An Exact Model for Rotor Field-Oriented Control of Single-Phase Induction Motors

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Abstract

This work presents a new Rotor Field-Oriented Control (RFOC) technique for single-phase Induction Motors (IMs). The proposed method uses two rotational transformations, which extract from the steady-state equivalent circuit of single-phase IM. It is proved by using proposed rotational transformations, the single-phase IM asymmetrical equations change into symmetrical equations. In the proposed technique, the assumption of $(M_q/M_d)^2 = L_{qs}/L_{ds} = a^2$ which is usually used in other FOC of single-phase IMs, is not considered. Performance of the proposed technique is assessed using MATLAB/SIMULINK. Extensive simulation results show the performance and correctness of the proposed method.

Keywords: *new RFOC technique, rotational transformations, single-phase induction motor*

1. Introduction

Single-phase Induction Motors (IMs) have been broadly employed in low power applications. In these applications the motor operate at low efficiency, fixed speed and consume about 10% of electrical energy. During the last decades, single-phase IM drives have been thoroughly discussed by researchers. Single-phase IMs with two main and auxiliary windings can be considered as two-phase IMs, since these stator windings are displaced 90° from each other. A Four-Switch Inverter (FSI) topology is used in this paper as illustrated in Figure 1, has been proposed as a low cost solution for single-phase IM drives [1, 2].

Variable speed drives can provide reliable dynamic systems and important savings in energy custom and costs of the electrical machines [1-11], [13-16]. Recently, some high performance single-phase IM drive systems were proposed. In these schemes, rotor and stator Field-Oriented Control (FOC) principles are adapted to the single-phase IM model [1-3], [6-10]. Winding asymmetry due to the different inductances and resistances of the main and auxiliary stator windings in single-phase IM causes extra coupling between windings. This asymmetry effects on the motor operation and produces torque and current pulsations [11]. By using a transformation matrix, the compensation of the single-phase IM asymmetry was presented in [2]. In the previous methods for vector control of single-phase or unbalanced two-phase IMs, the assumption of $(M_q/M_d)^2 = L_{qs}/L_{ds}$ is normally applied [2-3], [6-10]. The differences in the d and q stator with considering of $(M_q/M_d)^2 = L_{qs}/L_{ds}$ and without considering of $(M_q/M_d)^2 = L_{qs}/L_{ds}$, are reflected in the speed and hence the torque responses of the drive system. In this paper, a new RFOC strategy for single-phase IM drive is investigated. In the proposed scheme, the backward component in the stator voltages due to this assumption $((M_q/M_d)^2 = L_{qs}/L_{ds})$ as previously ignored in [2-3], [6-10] will be taken into account. The remainder of this work is organized as follows. The modeling of the single-phase IM is presented in section 2. In section 3, the main idea of proposed vector control for single-phase IM discussed and subsequently a new control strategy based on RFOC is presented. The effectiveness of the proposed method is verified using MATLAB/SIMULINK and presented in section 4. Finally, conclusion is presented in section 5.

2. Modeling of the Single-Phase IM

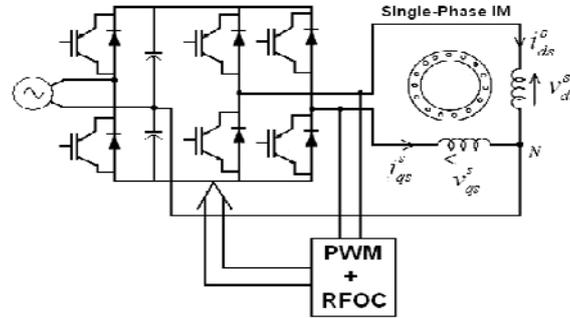The basic drive system which is studied in this paper is shown in Figure 1.

