Energy efficiency calculation of traction asynchronous motor with impulse supplying using finite element modeling of electromagnetic field

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Abstract: **Based on different methods, increasing of losses in asynchronous motor with impulse voltage supplying is defined.**

Keywords: **Asynchronous motor, additional losses, losses increase coefficient, impulse voltage supplying.**

Now, asynchronous motors (AM) are widespread in different applications. AM are often supplied from impulse voltage source. For example it may be a frequency converter with pulse width voltage modulation. Output impulse voltage contains a spectrum of higher harmonics. It causes additional losses in windings and steel in AM [1]. Calculating of additional losses is actually, because it may help in increasing of energy efficiency of AM being supplied by an impulse voltage source.

The main forms of impulse voltage are shown in Fig.1.

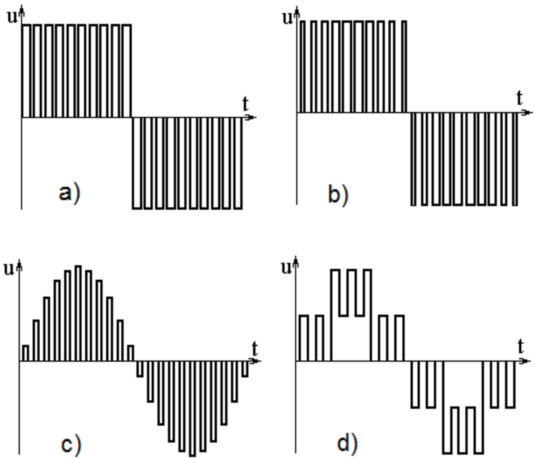

Fig. 1. The main forms of impulse voltage: constant width of impulses (a); sinusoidal width of impulses (b); sinusoidal height of impulses (c); impulse-step height of impulses.

Parameters of impulse voltage are pulse ratio (γ) and number of impulses on a half-cycle (N).

Assume that resistances of rotor and stator windings for different harmonics are proportional to number of harmonic and their self inductance are not depends on number of harmonic. In this case coefficients of electrical losses increase may be found from formula (1); coefficient of steel losses increase – from (2); coefficient of total losses increase – from (3) [1].

$$K_{el1} = 1 + K_I \cdot \sum_{\nu=5}^{\infty} \left[\frac{1}{\nu} \left(\frac{U_\nu}{U_1} \right)^2 \right] \tag{1}$$

$$K_{st1} = 1 + K_{hight.harm} \cdot \sum_{\nu=5}^{\infty} \left[\frac{1}{\nu^{0.7}} \left(\frac{U_\nu}{U_1} \right)^2 \right] \tag{2}$$

$$K_{sum1} = \frac{P_{el.nom}}{P_{sum.nom}} \cdot K_{el} + \frac{P_{st.nom}}{P_{sum.nom}} \cdot K_{st} \tag{3}$$

where K_I – rate of starting current; $K_{hight.harm}=2\div3$ – the factor considering increase of losses in a steel at magnetic reversal on partial cycles; U_1 and U_ν – amplitude of the first and ν harmonics; $P_{el.nom}$, $P_{st.nom}$ and $P_{summ.nom}$ – electric losses, losses in steel and total losses in the rated operation.

However, we can use more accurate dependences of resistance and inductive reactance of frequency (shown in Fig 2). These dependences founded using the finite element method for calculating of the electromagnetic field for different frequencies. Coefficient of losses increase in this case (assuming that the resistance of stator winding is constant) may be found from (4).

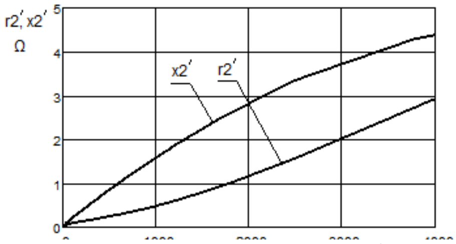

Fig. 2. Resistance and inductive reactance of rotor winding

$$K_{el2} = \frac{P_{el.nom} + \sum_{\nu=5}^{\infty} \frac{3 \cdot U_\nu^{\,2} \left(R_1 + R'_{2\nu}\right)}{2 \cdot \left[\left(R_1 + R'_{2\nu}\right)^2 + \left(X_1 + X'_{2\nu}\right)^2\right]}}{P_{el.nom}} \tag{4}$$

In addition, based on finite element modeling of electromagnetic field on AM pole pitch losses increase coefficients (K_{el3}, K_{st3}, K_{sum3}) are calculated . All results of calculating for AM (170 kW, N=10, γ=0,542) given in table I (η_1, η_2, η_3 – coefficients of efficiency calculated by different methods).

TABLE I
COEFFICIENTS OF LOSSES INCREASE

Form of voltage	Constant width	Sinusoidal width	Sinusoidal height	Impulse-step height
K_{el1}	3,106	1,660	2,685	2,132
$K_{el.2}$	1,892	1,266	1,663	1,497
$K_{el.3}$	1,934	1,261	1,446	1,830
K_{st1}	1,237	1,087	1,218	1,120
K_{st3}	1,570	1,061	1,145	0,861
K_{sum1}	2,808	1,569	2,451	1,971
K_{sum2}	1,787	1,237	1,592	1,437
K_{sum3}	1,867	1,224	1,391	1,652
η_1	0,818	0,885	0,836	0,862
η_2	0,873	0,905	0,884	0,893
η_3	0,873	0,909	0,899	0,884

Work is performed within the contract with the Ministry of Education and Science of the RF 02.G25.31.0049.

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