

Method for Identifying PMSM Parameters Using the Power Analyzer PW8001

This technical article presents a simple method for using Hioki’s Power Analyzer PW8001 to identify motor parameters (L_d , L_q , K_e , etc.) that are necessary when implementing vector control of permanent magnet synchronous motors.

1. Introduction

Permanent magnet synchronous motors (PMSMs) are widely used in the field of power electronics due to their high efficiency, high power density, and low weight. Depending on the location of the permanent magnet on the rotor, PMSMs can be classified as either interior permanent magnet synchronous motors (IPMSMs) or surface permanent magnet synchronous motors (SPMSMs)¹⁾. Due to their ability to use not only the magnetic torque of the permanent magnet, but also inductance torque²⁾, the range of applications of IPMSMs, which embed the permanent magnetic inside the rotor, has grown to include EVs, aircraft, and inverter-powered household appliances^{3, 4)}.

Typically, an equivalent circuit model⁵⁾ for the motor expressed in terms of the permanent magnet’s N polar axis (d -axis) and the torque axis that is perpendicular to it (q -axis) is used when analyzing the characteristics of a PMSM and considering which control algorithm to use.

Equation (1.1) defines the output torque T for this equivalent circuit model.

$$T = P_n \phi_a i_q + P_n (L_d - L_q) i_d i_q \quad (1.1)$$

Here, P_n represents the number of poles of the motor; i_d and i_q , the d - and q -axis components of each phase’s armature current; Φ_a , the RMS value for the permanent magnet’s armature interlinkage magnetic flux; and L_d and L_q , the self-inductance of the d - and q -axes. The first term on the right side of Equation (1.1) indicates the magnetic torque, while the

second term on the right side indicates the reluctance torque. Because SPMSMs have constant magnetic resistance regardless of their rotor position, $L_d = L_q$ is true in Equation (1.1), and the output torque consists entirely of magnetic torque. By contrast, there is a difference in the d -axis and q -axis inductance in IPMSMs for structural reasons ($L_d \neq L_q$), causing the reluctance torque to play a part in determining the output torque. Consequently, in order to maximize the output torque of an IPMSM, it is extremely important to identify the motor parameters that serve as constants in the equivalent circuit model (the inductance values L_d and L_q in the direction of the d - and q -axes) with a high degree of precision so that the reluctance torque can be controlled⁶⁾.

2. Need for Identifying PMSM Parameters Using a Power Analyzer

Inductance measurement using an LCR meter would appear to provide a simple method for identifying the motor parameters L_d and L_q ⁷⁾. However, that method suffers from the problem that it can only be used to identify motor parameters while the motor terminals are open and the motor is in the stopped state; it does not allow identification of motor parameters in the operating state. L_d and L_q include magnetic saturation characteristics, and as variables they incorporate a variety of dependencies that take into consideration current and other factors. Consequently, in order to realize high-precision control of a PMSM, it is necessary to identify L_d and L_q in a state of actual operation.

This article addresses this problem by

introducing a simple yet high-precision method for identifying motor parameters in an operating state using the Power Analyzer PW8001.

3. Identification Principles

The output torque expressed in Equation (1.1) is based on the equation for a PMSM's voltage on the d - q coordinate axis. If we assume the following, the equation for a PMSM's voltage expressed on the d - q coordinate axis can be expressed as indicated in (3.1) below.⁵⁾

- i) The spatial distribution of magnetic flux in the gap between the stator and rotor takes the form of a sine wave running along the gap.
- ii) Voltage and current harmonic components can be ignored.
- iii) Iron (core) loss can be ignored.

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} R + pL_d & -\omega L_q \\ \omega L_d & R + pL_q \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} 0 \\ \omega\phi_a \end{bmatrix} \quad (3.1)$$

Here, v_d and v_q represent the d -axis and q -axis components of each phase's armature current; R , each phase's armature resistance; p , the differential operator (d/dt); ω , the rotation angle (electric angle) speed; and Φ_a ($=K_e$), the RMS value of the permanent magnet's armature interlinkage magnetic flux (induced voltage constant). If we assume a steady state (by ignoring the time derivative term) and express Equation (3.1) as a vector diagram for the d -axis and q -axis, the result is Fig. 3.1.