Figure 1. Single-phase IM Drive System

Neglecting the core saturation, the electrical and mechanical equations of the single-phase IM in the stator reference frame (superscript "*s*") are given as follows (All of the parameters in Equation (1) have been defined in [2]):

$$v_{ds}^s = r_{ds} i_{ds}^s + \frac{d\lambda_{ds}^s}{dt} \quad , \quad v_{qs}^s = r_{qs} i_{qs}^s + \frac{d\lambda_{qs}^s}{dt}$$

$$0 = r_r i_{dr}^s + \frac{d\lambda_{dr}^s}{dt} + \omega_r \lambda_{qr}^s \quad , \quad 0 = r_r i_{qr}^s + \frac{d\lambda_{qr}^s}{dt} - \omega_r \lambda_{dr}^s$$

$$\lambda_{ds}^s = L_{ds} i_{ds}^s + M_d i_{dr}^s \quad , \quad \lambda_{qs}^s = L_{qs} i_{qs}^s + M_q i_{qr}^s$$

$$\lambda_{dr}^s = M_d i_{ds}^s + I_r i_{dr}^s \quad , \quad \lambda_{qr}^s = M_q i_{qs}^s + I_r i_{qr}^s$$

$$\tau_e = \frac{Pole}{2}(M_q i_{qs}^s i_{dr}^s - M_d i_{ds}^s i_{qr}^s)$$

$$\frac{Pole}{2}(\tau_e - \tau_l) = J\frac{d\omega_r}{dt} + F\omega_r$$

$$(1)$$

3. Equations of Proposed RFOC for Single-Phase IM

Steady-state equivalent circuit of the single-phase IM can be shown as Figure 2 [12]. In this Figure, V_m, V_a, I_m and I_a are the main and auxiliary voltages and currents, "*a*" is the turn ratio ($a=N_a/N_m$) and "*j*" is the square root of "-1". E_{fm}, E_{fa}, E_{bm} and E_{ba} are the forward and backward voltage of magnetizing branch of the main and auxiliary windings. R_f, R_b, X_f and X_b are the forward and backward stator resistance and inductance in main winding. R_{lm}, R_{la}, X_{lm} and X_{la} are the leakage resistance and inductance of the main and auxiliary winding. With following change of variables:

$$V_f = \frac{1}{2}\left(V_m - j\frac{V_a}{a}\right) \quad , \quad I_f = \frac{1}{2}(I_m - jaI_a)$$

$$V_b = \frac{1}{2}\left(V_m + j\frac{V_a}{a}\right) \quad , \quad I_b = \frac{1}{2}(I_m + jaI_a)$$
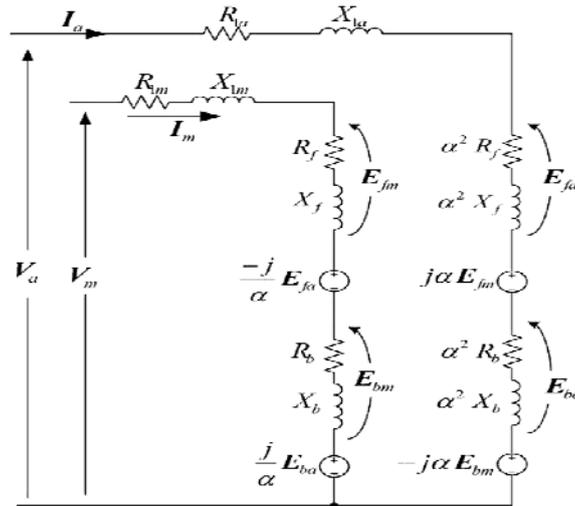
$$(2)$$

Figure 2. Steady-state Equivalent Circuit of the Single-phase IM

Figure 3 can be simplified as two balanced forward and backward circuit as follows [13, 14]:
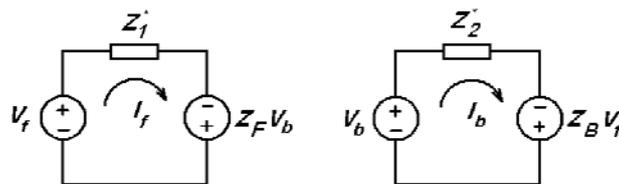

