefficient ($cos\,\varphi$),
- Oscillations of the synchronous motor;
- The regulation law of the motor's excitation voltage.

The optimal value of the excitation voltage required for regulation is provided to the system. That value has been determined by taking into consideration the powers of the synchronous and induction motors available in the workshop, their operation modes and the possibilities of ensuring $cos\,\varphi = 1$ in the bus [10].

III. An Automated Regulation System for the Synchronous Motor Excitation Mode

To develop the excitation regulation system, the following system of equations introduced in the operator form has been used:

$$\begin{cases} \Delta\theta(s) = W_1(s)\Delta I(s) + W_2(s)\Delta\varphi(s) \\ \Delta I(s) - I(s)\Delta\theta(s) - A_f(s)\Delta U_f(s) = 0 \\ \Delta U_f(s) = W_3(s)\ (s)\Delta I(s) \end{cases} \tag{1}$$

The $W_1(s)$, $W_2(s)$, $W_3(s)$, $I(s)$, $A_f(s)$ transfer functions are determined as follows:

$$W_1(s)\frac{s}{x_q(1+sT_{q1})}\left(\frac{cos^2\theta_o\,sin\varphi_o - sin\theta_o\,sin\varphi_o}{U+\dfrac{sT_qI_o\,cos\varphi_o}{x_q(1+sT_{q1})}}\right),$$

$$W_2(s)\frac{s}{x_q(1+sT_{q1})}\left(\frac{-I_o\,cos^2\theta_o\,sin\varphi_o + I_o\,sin\theta_o\,sin\varphi_o}{U+\dfrac{sT_qI_o\,cos\varphi_o}{x_q(1+sT_{q1})}}\right),$$

$$W_3(s) = \frac{K_1/r_f}{(1+sT_1)}\ ,$$

$$I(s) = U\,sin\theta_o\left(-\frac{s(T_d - T_{d1})}{x_d(1+sT_{d1})} + \frac{s(T_{d2} - T_d)}{x_d(1+sT_{d2})}\right) - \frac{sU\,cos\theta_o}{x_q(1+sT_{q1})},$$

$$A_f(s) = K_2 s\,.$$

The following designations have been used: T_d, T_{d2} - the time constants of longitudinal damper circuit; T_{d1} - the time constant of the excitation circuit; T_q, T_{q1} - the time constants of the quadrature-axis damper circuit; I_o - the initial value of the stator current; θ_o - the initial value of the synchronous motor internal angle; x_d, x_q - the inductive resistances of the stator by the longitudinal and cross axes respectively; r_f - the active resistances of the excitation winding; K_1, K_2 - the regulation coefficients.

The first equation of (1) has been obtained by the following equation characterizing the relation of the active power coefficient of the motor, the complete current of the stator and the internal angle θ.

$$cos\,\varphi = \frac{Utg\theta}{x_qI(1-tg\theta)}, \tag{2}$$

Equation (2) has been linearized by introducing the changes of the stator current, and the angles φ and θ in the following way:

$$I = I_o + \Delta I\,,\ \theta = \theta_o + \Delta\theta\,,\ \varphi = \varphi_o + \Delta\varphi\,.$$

The second equation of (1) has been obtained by linearizing the equation of the stator current introduced by reactive and active components.

With the help of the equation system introduced in the operator form, an automated regulator for a slow synchronous motor with nominal power of 600 kW and 3000 V of nominal voltage has been developed. In Fig. 1, the block diagram of the control system without a PID regulator is presented.