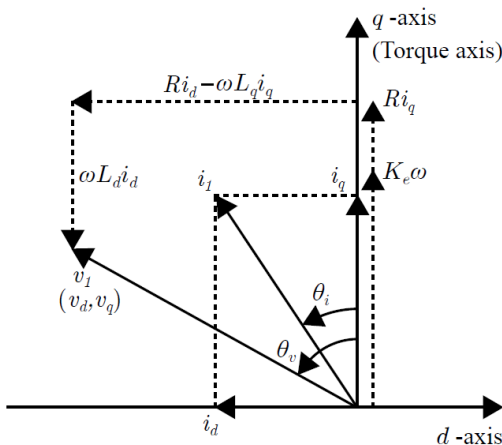


Fig. 3.1 PMSM vector diagram

Here, v_l and i_l represent the fundamental wave components of the phase voltage and phase current, respectively, while θ_v and θ_i represent the fundamental wave phase angle for the phase voltage and phase current, respectively. Based on Fig. 3.1, the voltage equations in the d -axis and q -axis directions are as follows:

$$K_e\omega + Ri_q = v_q - \omega L_d i_d \quad (3.2)$$

$$v_d = Ri_d - \omega L_q i_q \quad (3.3)$$

Solving for L_d and L_q yields:

$$L_d = \frac{v_q - K_e\omega - Ri_q}{\omega i_d} \quad (3.4)$$

$$L_q = \frac{Ri_d - v_d}{\omega i_q} \quad (3.5)$$

4. Identification procedure

4.1 Measurement of each phase's armature resistance R

First, use a resistance meter or other suitable instrument to measure each phase's armature resistance R .

4.2 Phase zero-adjustment and identification of the induced voltage constant K_e

After placing the terminals of the PMSM under measurement in the open state ($i_d = i_q = 0$), connect the motor terminals to the CH 1, 2, and 3 voltage inputs on the PW8001. Next, connect the encoder's A-phase pulse output to CH B (or CH F); the B-phase pulse output to CH C (or CH G); and the Z-phase pulse (origin signal) output to CH D (or CH H) (Fig. 4.1).

Configure the PW8001 by setting the motor analysis operation mode to "Single" and the measurement parameter to "Torque Speed Direction Origin."

Next, set the CH 1, 2, and 3 wiring type to 3P3W3M; the synchronization source and harmonic synchronization source to "Ext1"; and Δ conversion to "ON." Setting the measurement channel synchronization source and harmonic synchronization source

to “Ext1” allows measurement of the voltage and current phase angle using the inputted encoder pulse as a reference, while setting Δ conversion to “ON” allows conversion of line voltage to phase voltage for measurement.

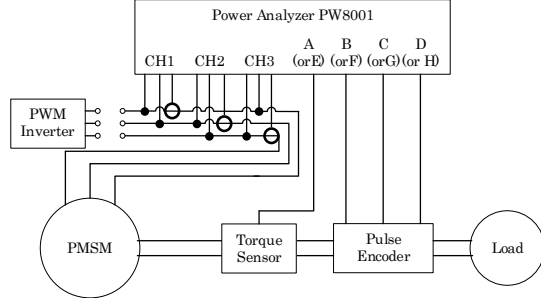


Fig.4.1 Wiring for phase zero-adjustment and identification of the induced voltage constant

Drive the motor in this state from the load side to generate an induced voltage and perform phase zero-adjustment on the PW8001. Doing so will cause θ_v and θ_i to become the phase voltage (that is, electric angle) based on the induced voltage phase occurring in the q -axis direction.

At this time, an induced voltage ($v_q = v_1$) will occur, and Equation (3.4) will become:

$$K_e = \frac{v_q}{\omega} = \frac{v_1}{2\pi f_1} \quad (4.1)$$

The equation now allows identification of K_e . Here, $f_1 (= \omega / 2\pi)$ indicates the frequency of the phase voltage's fundamental wave.