Figure 3. Simplified Equivalent Circuit of Single-phase IM

Where:

$$Z_1^* = Z_{lm} + 2Z_f + Z_d - Z_F Z_d$$
$$Z_2^* = Z_{lm} + 2Z_b + Z_d - Z_B Z_d \tag{3}$$
$$Z_F = \frac{Z_d}{Z_{lm} + 2Z_b + Z_d}$$
$$Z_B = \frac{Z_d}{Z_{lm} + 2Z_f + Z_d} \quad , \quad Z_d = \frac{1}{2}\left(\frac{Z_{la}}{a^2} - Z_{lm}\right)$$

As you can see, the equivalent circuit of single-phase IM splits to two circuits, each of them indicates a balanced motor which rotates in the forward and backward direction. By considering Figure 3 and Equations (3) we have:

$$
\begin{cases}
V_f \quad -j\dfrac{N_m}{N_a}V_a + V_m \\
I_f \quad -j\dfrac{N_a}{N_m}I_a + I_m
\end{cases}
\rightarrow
\begin{cases}
\begin{bmatrix} jV_f \\ V_f \end{bmatrix} = \begin{vmatrix} \dfrac{N_m}{N_a} & j \\ j\dfrac{N_m}{N_a} & 1 \end{vmatrix} \begin{bmatrix} V_a \\ V_m \end{bmatrix} \\[4mm]
\begin{bmatrix} jI_f \\ I_h \end{bmatrix} = \begin{vmatrix} \dfrac{N_a}{N_m} & j \\ j\dfrac{N_a}{N_m} & 1 \end{vmatrix} \begin{bmatrix} I_a \\ I_m \end{bmatrix}
\end{cases}
\tag{4}
$$

Equation (4) is the transformation matrixes for changing the variables from unbalanced form to balanced form (e.g., Figure 2 to Figure 3). With substation of Equations (5) in equations (4), we can obtain Equation (6) and (7).

$$
\begin{aligned}
&j \to \sin\theta_e, \; 1 \to \cos\theta_e, \; \frac{N_m}{N_a} \to \frac{N_q}{N_d} - \frac{M_q}{M_d} \\
&jV_1 \to v_{ds}^e, \; V_1 \to v_{qs}^e, \; V_a \to v_{ds}^s, \; V_m \to v_{qs}^s \\
&jI_1 \to i_{ds}^e, \; I_1 \to i_{qs}^e, \; I_a \to i_{ds}^s, \; I_m \to i_{qs}^s
\end{aligned}
\tag{5}
$$

Rotational transformation for voltage variables:

$$
\begin{bmatrix} v_{ds}^e \\ v_{qs}^e \end{bmatrix} = \begin{bmatrix} \dfrac{M_q}{M_d}\cos\theta_e & \sin\theta_e \\ -\dfrac{M_q}{M_d}\sin\theta_e & \cos\theta_e \end{bmatrix} \begin{bmatrix} v_{ds}^s \\ v_{qs}^s \end{bmatrix}
\tag{6}
$$

Rotational transformation for current variables:

$$
\begin{bmatrix} i_{ds}^e \\ i_{qs}^e \end{bmatrix} = \begin{bmatrix} \dfrac{M_d}{M_q}\cos\theta_e & \sin\theta_e \\ -\dfrac{M_d}{M_q}\sin\theta_e & \cos\theta_e \end{bmatrix} \begin{bmatrix} i_{ds}^s \\ i_{qs}^s \end{bmatrix}
\tag{7}
$$

In this equation, θe is the angle between the stationary reference frame and rotating reference frame. It is expected by using (6) and (7), unbalanced single-phase IM equations change into balanced equations form. By applying of these rotational transformations to the equations of single-phase IM and without the assumption of $(M_q/M_d)^2 = L_{qs}/L_{ds}$, we have (in the previous presented methods for FOC of single-phase IM the assumption of $(M_q/M_d)^2 = L_{qs}/L_{ds}$ is considered [2-3], [6-10]):

