Determination of the replacement circuit parameters and analysis of the mechanical characteristic of the asynchronous machine using the example: AIML71V4UZ

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Abstract. The parameters of the equivalent substitution circuit of the AIML71V4UZ type short-circuited rotor asynchronous machine, obtained from experimental tests, were investigated: measurement of the active resistance of the stator winding at constant current, no-load, and short-circuit. Based on these parameters, the calculation and construction of the mechanical characteristic of the electromagnetic torque covering both the motor and the generator modes were performed. The critical values of slip and torque were determined, and a significant difference in the absolute value of the critical torque in the generator mode compared to the motor mode was revealed. Conclusions were made about the range of stable operation and the specifics of using the machine as an asynchronous generator.

INTRODUCTION

Asynchronous (induction) machines are widely used in both motor and generator modes. To analyze their characteristics, replacement circuits are used, the parameters of which are determined by tests and serve as the basis for calculating the moment, current, power, and stability of operation. When switching to generator mode, the slippage becomes negative, and the machine gives power to the network when the rotor is driven by an external motor. Such a feature is described by classical sources: with negative slip, the machine works as a generator and delivers electrical energy to the network, and there is a maximum possible torque in the generator mode [1, 2].

The purpose of the work is to experimentally determine the parameters of the equivalent circuit of a specific machine and analyze its mechanical characteristic in a wide range of slippage, including the generator mode, with an assessment of critical moments and stable load conditions [3,4].

EXPERIMENTAL RESEARCH

For theoretical research, a series-produced short-circuited rotor type AIML71V4UZ asynchronous motor with the following nominal values was selected:

- power of 0.75 kW
- voltage 380/220 V
- current of 2.05/3.56 A
- rotation frequency 1395 min -1
- efficiency coefficient 74%
- cosφ = 0.75.

For theoretical research, the parameters of the substitution circuit of the AIML71V4UZ asynchronous machine were determined using known methods. The active resistance of the stator winding was determined using an ammeter and a voltmeter when powered by direct current. Measurements of phase resistance were carried out at three different voltage values at ambient temperature of 20°C. The average value of the active resistance of the three phases was 8.59 Ohms. The measured phase resistance was brought to a temperature of 75°C using the formula:

$$R_{75} = R_{cp} \cdot [1 + 0{,}004 \cdot (75 - 20)] \quad (1)$$

where 0.004 1/C is the temperature coefficient of resistance for copper.

The magnetization circuit parameters of the substitution circuit were determined based on the results of the asynchronous motor's no-load experiment, which was conducted at a nominal phase voltage of Upn=220V. The active power consumed and the phase current were measured. The following average values of the phase input resistances were obtained [5, 6].

$Z_0 = \frac{220}{1{,}4} = 157{,}1$ Ohm - full input impedance of the phase,

$R_0 = \frac{153}{3\cdot 1{,}4^2} = 26$ Ohm - active phase resistance,

$X_0 = \sqrt{157{,}1^2 - 26^2} = 154{,}9$ Ohm - inductive phase resistance.

A short circuit experiment was conducted at a reduced voltage supplied to the stator of the AIML71V4UZ asynchronous motor. The phase voltage U_{Pk}, the phase current I_{pk}, and the power consumed from the entire machine network P_k were measured. Based on experimental data, the input phase resistances in the short-circuit mode were determined:

Z_{pk}=27.22 Ohms, R_k=19.28 Ohms, X_{2k}=19.21 Ohms, X_1=X'_2=19.21/2=9.61 Ohms,

$R'_2 = R_{pk} - R_{75}$ = 19.28 - 10.48 = 8.8 Ohms.

When transitioning from the "T" - simulated circuit to the "G" - simulated circuit, the modulus of the rotor winding resistance reduction factor is determined by the formula:

$$C_1 = 1 + \frac{X_1}{X_M} = 1 + \frac{9{,}61}{154{,}9} = 1{,}06 \quad (2)$$

The "G"-shaped diagram of one phase of the asynchronous machine is presented in Figure 1.