4.3 Identification of the motor parameters

L_d and L_q using user-defined functions

Self-inductance (L_d and L_q) in the direction of the d and q -axes can be identified using R as measured in Section 4.1 and K_e as identified in Section 4.2. Connect the inverter's drive output to the motor terminals which were placed in an open state in Section 4.2 and operate the motor (Fig. 4.2). Based on Fig. 3.1, the following will obtain at this time:

$$v_d = -v_1 \sin \theta_v \quad (4.2)$$

$$v_q = v_1 \cos \theta_v \quad (4.3)$$

$$i_d = -i_1 \sin \theta_i \quad (4.4)$$

$$i_q = i_1 \cos \theta_i \quad (4.5)$$

If these equations along with Equations (3.4)

and (3.5) are configured as user-defined functions (UDFs), you can easily identify L_d and L_q while monitoring i_d and i_q .

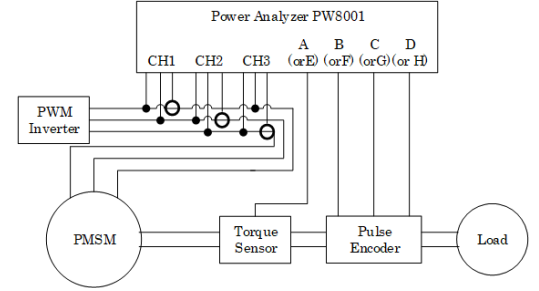


Fig. 4.2 Wiring when identifying motor parameters

Following are some specific example settings. First, set UDF₁₋₂ to i_d and i_q .

$$UDF_1 = -I_{\text{fnd1}} \cdot \sin \theta_{11}$$

$$UDF_2 = I_{\text{fnd1}} \cdot \cos \theta_{11}$$

Here I_{fnd1} and θ_{11} represent the basic measurement parameters for CH 1 on the PW8001, indicating the fundamental wave component of the current RMS value and the current q phase angle, respectively, as follows:

$$I_{\text{fnd1}} = i_1$$

$$\theta_{11} = \theta_i$$

Next, set L_d . The numerator of Equation (3.4) is as follows:

$$UDF_3 = U_{\text{fnd1}} \cdot \cos \theta_{U1} - (2\pi K_e) \cdot f_1 - R \cdot UDF_2$$

Here U_{fnd1} and θ_{U1} represent the basic measurement parameters for CH 1 on the PW8001, indicating the fundamental wave component of the voltage RMS value and the voltage phase angle, respectively, as follows:

$$U_{\text{fnd1}} = v_1$$

$$\theta_{U1} = \theta_v$$

The denominator of Equation (3.4) is as follows:

$$UDF_4 = (2\pi) \cdot f_1 \cdot UDF_1$$

Consequently, L_d can be expressed as follows:

$$UDF_5 = UDF_3 / UDF_4$$

Finally, set L_q . The numerator of Equation (3.5) is as follows:

$$\text{UDF}_6 = R \cdot \text{UDF}_1 - (-v_{\text{fnd1}}) \cdot \sin \theta_{U1}$$

The denominator of Equation (3.5) is as follows:

$$\text{UDF}_7 = (2\pi) \cdot f_1 \cdot \text{UDF}_2$$

Consequently, L_q can be expressed as follows:

$$\text{UDF}_8 = \text{UDF}_6 / \text{UDF}_7$$

Figs. 4.3 and 4.4 depict the UDF settings screen on the Power Analyzer PW8001 when UDF₁₋₈ have been configured in this way. In Figs. 4.3 and 4.4, $R = 3.2$ [Ω] and $K_e = 20$ [mV·s/rad], and the second and third terms on the right side of UDF₃ as well as the second term on the right side of UDF₆ have been set accordingly.

5. Conclusion

This article introduces a simple yet high-precision method for identifying motor parameters in an operating state using the Power Analyzer PW8001. Please see other resources^{8, 9)} that introduce how to use a Hioki Power Analyzer PW6001 to identify motor parameters along with actual measurement results. Note that the method introduced in this article yields motor parameters for an equivalent circuit model that assumes the circuit is in a steady state and that iron (core) loss can be ignored.