Rotor voltage equations:

$$
\begin{aligned}
[T_s^e]\begin{bmatrix} 0 \\ 0 \end{bmatrix} = {} & [T_s^e]\begin{bmatrix} M_d\dfrac{d}{dt} & \omega_r M_q \\ -\omega_r M_d & M_q\dfrac{d}{dt} \end{bmatrix}[T_{ts}^e]^{-1}[T_{ts}^e]\begin{bmatrix} i_{ds}^s \\ i_{qs}^s \end{bmatrix} \\
& + [T_s^e]\begin{bmatrix} r_r + L_r\dfrac{d}{dt} & \omega_r L_r \\ \omega_r L_r & r_r + L_r\dfrac{d}{dt} \end{bmatrix}[T_s^e]^{-1}[T_s^e]\begin{bmatrix} i_{dr}^s \\ i_{qr}^s \end{bmatrix}
\end{aligned}
\tag{8}
$$

After simplifying the equations of rotor voltages can be written as:

Rotor voltage equation:

$$
\begin{aligned}
0 &= r_r i_{dr}^e + M_q\frac{di_{ds}^e}{dt} + L_r\frac{di_{dr}^e}{dt} - (\omega_e - \omega_r)(M_q i_{qs}^e + L_r i_{qr}^e) \\
0 &= r_r i_{qr}^e + M_q\frac{di_{qs}^e}{dt} + L_r\frac{di_{qr}^e}{dt} + (\omega_e - \omega_r)(M_q i_{ds}^e + L_r i_{dr}^e)
\end{aligned}
\tag{9}
$$

Rotor flux equations:

$$
\begin{aligned}
[T_s^e]\begin{bmatrix} \lambda_{dr}^e \\ \lambda_{qr}^e \end{bmatrix} = {} & [T_s^e]\begin{bmatrix} M_d & 0 \\ 0 & M_q \end{bmatrix}[T_{ts}^e]^{-1}[T_{ts}^e]\begin{bmatrix} i_{ds}^s \\ i_{qs}^s \end{bmatrix} \\
& + [T_s^e]\begin{bmatrix} L_r & 0 \\ 0 & L_r \end{bmatrix}[T_s^e]^{-1}[T_s^e]\begin{bmatrix} i_{dr}^s \\ i_{qr}^s \end{bmatrix}
\end{aligned}
\tag{10}
$$

After simplifying the equations of rotor flux can be written as follows:
Rotor flux equation:

$$\lambda_{dr}^e = M_q i_{ds}^e + L_r i_{dr}^e$$
$$\lambda_{qr}^e = M_q i_{qs}^e + L_r i_{qr}^e \tag{11}$$

Electromagnetic torque equation:

$$\tau_e = \frac{Pole}{2}(M_q i_{qs}^s i_{dr}^s - M_d i_{ds}^s i_{qr}^s)$$

$$= \frac{Pole}{2}\begin{bmatrix} i_{dr}^s & i_{qr}^s \end{bmatrix}\begin{bmatrix} 0 & M_q \\ M_d & 0 \end{bmatrix}\begin{bmatrix} i_{ds}^s \\ i_{qs}^s \end{bmatrix}$$

$$-\left(\frac{Pole}{2}\begin{bmatrix} i_{dr}^s & i_{qr}^s \end{bmatrix}[T_s^e]^T\left([T_s^e]^{-1}\right)^T\right.$$

$$\left.\begin{bmatrix} 0 & M_q \\ -M_d & 0 \end{bmatrix}[T_{is}^e]^{-1}[T_{is}^e]\begin{bmatrix} i_{ds}^s \\ i_{qs}^s \end{bmatrix}\right) \tag{12}$$

