Using Average DC-Pulse Response of Stator Current forIdentification of Single -Phase Rotary Transformer Parameters

D. A. Khaburi, F. Tootoonchian
Electrical Engineering Department - Iran University of Science & Technology
Khuburi@IUST.ac.ir , Tootoonchian@IUST.ac.ir

Abstract--Because of temperature independence, highest resolution and noiseless outputs, rotary transformer together with brushless resolvers are widely used in high precision control systems. To apply efficient rotor position information to control algorithm, without any brushes noise, it is necessary to use rotary transformer. This paper is presented for parameter identification of rotary transformer that eliminates or reduces classic method disadvantages. It presents a DC-Pulse method based on a simple configuration, which increase estimated parameters accuracy and reduce time of test. On the other hand the classic method needs three or two tests to estimate parameters but proposed method needs just one test. Finally electrical parameters are estimated by comparing the average DC-Pulse current with current response function of mathematical curve fitting. Validation of the method and estimated parameters accuracy is performed by comparing experimental current test with simulation results.

Keywords: Rotary Transformer, Parameter Identification, Resolver

I. INTRODUCTION

ROTARY transformer is the most widely used where brushless signal transmission is necessary. Fig. 1-a shows the basic structure of tested rotary transformer in which a cylinder shaped magnet core with the primary coil is fixed inside the stator, while another bobbin magnet core with the secondary coil is fixed on the rotating shaft. A gap is provided between the primary and secondary coils in order to make them entirely non-contact with each other. A soft magnetic material is used for these cores to make the magnetic resistance small enough. Usually a sinusoidal AC electric energy is impressed on the primary coil and transmitted to the secondary coil instantaneously. Because of simple and sturdy structure of rotary transformer, it has been utilized for various purposes such as: Steering Roll Connectors (SRC), Resolvers, Non-contact Torque Sensors and etc. Recently developments in resolver to digital techniques have made it possible to use resolver without any additional hardware. Utilizing microcomputer can help us to define shaft position alone with a software subroutine. An efficient control algorithm necessitates knowing accurate rotor's position without any noise. Rotary transformer has the advantages such as completely noiseless operation and infinite rotating life. To identify resolvers output voltages, knowing rotary transformer's model and parameters is necessitate [1].

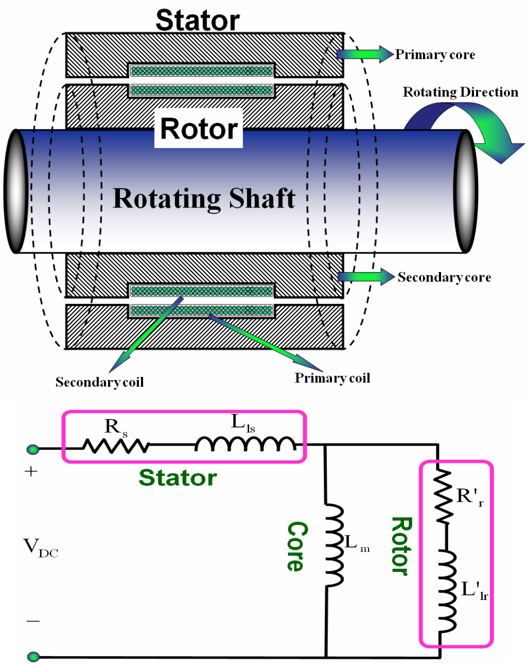
As in fig. 1-b rotary transformer's electrical equivalent circuit is similar to conventional transformer [2]. Therefore the methods used to identify conventional transformer's parameters, can be used with rotary transformer. In literature there are many methods for determination of transformer parameters that can be classified in groups: Classic method & new methods [2]. In the classic method parameters of transformer are estimated by well known short-circuit and no-load tests, that it has disadvantages like as:

1) Time consuming
2) Low accuracy

Equivalent circuit of rotary transformer is as same as induction motor [3-4]. So, the new methods are presented for elimination or reduction of classic method disadvantages in induction motors can be useful for rotary transformers too. Some of these methods are: genetic algorithms [5-6] or neural networks [7-9]. Other works are performed to improve the accuracy [10] and there are some works to reduce time of tests. Each of these methods has its advantages & disadvantages. This paper presents a DC-Pulse method based on a simple configuration, which increase estimated parameters accuracy and reduce time of test. In this method, rotary transformer's parameters are determined by analyzing the stator currents response to the DC-Pulse voltage, applied to the stator windings. An exponential curve is fitted to the stator current response in DC charge and discharge condition. Coefficients & time constants of these fitted curves can be determined. Then rotary transformer parameters will be calculated according to the related equations.