Since the identification method introduced in this article makes it comparatively easy to measure the current dependency of the motor parameters L_d and L_q , it can be used to create tools like L_d and L_q maps and torque maps while the motor is in an operating state in order to implement optimal control of PMSMs.

References

- 1) Control-use Electromagnetic Actuator Drive System Investigation Committee: "Control-use Electromagnetic Actuator Drive Systems," Technical Reports of The Institute of Electrical Engineers of Japan, No. 719, pp.1-8 (1993).
- 2) Y. Takeda, N. Matsumoto, S. Morimoto and Y. Honda: Interior Permanent Magnet Synchronous Motor Design and Control, Ohmsha (2011).
- 3) Y. Hori: "Future Vehicle driven by Electricity and Control - Research on 4 Wheel Motored 'UOT March II,'" IEEE Trans. on Industry Electronics, Vol. 51, No. 5, pp.954-462 (2004).
- 4) P. Alvarez, M. Satrustegui, I. Elosegui and M. Martinez-Iturralde: "Review of High Power and High Voltage Electric Motors for Single-Aisle Regional Aircraft," IEEE Access, Vol. 10, pp.112989-113004 (2022).
- 5) S. Morimoto, Y. Takeda and T. Hirasaka: "Method for Measuring the Constants of a PM Motor dq Equivalent Circuit," Transactions of The Institute of Electrical Engineers of Japan D, Vol. 113-D, No. 11, pp.1330-1331 (1993).
- 6) H. Domeki: Capable Field Tools: Electric Motor Drive Basics and Applications, Kato Bunmeisha (2010).
- 7) M. Shogo, K. Masanobu, T. Yoshiyasu, T. Mamoru, S. Toru, O. Motomichi, H. Tsuyoshi and A. Takashi: "Development of a Stator-Magnetless Linear Synchronous Motor for Sensorless Control," IEEE Transactions on Industry Applications, Vol. 53, No. 5, pp.4559-4568 (2017).
- 8) HIOKI E.E. Corp.: "Identification of PMSM Parameters with the Power Analyzer PW6001" (White Paper) (2016).
- 9) HIOKI E.E. Corp.: "Identification of PMSM Motor Parameters with a Power Analyzer" (White Paper) (2016).

0000-00-00 00:00:00

1	2	3	4	USB
5	6	7	8	

UDF1 = $(-I_{fd1}) * \sin(\theta_{I1})$

Name MAX Auto Integ OFF XXX.XXX

UDF2 = $I_{fd1} * \cos(\theta_{I1})$

Name MAX Auto Integ OFF XXX.XXX

UDF3 = $U_{fd1} * \cos(\theta_{U1}) - 2.00000 * 3.14159 * f_{U1} * 20.0000 - 1.20000 * UDF_2$

Name MAX Auto Integ OFF XXX.XXX

UDF4 = $2.00000 * 3.14159 * f_{U1} * UDF_1$

Name MAX Auto Integ OFF XXX.XXX

Save file

Load file

1 - 4

5 - 8

9 - 12

13 - 16

17 - 20

WIREING

CHANNEL

COMMON

EFFICIENCY

UDF

MOTOR

Fig. 4.3 Example PW8001 UDF settings (UDF₁₋₄)

0000-00-00 00:00:00

1	2	3	4	USB
5	6	7	8	

UDF5 = UDF_3 / UDF_4

Name MAX Auto Integ OFF XXX.XXX

UDF6 = $1.20000 * UDF_1 - (-U_{fd1}) * \sin(\theta_{U1})$

Name MAX Auto Integ OFF XXX.XXX

UDF7 = $2.00000 * 3.14159 * f_{U1} * UDF_2$

Name MAX Auto Integ OFF XXX.XXX

UDF8 = UDF_6 / UDF_7

Name MAX Auto Integ OFF XXX.XXX

Save file

Load file

1 - 4

5 - 8

9 - 12

13 - 16

17 - 20

WIREING

CHANNEL

COMMON

EFFICIENCY

UDF

MOTOR

Fig. 4.3 Example PW8001 UDF settings (UDF₅₋₈)