

Estimating the Technological Deviation Impact on the Value of the Output Parameter of the Induction Converter

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Abstract—Based on the experimental data, the impact of resistance and reactance of the winding, as well as the magnetic permeability of the magnetic circuit steel material on the value of the electromotive force of the induction converter is investigated. The obtained results allow estimating the main technological spreads and determining the maximum level of the electromotive force change. By the method of experiment planning, the expression of a polynomial for the electromotive force which can be used to estimate the adequacy of mathematical models to be used at the investigation and design of induction converters is obtained.

Keywords—Induction converter, electromotive force, expectation, technological spread, deviation, planning an experiment, polynomial, confidence level.

I. INTRODUCTION

At present, in connection with development of electric power systems, as well as systems of automatic control, automatics and a number of trends of modern equipment development, the interest towards the problems of investigation and improvement of the induction converters is continually increasing. The operation of an induction converter proceeds under complicated conditions since the object of measurement is as a rule, a complicated, versatile process characterized by a great number of parameters, each of which influences the induction converter together with other parameters. Here, we are interested only in one parameter which we call a measured value, while all the other parameters of the process are considered by us to be interference [1], [2].

The performed analysis of the existing investigation methods aimed at investigating and designing more improved induction converters has shown that they do not allow to efficiently estimate the characteristics of electromagnetic parameters of the induction converter at different technological deviations [3]-[5].

II. THE CURRENT STATE OF THE PROBLEM

The operation of an induction converter is based on the application of electromagnetic induction according to which, the electromotive force (EMF) in the circuit is determined by:

$$e = -d\psi/dt, \quad (1)$$

where ψ is the magnetic-flux linkage with the circuit.

So, the output value of the induction converter is the EMF, and the input one is the speed of the change of the magnetic-flux linkage. Based on what was said above, for the complex estimation of the parameters, and the operating characteristics of the converter, we will investigate the change of its EMF.

It is well-known that the error of the measurement results adds up from systematic and random components [6]:

$$\delta = \delta_{sys} + \delta_{rand}, \quad (2)$$

$$\delta_{sys} = \delta_m + \delta_{inst} + \delta_{sub}, \quad (3)$$

where δ_m is the error conditioned by the approximation degree of mathematical description; δ_{inst} the instrument error; δ_{sub} the subjective errors related to the individual peculiarities and the observer's qualification.

The random errors are determined in the form:

$$\delta_{rand} = \delta_f + \delta_t + \delta_e, \quad (4)$$

where δ_f is the error connected with the random factors at carrying out series of uniform experiments on the model; δ_t , the error connected with the random technological spreads of parameters and characteristics; δ_e , the error conditioned by systematic errors of experimental methods for determining the parameters of the studied model.

Considering that the main peculiarity of errors is their unpredictability from one reading to the other, the methods of the probability theory and mathematical statistics are applied at describing the random error [7].

For the purpose of minimizing the systematic error conditioned by the mathematical model approximation degree, the non-uniform distribution of induction along the magnetic circuit is taken into consideration [8], and the optimal values of the winding wire diameter, the number of turns, the section and the average length of the magnetic circuit providing the minimum angular, current and amplitude –frequency errors are determined [8].

In the developed mathematical model of an induction converter [8], a special attention is paid to the determination of the admissible deviation of the EMF at shifting the position of

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the current conductor in the magnetic circuit window, and changing the gap size which may cause random errors. However, there are several unavoidable errors which are typical of the well-known methods aimed at investigating and designing more perfect induction converters, and which should be estimated and considered in calculations:

- the value of the material's magnetic permeability can considerably change not only at different lots of the material of one trademark, but also in separate items in the same lot.
- the resistance value of the winding can change at the same number of turns which is connected with the technology of making the winding.

Thus, it becomes obvious that despite the observed impact of technological deviations on the output parameter, its quantitative evaluation is not available. Based on what was mentioned above, estimating the technological deviation impact on the value of the converter's electromotive force is an urgent task.

III. THE INVESTIGATION GOAL AND THE SUBSTANTIATION METHOD

The goal of the work is to estimate the impact of technological deviations on the value of an induction converter electromotive force.

Considering that at maintaining a contactless current measuring device, a change in the output value of the induction converter is observed, to solve the set task by the method of experiment planning, a polynomial of the EMF is obtained.

To estimate the technological parameter impact on the investigation results, and the calculations of the induction converter, first of all, the spread of the winding's resistance and reactance, as well as the magnetic permeability of the magnetic circuit steel material were determined.