II. ROTARY TRANSFORMER MODEL

A rotary transformer relies on the induction of voltage and current in its rotor from the stator circuit. Based on the conventional transformer, the equivalent circuit of rotary transformer at standstill is shown in fig. 1-b. In this model core loss is omitted and would be considered along with winding losses. Note that the secondary tap of rotary transformer (rotor) is shorted and its parameters are referred to primary (stator) side.



(b)

Fig 1: (a) Basic structure of rotary transformer (b) Equivalent circuit of rotary transformer at standstill

If the stator winding of the rotary transformer is excited by a DC-Pulse voltage, the stator current transfer function based on the circuit model of fig. 1 can be obtained as follows:
Charge condition:

$$I_s(s) = |V_s| \cdot \frac{1}{r_{s1}} \cdot \frac{1 + T_{r1}s}{1 + (T_{r1} + T_{s1})s + (\sigma_1 T_{r1} T_{s1})s^2} \qquad (1\text{-a})$$

Discharge condition:

$$I_s(s) = |V_s| \cdot \frac{L_{s2}}{{r_{s2}}^2} \cdot \frac{1 + (\sigma_2 T_{r2})s}{1 + (T_{r2} + T_{s2})s + (\sigma_2 T_{r2} T_{s2})s^2} \qquad (1\text{-b})$$

Applying inverse Laplace transformation to equation (1-a, b) stator current for charge and discharge condition in time domain written as:

$$i_{s1}(t) = A_0(1 + A_1 e^{-\frac{t}{T_1}} + A_2 e^{-\frac{t}{T_2}}) \qquad (2\text{-a})$$

$$i_{s2}(t) = B_0(B_1 e^{-\frac{t}{\tau_1}} + B_2 e^{-\frac{t}{\tau_2}}) \qquad (2\text{-b})$$

Curve fitting to experimental result defines coefficients and time constants, A_1, $A_{2,}$ $T_{1,}$ T_2, B_1, $B_{2,}$ τ_1 and τ_2. Based on equation (2–a, b) and these defined coefficients and time constants, rotary transformer parameters are:

$$T_{s1} = A_1(T_2 - T_1) + T_2 \qquad (3)$$

$$T_{r1} = T_1 + T_2 - T_{s1} \qquad (4)$$

$$\sigma_2 = \frac{T_1 T_2}{T_{r1} T_{s1}} \qquad (5)$$

$$T_{s2} = B_1\tau_1 - B_2\tau_2 \qquad (6)$$

$$T_{r2} = \tau_1 + \tau_2 - T_{s2} \qquad (7)$$

$$\sigma_2 = \frac{\tau_1 \tau_2}{T_{r2} T_{s2}} \qquad (8)$$

$$r_s = \frac{|V_s|}{2}\left(\frac{1}{A_0} + \frac{1}{B_0}\right) \qquad (9)$$

$$L'_r = L_s = \frac{1}{2}(r_{s1}.T_{s1} + r_{s2}.T_{s2}) \qquad (10)$$

$$L_m = \frac{1}{2}(L_{s1}\sqrt{1-\sigma_1} + L_{s2}\sqrt{1-\sigma_2}) \qquad (11)$$

$$L'_{lr} = L_{ls} = L_s - L_m \qquad (12)$$

$$r'_r = \frac{1}{2}\left(\frac{L_{s1}}{T_{r1}} + \frac{L_{s2}}{T_{r2}}\right) \qquad (13)$$

III. EXPERIMENTAL TEST SETUP

Fig. 2 shows the test configuration of mentioned method. A 0.2 watt, 10Vp-p and 4 kHz rotary transformer is used for test. The DC voltage source of this setup is chosen to provide rated current of rotary transformer. When switch S is opened and closed, stator current (Is) will be sensed by Hall-Effect current sensor and its output voltage is delivered to the PC via an A/D cart or monitored on digital oscilloscope.

Experimental recorded data of current curve, is shown in fig. 3-a. It combines from two curves, charge and discharge. These curves are fitted by exponential equations of (2-a, b) which is shown in fig. 3-b, c.