Therefore, we have:

$$\tau_e - \frac{Pole}{2}M_q(i_{qs}^e i_{dr}^e - i_{ds}^e i_{qr}^e) \tag{13}$$

Stator voltage equations:

$$[T_{vs}^e]\begin{bmatrix} v_{ds}^s \\ v_{qs}^s \end{bmatrix} -$$

$$[T_{vs}^e]\begin{bmatrix} r_{ds} + L_{ds}\dfrac{d}{dt} & 0 \\ 0 & r_{qs} + L_{qs}\dfrac{d}{dt} \end{bmatrix}[T_{is}^e]^{-1}[T_{is}^e]\begin{bmatrix} i_{ds}^s \\ i_{qs}^s \end{bmatrix}$$

$$+[T_{vs}^e]\begin{bmatrix} M_d\dfrac{d}{dt} & 0 \\ 0 & M_q\dfrac{d}{dt} \end{bmatrix}[T_s^e]^1[T_s^e]\begin{bmatrix} i_{dr}^s \\ i_{qr}^s \end{bmatrix} \tag{14}$$

Equations of stator voltage can be simplified as following equation:

$$\begin{bmatrix} v_{ds}^e \\ v_{qs}^e \end{bmatrix} = \begin{bmatrix} r_{qs} + L_{qs}\dfrac{d}{dt} & -\omega_e L_{qs} \\ \omega_e L_{qs} & r_{qs} + L_{qs}\dfrac{d}{dt} \end{bmatrix}\begin{bmatrix} i_{ds}^e \\ i_{qs}^e \end{bmatrix}$$
$$+\begin{bmatrix} M_q\dfrac{d}{dt} & -\omega_e M_q \\ \omega_e M_q & M_q\dfrac{d}{dt} \end{bmatrix}\begin{bmatrix} i_{dr}^e \\ i_{qr}^e \end{bmatrix} + \begin{bmatrix} \left(\dfrac{M_q^2}{M_d^2}r_{ds} - r_{qs}\right) + \left(\dfrac{M_q^2}{M_d^2}L_{ds} - L_{qs}\right)\dfrac{d}{dt} & \omega_e\left(\dfrac{M_q^2}{M_d^2}L_{ds} \quad L_{qs}\right) \\ \omega_e\left(\dfrac{M_q^2}{M_d^2}L_{ds} - L_{qs}\right) & \left(\dfrac{M_q^2}{M_d^2}r_{ds} \quad r_{qs}\right) + \left(\dfrac{M_q^2}{M_d^2}L_{ds} - L_{qs}\right)\dfrac{d}{dt} \end{bmatrix}\begin{bmatrix} i_{ds}^{-e} \\ i_{qs}^{-e} \end{bmatrix} \tag{15}$$

Generally, Equation (15) are included two terms; forward terms (superscript "*e*") and backward terms (superscript "-*e*"). It is because of unequal main and auxiliary resistances and

inductances in the single-phase IM equations. Equation between forward and backward term is as follows:

$$i_{ds}^{-e} - \cos^2 \theta_e i_{ds}^e - \sin \theta_e . \cos \theta_e i_{qs}^e$$
$$i_{qs}^{-e} = -\sin \theta_e . \cos \theta_e i_{ds}^e + \sin^2 \theta_e i_{qs}^e \qquad (16)$$

As expected, using proposed transformation matrixes (Equations (6) and (7)) equations of the rotor voltage, flux, torque and stator voltage are obtained like balanced motor. In RFOC method, the rotor flux vector is aligned with d-axis; ($\lambda_{dr}^e = |\lambda_r|$, $\lambda_{qr}^e = 0$), based on this assumption, Equation (15) can be classified as follows:

$$v_{ds}^e = v_{ds}^{d-f} + v_{ds}^{ref-f} + v_{ds}^{d-b} + v_{ds}^{ref-b}$$
$$v_{qs}^e = v_{qs}^{d-f} + v_{qs}^{ref-f} + v_{qs}^{d-b} + v_{qs}^{ref-b} \qquad (17)$$

