DEFINING THE SPECIFIC LOSSES OF ACTIVE POWER IN SYNCHRONOUS ELECTRIC MOTORS FOR THE GENERATION OF REACTIVE POWER

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ABSTRACT. The paper presents a methodology for the experimental defining of the specific losses of active power in the synchronous electric motors for the generation of reactive power. Experimental tests in the operation of powerful synchronous electric motors, driving mill units, disintegrators and pumps are made. The specific losses of active power for the generation of reactive power are defined in the synchronous electric motors in big mining and mineral processing enterprises in the country.

Keywords: specific losses, compensation of reactive loads

ОПРЕДЕЛЯНЕ СПЕЦИФИЧНИТЕ ЗАГУБИ НА АКТИВНА МОЩНОСТ НА СИНХРОННИ ЕЛЕКТРОДВИГАТЕЛИ ЗА ГЕНЕРИРАНЕ НА РЕАКТИВНА МОЩНОСТ

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РЕЗЮМЕ. Дадена е методика за експериментално определяне на специфичните загуби на активна мощност в синхронни електродвигатели за генериране на реактивна мощност. Проведени са експериментални изследвания в практиката на мощни синхронни електродвигатели, задвижващи мелнични агрегати, дезинтегратори и помпи. Определени са специфичните загуби на активна мощност за генериране на реактивна мощност в синхронните електродвигатели на големи минно-обогатителни предприятия в страната.

Ключови думи: специфични загуби, компенсиране на реактивни товари

Introduction

The powerful synchronous electric motors have a wide application in our mining industry. They are used for driving of mill units, pumps, ventilation units and compressors. For instance, the overall installed power of the synchronous electric motors in the mineral processing plant in Asarel Medet JSC is 54.2 MW, of which 41.7 MW are operational. 13 synchronous electric motors with an overall installed power of 28.2 MW are in constant operation in the flotation mill in Elatsite Med JSC. The synchronous electrical motors operate in a regime for generation of reactive power with capacitive character which facilitates ensuring the balance of the reactive power for the overall enterprise. This is of particular importance for enterprises that do not have to achieve an average power factor below the neutral (cosφ = 0.9) for a 15 minute interval.

In order to compensate the reactive loads in the mining enterprises in our country capacitor batteries, operating mainly at a medium voltage of 6 kV, are also used. The elimination of the cost of consumed excess or reactive energy returned to the system, in accordance with the current electricity tariff and the maximum unloading of the reactive power grids, should be considered as a condition for optimal operation of compensating devices. The solution of the complex problem for optimum combined compensation of reactive loads in big enterprises requires assessment of the losses of active power for the generation of reactive power by the compensating devices.

The specific losses of active power for the generation of 1kVAr reactive power by the modern medium voltage capacitors are unambiguously accepted in the literature and are about 0.003 kW/kVAr. However, there is a different problem with the loss of active power by synchronous electric motors. There is insufficient data, often in a wide range of the specific losses during the reactive power generation, in the literature. For example, in (Dankov, 1991) are quoted values of specific losses of 0.009-0.05 kW/kVAr. Significantly higher values are given in (Fedorov, Kamneva, 1984): synchronous electric motors with power up to 5000 kW – 0.05-0.1 kW/kVAr; for low-speed motors - 0.1-0.15 kW/kVAr. The conducted experimental studies of synchronous electric motors of 2.5 MW and 1.6MW in (Chobanov, Menteshev, 2007) show an average value of the specific losses of 0.03 kW/kVAr. Apart from the large differences in the quoted values, it is not explained in what operating conditions the specific losses are obtained and whether they reflect the losses in all the units of the synchronous motor - coordinating transformer, rectifier, rotor coil and stator coil.