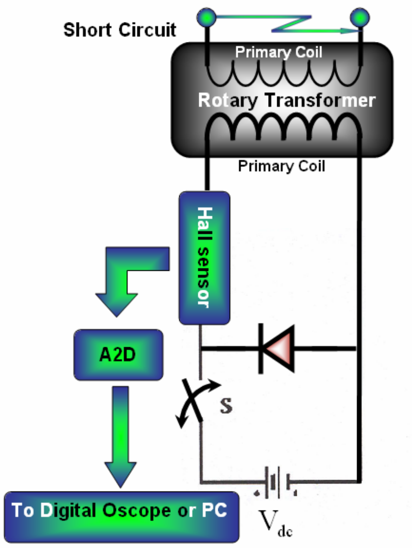
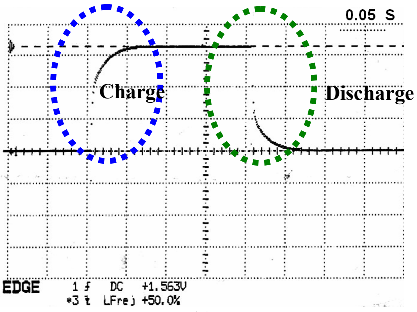
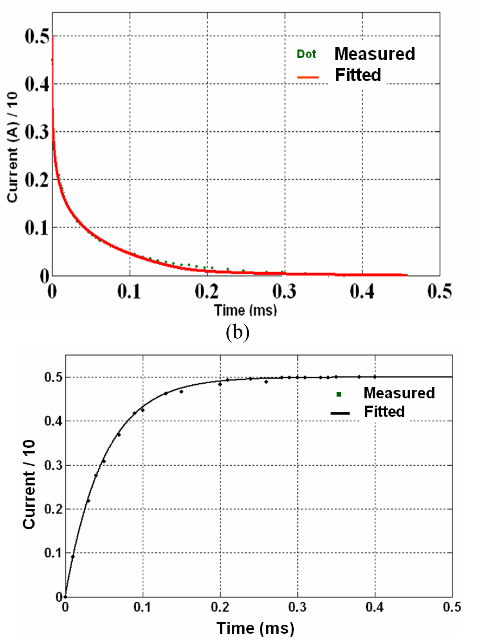


Fig. 2: Test setup configuration



(a)



(b)

(c)

Fig 3: (a) Current response (Sensor output on digital oscilloscope), (b) Discharge fitted Curve (c) Charge fitted Curve.

By curve fitting, coefficients and time constants of current equations can be obtained. Finally using equations (9-13), the parameters are calculated. For under test rotary transformer estimated parameters by using mentioned and classic methods are presented in table I & II respectively.

IV. METHOD VALIDATION

In order to evaluate accuracy of the proposed method, load test is performed. In this test rotary transformer is excited by rated voltage and frequency with an ohmic load (R_L = 156 Ω). In fig. 4 experimental stator current compared with simulation result based on estimated parameters are shown in table I.

Fig. 5 shows similar comparison, is done for experimental result and simulation one, based on the parameters, estimated by classic method (presented in table II). Fig. 4 and fig. 5 show that curves in fig. 4 are closer than the curves in fig. 5. The comparison between experimental results and two simulation results are presented in fig. 6 and table III.

TABLE I

ESTIMATED PARAMETERS BASED ON AVERAGE DC-PULSE METHOD

Rs	125.95	L'lr	0.0016
R'r	53.49	Lls	0.0016
Lm	0.0120	[R]= Ω	[L]= H

TABLE II

ESTIMATED PARAMETERS BASED ON CLASSIC METHOD

Rs	125.95	L'lr	0.0013
R'r	53.1	Lls	0.0013
Lm	0.0114	[R]= Ω	[L]= H

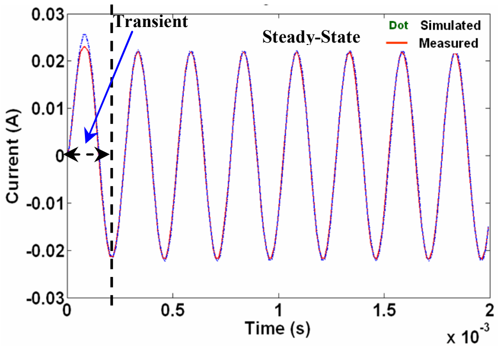


Fig. 4: Comparing load test response using obtained parameters from proposed method and experimental test

