Optimal Parameter Determination Asynchronous Traction Engine to Improve Operating Performance

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Abstract: Increasing the energy performance of rolling stock is one of the most relevant railway transport. One of the ways to achieve these tasks is to determine the optimal parameters of the traction drive of the rolling stock, with which you can create computer simulation models. In this article, the optimal parameters of an asynchronous traction motor of an electric rolling stock are determined. Determination of the parameters of the ATM is necessary to create a computer simulation model that allows reproducing electromagnetic processes in a traction electric drive and converters, as well as processing functions of the simulation results obtained that are adequate to the real conditions of use on electric rolling stock of converters with various control algorithms in traction and regenerative braking modes. In the article, the modes of idling, short circuit and rated load are used to determine the parameters of the ATM in relation to the T-shaped replacement circuit using the method of separation of losses in the engine. Losses in traction converters and traction gearboxes are taken into account in accordance with the power developed by the ATM. The results obtained can be used in a computer simulation model designed to reproduce electromagnetic processes in a traction electric drive and converters, when determining the energy characteristics of electric locomotives with asynchronous traction motors.

1 INTRODUCTION

In the years after independence, the construction of new and electrification of existing railways has been developing rapidly in the Republic of Uzbekistan [1-5]. To date, the whole republic is permeated with threads of railways that make up about 6.15 thousand km, of which 1,783 thousand km have been electrified. To replace the outdated electric locomotives of the “VL” series with collector traction motors, electric locomotives of the “O'zbekiston” series produced by “P.R.China” with asynchronous traction motors (ATM) were brought. The new family of electric locomotives are characterized by greater power and high efficiency due to ATM, which are controlled by “GTO” thyristors for the first generation of electric locomotives and “IGBT” transistors for subsequent ones. For passenger high-speed traffic up to 160 km/h, electric locomotives “O'zbekiston Yo'lovchi” are operated, shown in Figure 1.

One of the urgent problems of railway transport is to increase the energy performance of rolling stock. To achieve these goals, it is necessary to determine the characteristics of the traction drive, as well as to create a computer model to simulate electromagnetic processes in converters and electric drives. Losses and expenses of electric locomotive electricity can be determined only by analytical methods.

Figure 1: Electric locomotive "O'zbekiston Yo'lovchi".

2 METHODS AND MATERIALS

The determination of the parameters of the ATM windings is mostly complicated by the technical conditions of the test modes. Based on the no-load and short-circuit modes, by the method of separation of losses in the rated load mode, it is possible to determine analytically the parameters of the ATM active resistance, the inductance of scattering of the stator and rotor windings, losses in steel, in stator copper and mechanical losses.

The method of analytical calculation was used with further development of a model of a traction asynchronous motor in the MATLAB Simulink package. The resistance of the stator phase windings in this case is determined by the loss power ΔP_{smn} in copper at rated load [6-10], (ohms)

$$r_s = \frac{\Delta P_{SM.N}}{3 I_{SN}^2}, \quad (1)$$

where I_{sn}- is the current of the stator phase in the nominal mode.

We determine the power loss in the copper of the stator at rated load by the formula (W)

$$\Delta P_{sm.n} = \frac{P_n \times 10^3}{\eta_n}\left(1 - (\eta_n + s_n)\right) - (\Delta P_{mech.n} + \Delta P_{s.ct.n} + \Delta P_{s.dm}). \quad (2)$$

where s_n is the sliding of the rotor in the rated load mode, P_n is the power of the rated mode, $\eta_н$ is the efficiency of the rated mode, $\Delta P_{s.ct.n}$ is the power of losses in the stator steel in the rated load mode, $\Delta P_{mech.n}$ is the power of mechanical losses in the rated load mode, $\Delta P_{s.dm}$ is the power of additional losses in the stator copper due to the spatial harmonics of the stator current.

The power of mechanical losses in the rated load mode can be taken $\Delta P_{mech.n} = 0{,}002 \frac{P_n}{\eta_n} \times 10^3$ (W), the power of additional losses from spatial harmonics of the current $\Delta P_{s.dm} = 0{,}005 \frac{P_N}{\eta_N} \times 10^3$W.

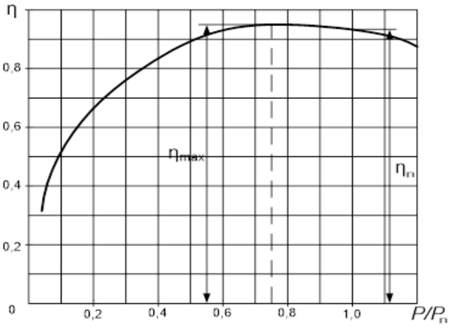

Figure 2: Dependence of the efficiency of the ATM on the load.