IV. THE INVESTIGATION RESULTS

Measurements of the winding resistance and reactance, as well as the magnetic permeability of the magnetic circuit steel material are carried out on 15 induction converters (Table I). To process the results of observation [9], [10] in accordance with the experimental data introduced in the table, the expectation of random values is used. In this case, these values are the winding resistance and reactance, the magnetic permeability of the magnetic circuit material:

$$M(R_2) = \sum_{k=1}^N n_k R_{2k} / N, \quad (5)$$

$$M(L) = \sum_{k=1}^N n_k L_k / N, \quad (6)$$

$$M(\mu) = \sum_{k=1}^N n_k \mu_k / N, \quad (7)$$

where N is the number of independent experiments; n the quantity of repeated results.

Assuming that the random values R_2, L, μ are distributed by normal law, the spread of the observed parameters can be determined in the form [7], [11]:

$$\Delta = t(N) \frac{\sigma}{\sqrt{N}}, \quad (8)$$

where σ is the standard deviation; $t(N)$ - the Student's coefficient.

Thus, the spread at confidence level of 0,99 will be:

- for the resistance of the winding - $\Delta_{R_2} = 3,475\%$;
- for inductive impedance of the winding - $\Delta_L = 0,65\%$;
- for the magnetic circuit steel permeability - $\Delta_\mu = 2,1\%$.

To estimate the impact of technological spreads on the results of the EMF E at different values of the measured current, the results of experimental data are used.

TABLE I
EXPERIMENTAL DATA OF THE WINDING RESISTANCE AND REACTANCE, AS WELL AS THE MAGNETIC PERMEABILITY OF THE MAGNETIC CIRCUIT STEEL MATERIAL

N	Resistance R_2, Om	Inductive Impedance L, Hn	The magnetic circuit steel permeability μ
1	202	0,623	0,0142
2	200	0,621	0,0143
3	200	0,6225	0,0143
4	202	0,623	0,01425
5	202	0,6225	0,01435
6	200	0,626	0,0143
7	204	0,626	0,0143
8	199	0,624	0,0143
9	201	0,621	0,01445
10	204	0,622	0,0145
11	203	0,624	0,0140
12	205	0,621	0,0143
13	209	0,621	0,01425
14	195	0,580	0,01425
15	204	0,621	0,01465
<hr/>			
$M(R_2) = 202$		$M(L) = 0,622$	$M(\mu) = 0,0143$
$\sigma(R_2) = 9,09$		$\sigma(L) = 0,0052$	$\sigma(\mu) = 0,000399$
$\Delta_{R_2} = 7,0$		$\Delta_L = 0,004$	$\Delta_\mu = 0,0003$

The experiment was carried out on the model of the induction converter constructed according to the design data. The determining factors R_2, L, μ varied in the range corresponding to the design data of the spreads.

As basic values R_2, L, μ expectations corresponding to them were used, as they coincide with the centre coordinates of distribution of these values

$$R_2 \pm \Delta_{R_2} = 202 \pm 7;$$

$$L \pm \Delta_L = 0,622 \pm 0,004;$$

$$\mu \pm \Delta_\mu = 0,0143 \pm 0,003.$$

To investigate the impact of technological spreads on the result of the EMF E , the method of the experiment planning [10] is used. The polynomial for E has the form:

$$E = \beta_0 + \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_1 Z_2 + \beta_5 Z_1 Z_3 + \beta_6 Z_2 Z_3 + \beta_7 Z_1 Z_2 Z_3, \quad (9)$$

where Z_1, Z_2, Z_3 are the coded factors; $\beta_0, \beta_1, \dots, \beta_7$ - polynomial coefficients.

The polynomial coefficients are determined by:

$$\beta_i = \frac{1}{N} \sum_{k=1}^N Z_{ik} E_k, \quad (10)$$

where E_k is the studied EMF of the converter; N - the number of the experiments carried out; k - the ordinal number of the experiment.

The value of coefficients β_i is estimated by the criterion which, for each coefficient, is determined through:

$$T_i = \frac{N\beta_i^2}{\sigma_1^2[E]}, \quad (11)$$

where $\sigma_1^2[E]$ is the residual variance:

$$\sigma_1^2[E] = \frac{1}{f_1} \sum_{k=1}^N (E_k^2 - N\beta_i^2), \quad (12)$$

and is compared with the tabular quantiles of Student's distribution [12], at the freedom degree $f_1 = 8$ and the confidence level 0,95 respectively. If $T_i > T_{tab} = 1,86$, the coefficient β_i is recognized as significant, otherwise - insignificant. In Table II, the significant coefficients are marked with an asterisk.