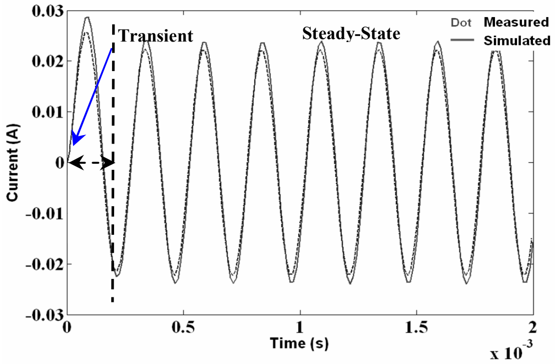


Fig. 5: Comparing load test response using obtained parameters from classic method and experimental test

TABLE III

COMPARISON BETWEEN LOAD TEST RESPONSE USING OBTAINED PARAMETERS FROM CLASSIC & AVERAGE DC-PULSE METHODS WITH MEASURED RESPONSE

	Measured	Simulated With Classis Method	Simulated With Average DC-Pulse Method
Steady-State Amplitude	0.0218	0.0238	0.0222
Transient Amplitude	0.0254	0.0282	0.0267

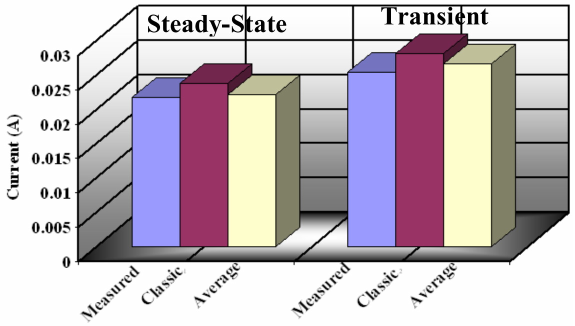


Fig. 6: Comparison between load test response using obtained parameters from classic & average DC pulse methods with measured response

TABLE IV

ABSOLUTE ERROR COMPARISON BETWEEN TWO METHODS CONSIDERING MEASURED RESULTS

	Steady-State Error	Transient Error
Classis Method	9.174 %	11.024 %
DC-Pulse Method	1.835 %	5.118 %

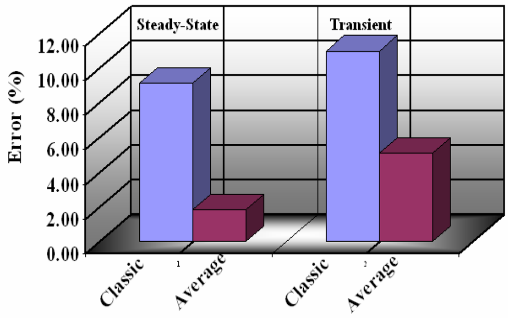


Fig 7: Absolute error comparison between two methods considering measured results

Table IV and fig. 7 show that in steady state and transient condition, Average DC-Pulse method is more accurate than classic one. These results validate the proposed method and indicate that the Average DC-Pulse method, not only is fast and simple, but also accurate than classic one.

V. CONCLUSION

In this paper a new approach based on DC-Pulse current excitation is presented and applied to a rotary transformer stator winding. Stator current is measured and current curve is drawn. An exponential function is fitted to this curve. By using coefficients and time constants of exponential function, rotary transformer parameters are estimated. Comparison the results of experimental and simulation load tests, validates obtained parameters. The advantages of this method are:

- Simplicity of configuration
- Accuracy of results
- Reduction of test time.

VI. ACKNOWLEDGEMENT

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VII. REFERENCES

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I. VIII. BIOGRAPHIES

D. A. Khaburi has received his B.Sc degrees in Electrical Engineering from the Sharif University, Tehran, Iran in 1991. Dr Khaburi has received his M.Sc. and PhD degrees in Electrical Engineering from INPL, Nancy, French, in 1994 and 1998, respectively. His research interests are modeling of electrical machines and drives. Since January 2000 he is assistant professor at Electrical Engineering faculty of Iran University of science and technology.

Farid Tootoonchian has received his B.Sc. and M.Sc. degrees in Electrical Engineering from the Iran University of Sciences and Technology, Tehran, Iran in 2000&2007 respectively. His teaching and research interest is design and control of electrical machines.