The lack of accurate data on the values of specific losses of the active power for reactive power generation is a significant obstacle for conducting a proper technical and economic analysis to optimize the allocation of reactive capacities within the plant. The purpose of this study is to develop the actual specific losses of active power to generate reactive power (α) of the main synchronous electric motors in our mining and mineral processing plants. During the production process, experimental tests of different types of synchronous machines were performed under normal operating modes and the values of α were determined.

Measuring equipment

All experimental studies were carried out with modern digital network analyzers FLUKE 437-II, FLUKE 435-II и FLUKE-43B. Accuracy class of the instruments during measurement:

- of the voltage ± 0.1% of nominal (1000V);
- of the current for the corresponding clamp-on ammeter ±0.5%;
- of the power ±1.0%.

Methods for conducting the experiment

The objective is to selectively determine the specific losses of active power in the stator coil, in the rotor coil and in the transformer-rectifier coordinating unit. For this purpose, a three-phase network analyzer is connected to measure current and power in the stator coil of the motor. A second three-phase network analyzer is connected to measure the current and the input power of a matching transformer. A single-phase FLUKE-43 network analyzer is used to measure the power, current and voltage for determining the losses only in the synchronous motor. The experiment aims at capturing how the specific losses α are changed at different values of the generated reactive power, stepwise changing the magnitude of the field current, and recording all measured quantities.

Experimental tests

The described methodology will be illustrated with the results from the measurements of a synchronous electric motor type SDS 19-56-40 u4, driving mill unit type MSHTS 4.5 x 6.0, indicated in the text with MA1.

Fig. 1 shows the change of the active and reactive power as well as the current in the stator and the rotor captured by the experimental tests of mill unit M1. From the dependencies shown, it can be seen that the change of the field current (Irotor) significantly changes the reactive power (Q) and the stator current (Ist), but the active power (P) remains almost constant. Therefore, the determination of the active losses in the stator coil of the electric motor does not have to be done by reading the drawn active power at change of the field current. The losses are calculated by considering the change of the current in the stator coil for certain values of the field current and the active losses are calculated by the formula:

$$\Delta P = 3.I_{st}^{2}.R_{st}.10^{3}, kW \qquad (1)$$

where: I_{st}, - current in the stator coil of the synchronous electric motor, A;

R_{st} - active resistance of the stator coil of the synchronous electric motor, Ω.