The power of losses in steel in the rated load mode is almost equal to the power of losses in steel for the rated load mode [11]. The latter can be determined from the condition of equality of the main losses in steel and copper of the stator at the maximum efficiency of the motor n_{max} corresponding to the mode of the rated load [12-16] (Figure.2), (W):

$$\Delta P_{s.ct.\frac{3}{4}} = \frac{3}{4 \times 2} \frac{P_n \times 10^3}{\eta_{max}} (1 - \eta_{max}) - (\Delta P_{mech.\frac{3}{4}} + \Delta P_{sdm}). \quad (3)$$

Mechanical losses at the nominal rotor speed practically do not depend on the load, therefore, it can be assumed with sufficient accuracy that $\Delta P_{mech.3/4} = \Delta P_{mech.n}$.

The resistance of the rotor, reduced to the resistance of the stator phase, can be calculated by the power of losses in the rotor at nominal slip and the reduced rotor current I'_{rn} (ohms):

$$r'_r = \frac{P_n \times 10^3 \times s_n}{3 {I'_{rn}}^2}. \quad (4)$$

We find the rotor current reduced to the stator current for the rated load mode according to the formula (A):

$$I'_{rn} = I_{sn} \sqrt{1 - \left(\frac{I_{s0}}{I_{sn}}\right)^2 - \frac{I_{s0}}{I_{sn} 2 b_n}}. \quad (5)$$

In which $I_{s0}$is the idling current of the ATM at the rated voltage and the rated frequency of the stator current, b_n is the multiplicity of the greatest electromagnetic moment.

The value of $b_n$is determined by the rated load mode and the inductive short-circuit resistance $X_k$of the motor:

$$b_n = \frac{U_{sn}^2 (1 - s_n)}{\sqrt{3} \times 2 c_1 (P_n \times 10^3 + \Delta P_{mech.n}) X_k}, \quad (6)$$

where c_1 is the coefficient of reduction of the parameters of the ATM windings to the G-shaped substitution scheme.

The total short-circuit resistance for the ATM stator phase is determined by the multiplicity of the short-circuit current $K_{1s/c}$=7-8 (ohms), equal to:

$$Z_k = \sqrt{X_k^2 + (c_1 r_k)^2} = \frac{U_{sn}}{\sqrt{3} I_{sn} K_{1s/c}}, \quad (7)$$

here r_k is the short circuit resistance of the motor, $r_k = r_s + r_r'$.

The inductive resistance of a short circuit can be determined from the formula (ohms):

$$X_k = Z_k \sqrt{1 - cos^2 \varphi_{s/c}}. \quad (8)$$

In which $cos\ \varphi_{s/c}$ is the motor power factor for the short circuit mode, we preliminarily accept $cos\ \varphi_{s/c} = 0{,}15{\sim}0{,}2$.

Idle current ATM (A):

$$I_{s0} \approx I_{sn}(sin\varphi_{sn} - \frac{cos\varphi_{sn}}{2b_n}), \qquad (9)$$

where $\cos\varphi_{sn}$ is the engine power factor for the rated mode.

After performing calculations according to (1) – (9), the values of $r'_r, X_k, c_1 \approx 1 + \frac{Z_k}{2Z_0}$ should be clarified and the refined calculation of the active and inductive resistances of the stator and rotor of the ATM should be repeated.

From the experience of designing an ATM with a capacity of 1-1.3 MW, the ratio of the stator phase scattering inductance and the reduced rotor phase scattering inductance in relative units is 1: 0.8.

Stator phase scattering inductance ($L_{s\sigma}$ (H)):

$$L_{s\sigma} = \frac{X_k}{1{,}8\times 2\pi\times f_{sn}}, \qquad (10)$$

where f_{sn} is the frequency of the stator voltage in the nominal mode.