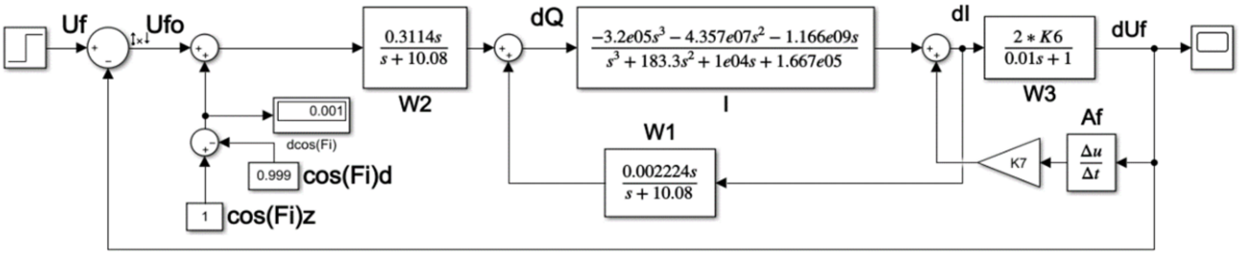

Fig. 1 A block diagram of the control system without a regulator

In Fig. 2, the structural model of the closed-loop system introduced in Fig. 1 is shown, in which the $H(s)$ transfer function has been obtained for the open-loop system included in it.

$$H(s)=\frac{-1{,}119\cdot 10^{4}s^{2}+3{,}003\cdot 10^{-11}s+7{,}545\cdot 10^{-13}}{s^{3}+100{,}1s^{2}+8{,}53s+64{,}7}. \tag{3}$$

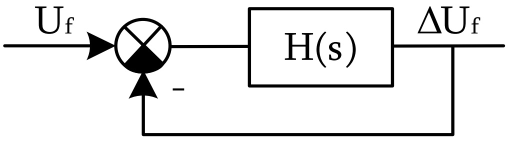

Fig. 2 A structural model of the closed system without a PID regulator

To investigate the obtained open-loop system, the Nyquist plot has been plotted (Fig. 3). The plot includes the point (-1, j0) from what it follows that the closed-loop system is unstable.

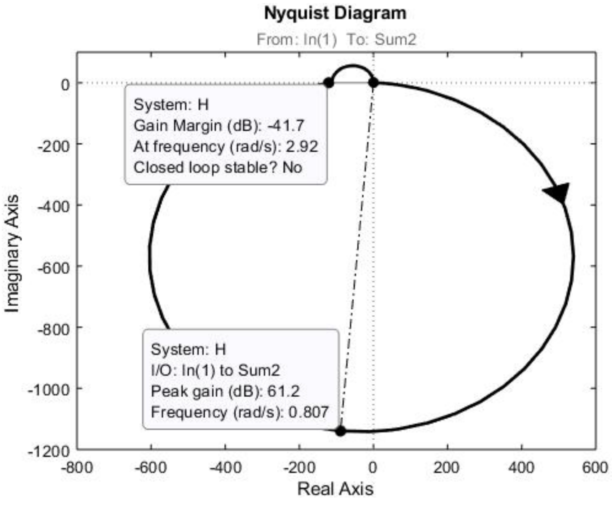

Fig. 3 The Nyquist plot of the open-loop system

The instability of the system without a PID regulator can also be noticed by the character of the output signal of the model plotted in the Simulink environment. In case of the ramp input signal, the output signal is unstable (Fig. 4).

The dependences obtained show that the control system needs to be improved. For that purpose, a PID regulator has been designed (Fig. 5).

The transfer function of the PID regulator will be [11], [12]:

$$C(s)=K_{p}+Ki\frac{1}{s}+sK_{d}\,,$$

where K_p is the proportional coefficient of amplification, Ki is the integral coefficient of amplification, K_d is the differential coefficient of amplification.

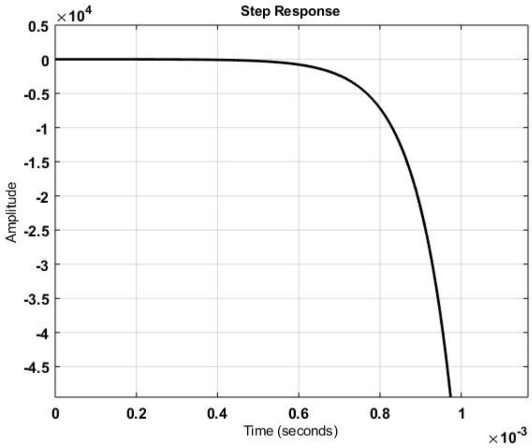

Fig. 4 The curve of the transient process of the closed-loop system without a PID regulator