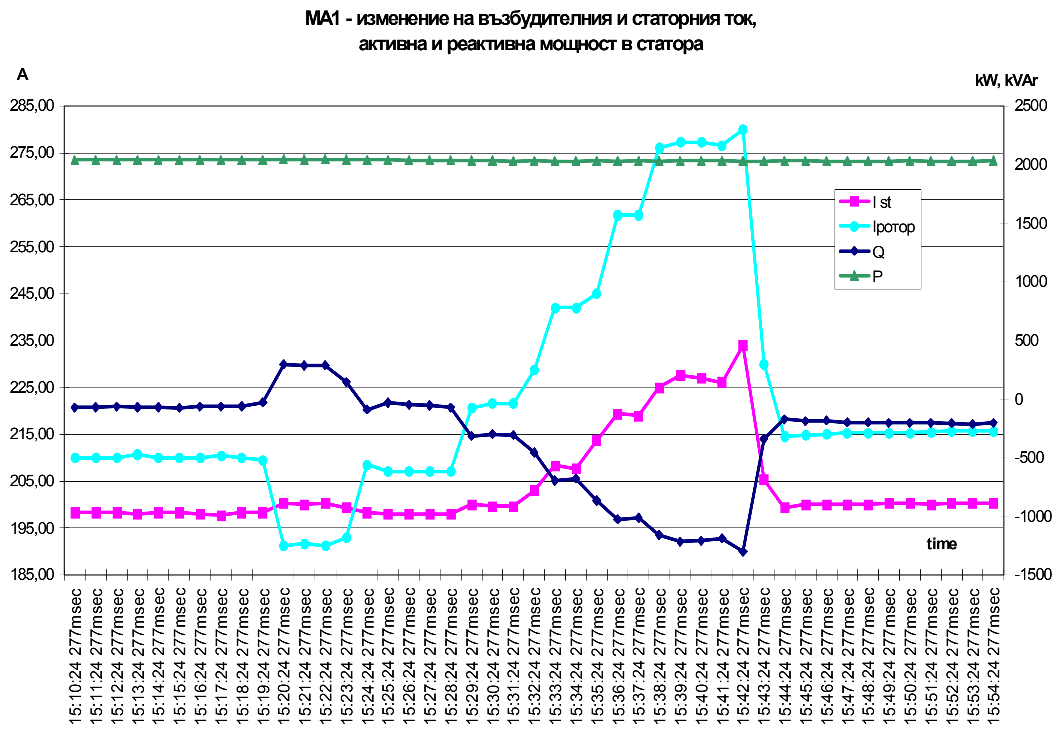

Fig. 1. MA1 – change in the field and stator current, acive and reactive power in the stator

To determine the losses in the excitation circuit, the three-phase active power on the ~ 380V side of the transformer supplying the thyristor exciter TE-8E for different field current values is measured. Thus, the losses in the power transformer, the losses in the rectifier itself and the losses in the rotor coil are taken into account. The constant current losses in the rotor coil are reported by the single-phase network analyzer

Table 2 gives the results of the measurements of mill unit M1. For each value of the field current Ic, the current in the stator Ist, the active power P and the reactive Q in the stator of the synchronous electric motor are registered. The "-" sign before the reactive power means that the synchronous machine generates reactive power of capacitive character, and the positive values of Q mean reactive power consumption with inductive character.

Table 2. *Specific losses of active power for the generation of reactive power in a synchronous motor type SDS 19-56-40 u4 (M1).*

I rotor, A	I st, A	P rotor, kW	P ~380, kW	P st, kW	Q st, kVAr	Losses for excitation, kW/kVAr	Losses in the rotor, kW/kVAr	Losses in the stator, kW/kVAr	Overall losses, kW/kVAr
191.2	200.0	18.3	23.3	2046	288				
207.1	198.0	20.6	27.3	2039	-37				
210.0	198.3	21.0	27.5	2040	-92				
215.3	199.1	21.8	28.6	2034	-183	0.0092	0.0085	0.0012	0.0104
221.6	**200.6**	**22.8**	**30.8**	**2036**	**-298**	**0.0134**	**0.0086**	**0.0016**	**0.0150**
242.0	208.0	26.5	36.6	2033	-677	0.0145	0.0092	0.0026	0.0171
261.8	219.0	30.2	42.8	2033	-1025	0.0157	0.0098	0.0036	0.0193
277.3	227.0	33.3	46.8	2034	-1210	0.0166	0.0108	0.0042	0.0208

The three-phase active power (P ~ 380) of the coordinating transformer (TC3B 100) to the thyristor exciter TE-8E is also registered. The table also shows the power change in the DC rotor circuit (P rotor). The table also shows the power change in the DC circuit in the rotor (P rotor).

The specific losses of active power for generating reactive (kW / kVAr) total for the excitation circuits, stator coil and total specific losses are determined. For example, at an operating field current of 221.6 A, the stator current is 200.6 A, the rotor coil power is 22.8 kW, and the power output from the 380V side of the matching transformer is 30.8 kW. The synchronous motor is loaded with an active power of 2036 kW and generates a capacitive output of 298 kVAr. Under these conditions, the overall specific active losses for reactive power generation are 0.015 kW/kVAr, distributed as follows: in stator coil - 0.0016 kW/kVAr, in the excitation - 0.0134 kW/kVAr. Of these, the specific losses in the rotor coil are 0.0086 kW/kVAr and the remaining 0.00726 kW/kVAr are in the matching transformer and rectifier.