The rotor phase scattering inductance ($L'_{r\sigma}$(H)) reduced to the stator phase is equal to:

$$L'_{r\sigma} = \frac{X_k\times 0{,}8}{1{,}8\times 2\pi\times f_{sn}}. \qquad (11)$$

The total resistance of the motor phase in idle mode (Z_0, ohms) :

$$Z_0 = \frac{U_{sn}}{\sqrt{3}\times I_{s0}}. \qquad (12)$$

Active component of the no-load current of the stator phase, (I_{s0a}, (A)) :

$$I_{s0a} = \frac{\Delta P_{s.ct.3/4} + (r_s\times I_{s0}^2) + \Delta P_{s.dm} + \Delta P_{mech.n}}{\sqrt{3}\times U_{sn}}. \qquad (13)$$

Magnetization current of the stator phase, (I_μ, A)):

$$I_\mu = \sqrt{I_{s0}^2 - I_{s0a}^2}. \qquad (14)$$

The mutual induction resistance (X_μ, ohms) of the stator and rotor phase windings is calculated by the (15):

$$X_\mu = \frac{U_{sn}}{\sqrt{3}\times I_\mu} - X_{s\sigma}. \qquad (15)$$

In which $X_{s\sigma}$ is the inductance resistance of the stator phase scattering, $X_{s\sigma} = 2\pi f_{sn} L_{s\sigma}$.

The mutual inductance of the stator and rotor phase winding, reduced to the stator (L_μ, H) is equal to:

$$L_\mu = \frac{X_\mu}{2\pi f_{sn}}. \qquad (16)$$

3 RESULTS AND DISCUSSION

Based on formulas (10) - (16), the calculation of the main parameters of the ATM "1TB2624–0GA02" used on electric locomotives "O'zbekiston Yo'lovchi" was performed. Passport data, design parameters and electrical values characterizing the operating modes of ATM "1TB2624–0GA02" are given in Table 1 and Table 2.

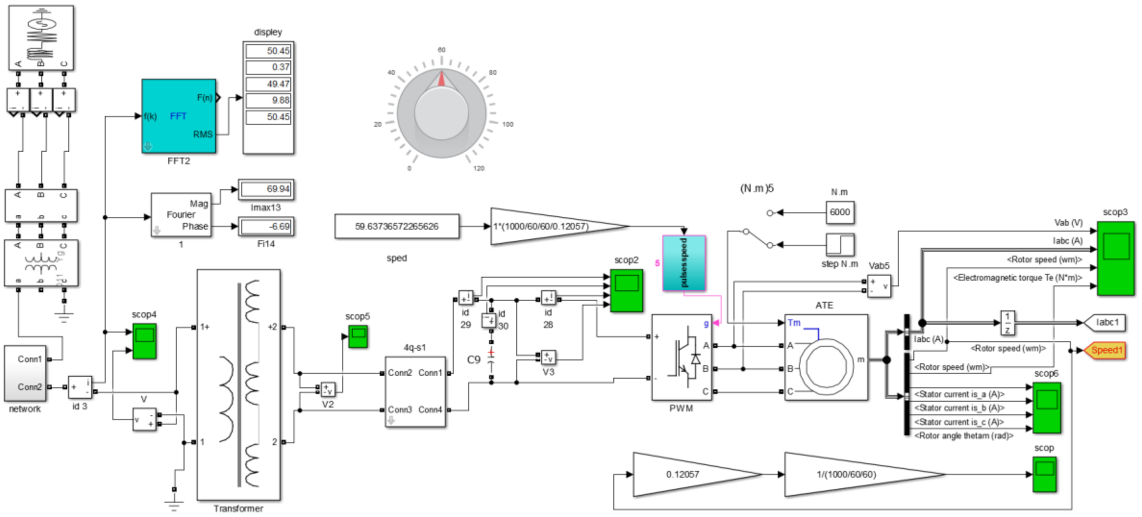

Figure 3: Computer model of an AC electric locomotive of a series "O'zbekiston Yo'lovchi" with 4q-S converters and automatic control system.

Table 1. Passport data of ATM "1TB2624-0GA02".

Parameters	Designation	Meaning
Rated power, kW	P_H	1020
Rotation speed, rpm	n_n	1484
Rated line voltage, V	U_{sn}	2063
Rated current, A	I_{sn}	330
Power factor at 100% load	$\cos \phi_{sn}$	0,85
Efficiency factor	η_n	0,95
Rated frequency of the stator current, Hz	f_{sn}	50
Number of pole pairs	p	2
Nominal rotor slip	s_n	0,011

Based on the data obtained, a mathematical model of the power supply and control scheme of the traction asynchronous motor "1TB2624-0GA02" of the electric locomotive "O'zbekiston Yo'lovchi" was created in the MATLAB Simulink software package, which is shown in Figure 3.

Simulation processes were performed at the voltage of the feeders of the traction substation of 27.5 kV and the greatest distance from the substation at 20 km, which corresponds to the equivalent electrical resistance of the network for a distance of 10 km with two-way power supply. The voltage of the DC link (output filters 4q-S of the converter) is taken equal to U_{dc}=2800 V. The load of the ATM was set by the value of the moment of resistance from $0.25M_{sn}$ to $1.25M_{sn}$ at a nominal frequency of the stator voltage of 50 Hz. Oscillograms of the stator voltage, stator currents, rotor speed, electromagnetic torque of ATM at rated load are shown in Figure 4.