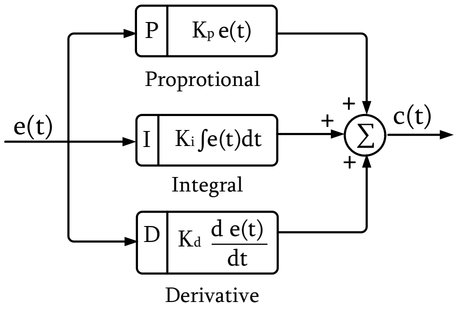

Fig. 5 The block diagram of the PID regulator

For the considered case, the following values of the PID regulator coefficients have been obtained: $K_p=-0{,}3471$; $Ki=-92{,}5677$; $K_d=1{,}150\cdot 10^{4}$.

The transfer function of the open-loop system with a PID regulator (Fig. 6) has the following form.

$$G(s) = \frac{3754s^3 + 1{,}424 \cdot 10^6 s^2 + 1{,}035 \cdot 10^8 s - 7{,}524}{s^4 + 200{,}1s^3 + 1{,}002 \cdot 10^4 s^2 + 917{,}7s + 6470}.$$

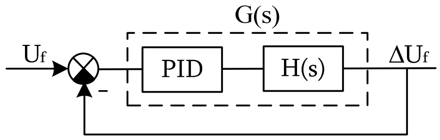

Fig. 6 The diagram of the closed-loop system with a PID regulator

From the Nyquist curve of the open system with a PID regulator, it can be seen that the hodograph does not include the point (-1, j0), that is the closed system is stable (Fig. 7).

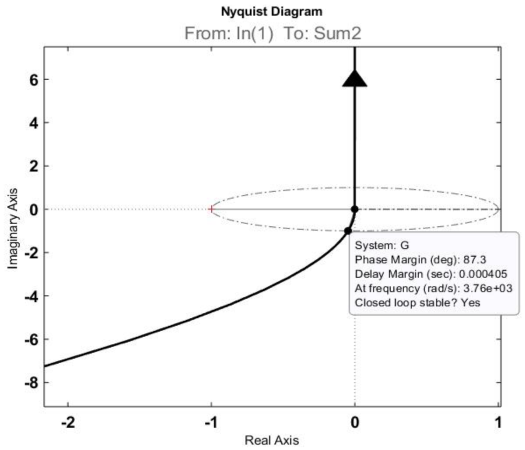

Fig. 7 The Nyquist curve of the open-loop system G

For the closed system, the transfer function has been obtained:

$$F(s) = \frac{3754s + 1{,}055 \cdot 10^6}{s^2 + 3856s + 1{,}055 \cdot 10^6}$$

After introducing the PID regulator, the time change of the excitation voltage signal on the output of the system has been estimated (Fig. 8).

The analysis of the transient process curve shows that as a result of introducing the PID regulator the operation modes of the system improve.

TABLE I
DATA ON TESTING THE EXCITATION MODE REGULATOR ACCORDING TO THE ASSIGNED $\cos\varphi$ AND U_F

Assigned data			
$\cos\varphi$	$U_f = 40$ V	$U_f = 60$ V	$U_f = 100$ V
Data obtained due to the regulation			
1	39.97	59.96	99.94
0.99	39.98	59.97	99.94
0.98	39.98	59.99	99.96
0.9	40.08	60.07	100
0.8	40.08	60.16	100.1
0.7	40.27	60.26	100.2
0.5	40.48	60.46	100.4