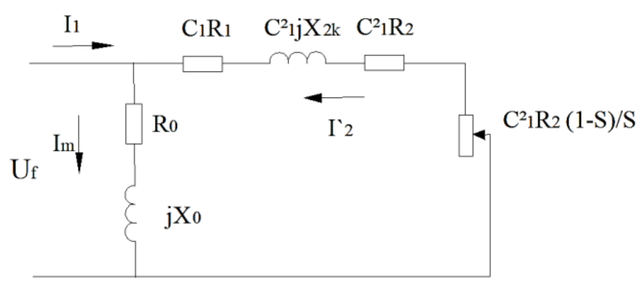

Figure 1. Replacement diagram of an asynchronous machine after combining the above-mentioned resistances

a) $C_1\cdot R_1$=1,06·10,48=11,1 Ohms
b) $C^2_1\cdot R_2$=$1{,}06^2\cdot 8{,}8$=9,89 Ohms,
c) (R_1+R_M) =R_0=26 Ohms,
d) (X_1+X_M) =X_0=154,9 Ohms,
e) $C^2_1\cdot X_{2k}$ =$1{,}06^2\cdot 19{,}21$=21,58 Ohms,

The substitution scheme shown in Figure 1 and its designated parameters R_0, X_0, R_1, R_2, X_1, X'_2 are adopted for calculating and analyzing the mechanical characteristics of the asynchronous generator, which are constant, independent of the rotor's slippage [7, 8].

MECHANICAL CHARACTERISTIC OF AN ASYNCHRONOUS MACHINE

It is known that the dependence of the electromagnetic moment Mem is determined by the formula applicable to the substitution circuit shown in Figure 1:

$$M_{em} = \frac{m\cdot p\cdot U_f^2\cdot \frac{R_2}{s}}{\omega_1\left[(R_1+C_1\cdot\frac{R_2}{s})^2+C_1\cdot X_{2k}^2\right]} \quad (3)$$

where m=3 is the number of phases of the asynchronous machine;

p=2 - number of pole pairs for the AIML71V4UZ asynchronous machine;

U_p=220 V - nominal phase voltage;

R_2 = 8.80 Ohm - active resistance of the rotor winding;
ω_1= 2πf = 2·3,14·50=3,14 - angular frequency at the network frequency f=50 Hz;
R_1=10.48 Ohm - active resistance of the stator winding;
X_{2k}=19.21 Ohm - inductive resistance of the rotor winding;
C_1 = 1.06 is the modulus of the coefficient for bringing the stator parameters to the rotor circuit of the G-shaped replacement circuit.

Based on the dependence (2.3), the calculation of the electromagnetic torque of the asynchronous machine was performed at a constant phase voltage of U_p=220 V and constant parameters of the substitution circuit.

For comparison, the nominal data were calculated.

The slip in the nominal mode of the asynchronous motor is determined

$$S_n = \frac{n_1 - n_2}{n_1} = 0{,}07 \tag{4}$$

The rotor torque in nominal mode is determined by

$$M_n = \frac{9550 \cdot P_n}{n_n} = \frac{9550 \cdot 0{,}75}{1395} = 5{,}13\ N \cdot m \tag{5}$$

Based on the calculated data, a graph of the mechanical characteristics of the asynchronous machine, presented in Figure 2, was constructed.