The percentage ratio of losses in the individual units of the synchronous electric motor in normal operating mode is: in the stator coil – 10.66%; in the rotor coil - 57.33%; and overall in the transformer and rectifier - 48.4%. With the increase of the field current, the specific losses also increase and with excitation of 277.3 A - the total specific losses are 0,0208 kW/kVAr. The percentage of losses in individual units also changes. Compared to the normal operating mode, the percentage of losses in the stator coil (20.19%) is almost doubled, at the expense of reducing the percentage of transformer and rectifier (27.88%).

The results obtained show in that the specific loss estimate for the specific losses in the rotor coil alone leads to significant errors of about 40-50%. For accurate estimation of the specific losses of active power for reactive power generation, it is necessary to simultaneously measure the values in the stator coil of the electric motor, the field current and the active power at the input of the matching transformer.

Table 2. *Specific losses kW/kVAR*

Type of motor	Driven machine	Coefficient of loading	Specific losses kW/kVAR
SDS-19-56-40 UHL-4 P = 2500kW, $U_н$ = 6kV, $I_н$ = 281A, n = 150min^{-1}, cos$_ц$ = 0.9, U_{exc} = 162V, I_{exc} = 225A, Efficiency = 95.0	Ball mills, type MSHTS 4.5 x 6.0.	0.8	0.0138
SDS 19-56-40 y4 P=2500 kW, Uн.=6 kV, Iн.=281 A, n=150 min^{-1},cos$_ц$=0.9, Uexc.=145 V, Iexc.=278 A, Efficiency=94.8	Ball mills, type MSHTS 4.5 x 6.0	0.82	0.0150
SDM-32-22-34 UHP-4 P = 1600kW, Uн.= 6kV, I_{stat} = 185A, n = 100min^{-1}, cos$_ц$ = 0.9, I_{exc} = 290A	Mills for wet self-grinding MMS 7.0 x 2.3.	0.3	0.0323
SDN -2-16-74 6UZ P = 2000kW, Uн.= 6kV, $I_{stat.}$= 221A, U_{exc} = 46V, n = 1000min^{-1}, cos$_ц$ = 0.9, Iexc.=295 A, Efficiency = 96,6	Pump	0.9	0.00717
SDS 3 I 5 -64-6UZ P = 2500kW, $U_н$ = 6kV, I_{stat} = 278A, $U_{exc.}$= 72 V, cos$_ц$ = 0.9	Pump	0.72	0.00728

According to the presented methodology, the specific losses of active power for generating reactive power from the main electric drives with synchronous electric motors in the mineral processing plants of Assarel-Medet JSC and Elatsite Med JSC have been experimentally determined. The results have been summarized in a Table 2. The well-known fact that higher-speed synchronous motors have lower specific losses has been quantitatively confirmed. For example, the low speed motor SDS-19-56-40 (n = 150 min^{-1}) has values of α = 0.0138 kW / kVAr, whereas the electric motor with the same power SDS 3 I 5-64-6ЭЗ (n = 1000 min^{-1}) has specific losses α = 0,00728 kW /kVAr.

Conclusion

The results obtained for the specific losses α during the conducted studies and the conducted technical and economic analyzes for optimum compensation of the reactive loads of large mining and mineral processing enterprises have led to the following:

1. A methodology for selectively determining the specific losses of active power in the individual units of the synchronous electric motor when generating reactive power is proposed.
2. According to the proposed methodology, data on the specific losses of the main synchronous electric motors in the mineral processing plants at Asarel-Medet JSC and Elatsite Med JSC have been obtained.
3. On the basis of the actual data on specific losses of active power for reactive power generation, a feasibility study was carried out to optimize the distribution of the reactive capacities in the processing plants at Asarel-Medet JSC and Elatzite Med JSC.
4. Asarel-Medet JSC has implemented the proposals in practice and has compensated the combined reactive loads - with synchronous electric motors and with capacitor batteries, which has led to a significant economic effect.

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