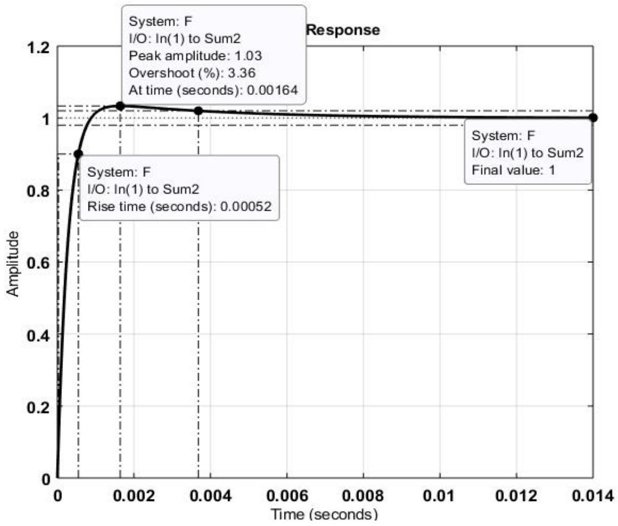

Fig. 8 The transient process curve of the closed-loop system with a PID regulator

For the considered case, we have obtained the following results: superregulation - $\delta = 3{,}36\%$, rise time - $t_r = 0{,}00052$ sec, settling time - 0,0038 sec.

The developed regulator has been tested for different assigned values of the motor's power coefficient ($\cos\varphi$) and excitation voltage (Table I).

The obtained results confirm that the developed system for regulating the synchronous motor excitation modes according to the assigned data ensure efficient regulation in a wide range of changes in $\cos\varphi$, load and supply voltage.

IV. CONCLUSION

The proposed automated system can be successfully used for regulating the electrical drive motor excitation system operating with changing load, which is applied in the production processes. It is more expedient to apply the system for keeping the optimal value of the assigned excitation voltage for the given situation stable. This is important for regulating the excitation mode of the synchronous motor serving as a source of reactive power.

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REFERENCES

[1] Austin Hughes, *Electric Motors and Drives, Fundamentals, Types and Applications*. University of Leeds, 2013, 439 p.

[2] Zhelezko Yu. S., *Compensation of the reactive power and improving the quality of electric energy*. Moscow: Energoatomizdat, 1985, 224 p.

[3] J. Machowski, J. W. Bialek, S. Robak, J. R. Bumby, "Excitation control system for use with synchronous generators," IEE Proc.-Gener. Transm. Distrib., Vol. 145, No. 5, September 1998.

[4] D. Sumina, G. Erceg, T. Idžotić, "Excitation control of a synchronous generator using fuzzy logic stabilizing controller" EPE 2005, Dresden, 2005.

[5] Pavlushko S. A., "Automatic excitation control of synchronous generators as an effective means to ensure the reliable parallel operation

of generation equipment and the united power system as a whole," Power Technology and Engineering. 2013, Volume 46, Issue 5, pp. 399–404.
[6] Papadopoulos D. P., Smith J. R. and Tsourlis G., "Excitationcontroller design of synchronous machine with outputfeedback using high and reduced order models", Archiv für Elektrotechnik, Vol. 72, 1998, pp.415-426.
[7] Fomin D. V., "Study of the system of automatic control of synchronous motor excitation in the function of the load angle," Proceedings of HEI. Electromekhanika, 2004, N 2, pp. 79-81.
[8] Devansh K. Shah, Swapnil N. Jani, "Simulation and Development of Automatic Excitation Control for Synchronous Motor," International Journal of Emerging Technology and Advanced Engineering, Volume 2, Issue 3, 2012.
[9] Arun Kumar Datta, Manisha Dubey, Shailendra Jain, "Modelling and Simulation of Static Excitation System in Synchronous Machine Operation and Investigation of Shaft Voltage," Advances in Electrical Engineering. 2014, pp. 1-9.
[10] Baghdasaryan M., Mailyan A., Davtyan D., "Using the Possibility of the Synchronous Motor Compensation in the Production Processes with Synchronous and Induction Motors," Austrian Journal of Technical and Natural Sciences. 2017, № 9–10, pp. 80-84.
[11] Ankhimyuk V. L., *Theory of automatic control*. Minsk: Visheyshaya shk., 2002, 352 p.
[12] Ang K. H., Chong G., Li Y., "PID control system analysis, design, and technology," IEEE Trans. on Control Systems Technology. Vol. 13. №. 4, pp. 559-576, July 2005.

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