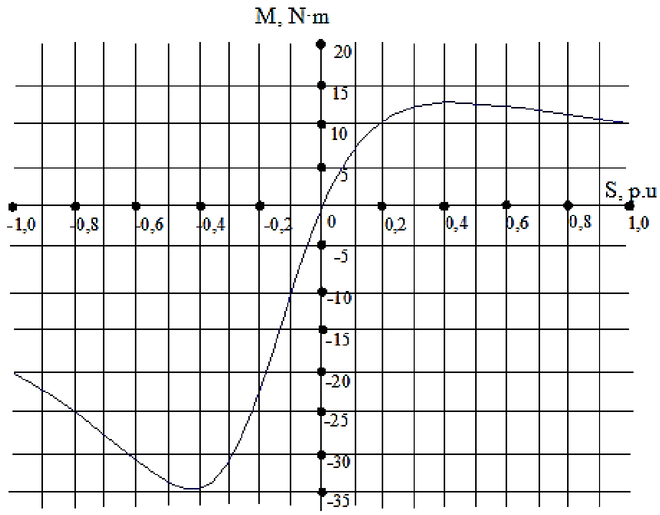

Figure 2 - Calculated mechanical characteristic of the asynchronous AIML71V4UZ machines

The engine mode corresponds to a change in slip from zero to one, and the generator mode corresponds to a change from zero to minus infinity. However, for practical use, the generator characteristics are of interest only within the range of the slip change from zero to minus one, which is reflected in Figure 2 [9, 10].

RESEARCH RESULTS

The mechanical characteristic has critical moment values both in the engine mode $+M_{cr}$ and in the generator mode $-M_{cr}$. Therefore, the load on the asynchronous machine can be within $\pm M_{cr}$.

The critical values of the slip S_{cr} and the moment M_{cr} are determined by formulas (6, 7) and have the following values for the ASIML71V4UZ asynchronous machine:

$$S_{cr} = \frac{C_1 \cdot R_2}{\sqrt{R_1^2 + C_1 \cdot X_k^2}} = \pm \frac{1{,}06 \cdot 8{,}8}{\sqrt{10{,}48^2 + 1{,}1 \cdot 19{,}21^2}} = \pm 0{,}42 \tag{6}$$

$$M_{cr} = \pm \frac{m \cdot p \cdot U_f^2}{2 \cdot C_1 \cdot \omega_1 \left[\pm R_1 + \sqrt{R_1^2 + C_1 \cdot X_k^2} \right]} \tag{7}$$

In the given formulas, the "plus" sign refers to the determination of a quantity for the engine mode, and the "minus" sign for the generator mode. It should be noted that the critical values of the moment differ in absolute value: for the motor $M_{cr.mot}$ = +12.66 N·m, for the generator $M_{cr.gen}$ = -34.40 N·m.

The operation of an asynchronous machine within ± M_{cr} has a stable nature of operation. The values of ±M_{cr} determine the stability limits. The nominal torque value of an asynchronous machine is selected approximately twice less than the critical value M_{cr} to ensure the machine's overloading capacity.

Calculations showed that the critical value of the torque in the generator mode is 2.68 times greater than the critical value in the motor mode in absolute value. The ratio of critical moments can be expressed by the formula [11, 12]:

$$m_{cr} = \frac{M_{cr.gen}}{M_{cr.mot}} = \frac{\sqrt{R_1^2+C_1 \cdot X_k^2}+R_1}{\sqrt{R_1^2+C_1 \cdot X_k^2}-R_1} \quad (8)$$

This ratio depends on the parameters of the substitution circuit R_1 and X_k, but does not depend on the active resistance of the rotor R_2. Consequently, when an additional resistance is introduced into the rotor circuit, the ratio (3) does not change its value [13, 14, 15].

CONCLUSIONS

1. The critical value of the asynchronous machine's torque in generator mode is several times greater than the corresponding critical value of the torque in motor mode. Consequently, when selecting an asynchronous motor by nominal torque to switch it to generator mode, its overloading capacity in generator mode can always be considered quite sufficient.
2. The multiplicity of the increase in the critical moment of the asynchronous machine in generator mode depends on the parameters of the substitution circuit R_1 and X_k and does not depend on the resistance of the rotor R_2. Consequently, when an active resistance is introduced into the rotor circuit, the multiplicity of the critical values does not change.
3. As can be seen from the mechanical characteristics, this critical moment ratio is also maintained for the nominal moments of the asynchronous machine in the generator and motor modes, thereby ensuring stable operation in the generator mode with a load exceeding the nominal power values of the motor mode.

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