The adequacy of polynomials is checked by Fisher's criterion, for what, the mean values of the zero level \bar{E} are found in the data of the experiments 9-13 (see Table II) and the experiment dispersion:

$$\bar{E} = \frac{1}{5} \sum_{k=9}^{13} E_k, \quad (13)$$

$$\sigma_2^2[E] = \frac{1}{4} \sum_{k=9}^{13} (E_k - \bar{E})^2. \quad (14)$$

Then, to estimate the differences between $\sigma_1^2[E]$ and $\sigma_2^2[E]$, the dispersion ratio is calculated:

$$F = \frac{\sigma_1^2[E]}{\sigma_2^2[E]}. \quad (15)$$

According to the tables presented in [12], for the number of the freedom degree of the numerator $f_1 = 8$ and the denominator $f_2 = 4$, we find that at confidence level 0,95, the dispersion ratio is:

$$F = 6,04$$

TABLE II
THE PLANNING MATRIX AND EXPERIMENTAL DATA

k	Factors								Responses	
	Z_0	Z_1	Z_2	Z_3	$Z_1 Z_2$	$Z_1 Z_3$	$Z_2 Z_3$	$Z_1 Z_2 Z_3$	$E(V)$ when $I_1 = 1000A$	$E(V)$ when $I_1 = 20A$
1	+	-	-	-	+	+	+	-	151	26,2
2	+	+	-	-	-	-	+	+	160	26,8
3	+	-	+	-	-	+	-	+	155	26,7
4	+	+	+	-	+	-	-	-	158	27,2
5	+	-	-	+	+	-	-	+	162	27,5
6	+	+	-	+	-	+	-	-	164	28,0
7	+	-	+	+	-	-	+	-	172	29,0
8	+	+	+	+	+	+	+	+	165	28,3
9	0	0	0	0	0	0	0	0	164,5	27,35
10	0	0	0	0	0	0	0	0	163,5	27,3
11	0	0	0	0	0	0	0	0	164,8	27,2
12	0	0	0	0	0	0	0	0	164	27,28
13	0	0	0	0	0	0	0	0	164	27,26
Values	The equation coefficients								Mean values	
									164,16	27,278
$E, I_1 = 1000A$	160,87 5*	0,87*	1,6*	4,8*	-1,875*	-2,125*	1,125*	-0,375*	$\sigma_1^2[E] = 0,81$; $\sigma_2^2[E] = 0,253$	
$E, I_1 = 20A$	27,462 *	0,1125 *	0,33*	0,7375 *	-0,1625*	-0,1625*	0,1125*	-0,1375*	$\sigma_1^2[E] = 0,0051$; $\sigma_2^2[E] = 0,003039$	

Testing for the polynomial adequacy for the EMF at different values of the measured current shows that the polynomial accuracy corresponds to the experiment data.

To find out the range of the change in the value E at the impact of technological spreads, it is necessary to find the confidence interval. In this case, the value E should be in the range of the confidence interval:

$$M[E] - k_1 \frac{\sigma_1[E]}{\sqrt{N}} < E < M[E] + k_2 \frac{\sigma_1[E]}{\sqrt{N}}, \quad (16)$$

where $M[E]$ is the expectation.

To determine the coefficients k_1 and k_2 , the normal law of distribution is selected as the obliqueness and slope sizes of the distribution curve E is equal to zero. In that case, we have:

$$k_1 = k_2 = -\arg \Phi[0,5(1+P)], \quad (17)$$

where Φ is the function of the normal distribution; P - is the confidence level.

According to the set confidence level $P = 0,95$ from the table presented in [12] we find out:

$$k_1 = k_2 = 2,52.$$

The confidence interval for several values of the measured current will be:

- at $I_1 = 1000 \text{ A}$ - $155,2 < E < 166,6$;
- at $I_1 = 20 \text{ A}$ - $26,7096 < E < 28,22$.

The investigation results of the technological deviation impact on the value of the electromotive force show that the change in the EMF at the magnetic permeability and the resistance of the winding is not more than 4%.

V. CONCLUSION

1. The proposed method for estimating the technological deviation impact on the value of the EMF change allows estimating the main technological spreads, and determining the maximum level of the electromotive force change.
2. The obtained expression for the polynomial for the EMF can be used to estimate the adequacy of mathematical models at investigating and designing induction converters.

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