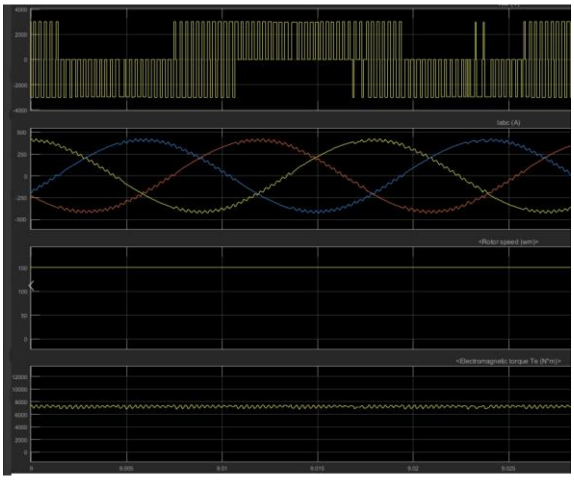

Figure 4: Oscillograms of stator voltage, stator currents, rotor speed, electromagnetic torque of ATM at rated load.

Table 2. Design parameters and basic electrical values of the ATM "1TB2624 – 0GA02".

Parameters and data	Designa-tion	Meaning
Loss power in the copper of the stator at rated load, W	$\Delta P_{sm.n}$	20132
The power of mechanical losses in the rated load mode, In	$\Delta P_{mech.n}$	2147
Power of additional losses from spatial harmonics of current, W	$\Delta P_{s.dm}$	5368
The power of losses in steel in the mode of ¾ of the rated load, W	$\Delta P_{s.ct.3/4}$	12616
The power loss in the rotor copper at rated load, W	$\Delta P_{rm.n}$	21742
Resistance of the stator phase windings, Ohms	r_s	0,059
The resistance of the rotor, reduced to the resistance of the stator phase, Ohms	r'_r	0,0337
Multiplicity of the greatest electromagnetic moment	b_n	1,9
Total short-circuit resistance, Ohms	Z_k	0,487
Inductive short-circuit resistance, Ohms	X_k	0,478
Inductive resistance of the stator phase scattering flows, Ohms	$X_{s\sigma}$	0,265
Inductive resistance of the rotor scattering flows reduced to the stator phase, Ohms	$X'_{r\sigma}$	0.212
Stator phase scattering inductance, H	$L_{s\sigma}$	0,0009181
The inductance of the scattering of the rotor phase, reduced to the stator phase, H	$L'_{r\sigma}$	0,0007345
The total resistance of the motor phase in idle mode, Ohms	Z_0	12,2017
Coefficient of reduction of winding parameters to the L-shaped substitution scheme	c_1	1,023
The rotor current reduced to the stator current for the rated load mode, A	I'_{rn}	349
Idle current, A	I_{s0}	99,12
The active component of the idle current of the stator phase, A	I_{s0a}	5,797
The magnetization current of the stator phase, A	I_{μ}	98,949
Inductive resistance of mutual induction of the stator and rotor phase windings, Ohms	X_{μ}	11,772
Mutual inductance of the stator and rotor, brought to the stator (magnetization inductance), H	L_{μ}	0,041

4 CONCLUSIONS

The study and development of ways to improve the energy efficiency of rolling stock is relevant. To increase the energy efficiency of rolling stock, it is necessary to determine the characteristics of the traction drive, as well as to create a computer model for modeling electromagnetic processes in converters and electric drives. Losses and costs of electric locomotive electricity can be determined only by analytical methods. Based on the results obtained, the following conclusions were made:

1) A method has been developed for calculating the parameters of the ATM based on experiments of idling and short circuit using computer modeling. Based on the results obtained from the experiment, the following conclusions were made. The analytical parameters in the Mathcad program were determined, which made it possible to improve the performance characteristics and choose the optimal operating modes of asynchronous traction motors.
2) The complex simulation computer model of an AC electric locomotive of a series "O'zbekiston Yo'lovchi" with 4q-S converters and automatic control system has been developed, allowing to conduct research of electromagnetic processes in power circuits.
3) The design parameters and electrical values are determined for the optimal operating modes of the ATM series "1TB2624–0GA02"electric locomotive of the series "O'zbekiston Yo'lovchi".

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