Where:

$$v_{ds}^{d-f} = \omega_e(-L_{qs} + \frac{M_q^2}{L_r})i_{qs}^e + (\frac{M_q^2}{T_r L_r})i_{ds}^e - \frac{|\lambda_r|M_q}{T_r L_r}$$

$$v_{ds}^{ref-f} = r_{qs}i_{ds}^e + (L_{qs} - \frac{M_q^2}{L_r})\frac{di_{ds}^e}{dt}$$

$$v_{ds}^{d-b} = -\omega_e(\frac{M_q^2}{M_d^2}L_{ds} - L_{qs})i_{qs}^{-e}$$

$$v_{ds}^{ref-b} = (\frac{M_q^2}{M_d^2}r_{ds} - r_{qs})i_{ds}^{-e} + (\frac{M_q^2}{M_d^2}L_{ds} - L_{qs})\frac{di_{ds}^{-e}}{dt} \qquad (18)$$

$$v_{qs}^{d-f} = -\omega_e(-L_{qs} + \frac{M_q^2}{L_r})i_{ds}^e + \frac{\omega_e|\lambda_r|M_q}{L_r}$$

$$v_{qs}^{ref-f} = r_{qs}i_{qs}^e + (L_{qs} - \frac{M_q^2}{L_r})\frac{di_{qs}^e}{dt}$$

$$v_{qs}^{d-b} = \omega_e(\frac{M_q^2}{M_d^2}L_{ds} - L_{qs})i_{ds}^{-e}$$

$$v_{qs}^{ref-b} = (\frac{M_q^2}{M_d^2}r_{ds} - r_{qs})i_{qs}^{-e} + (\frac{M_q^2}{M_d^2}L_{ds} - L_{qs})\frac{di_{qs}^{-e}}{dt}$$

In Equation (18), v_{ds}^{d-f}, v_{ds}^{d-b}, v_{qs}^{d-f} and v_{qs}^{d-b} can be generated by Decoupling Circuit and v_{ds}^{ref-f}, v_{ds}^{ref-b}, v_{qs}^{ref-f} and v_{qs}^{ref-b} can be generated by current PI controller as it is shown in Figure 4.

According to (9), (11) and (13), the equations of RFOC can be formulated and shown as Equation (19) and Figure 5 respectively (In Equation (19), T_r is rotor time constant).

$$|\lambda_r| = \frac{M_q i_{ds}^e}{1 + T_r \frac{d}{dt}} \quad , \quad \omega_e = \omega_r + \frac{M_q i_{qs}^e}{T_r |\lambda_r|} \quad , \quad \tau_e = \frac{Pole}{2}(\frac{M_q}{L_r})(|\lambda_r| i_{qs}^e) \qquad (19)$$
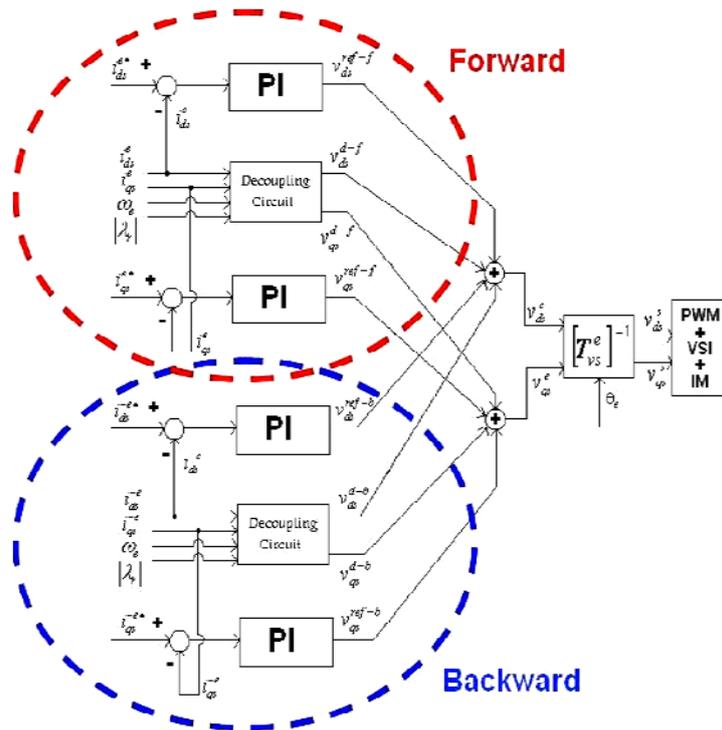
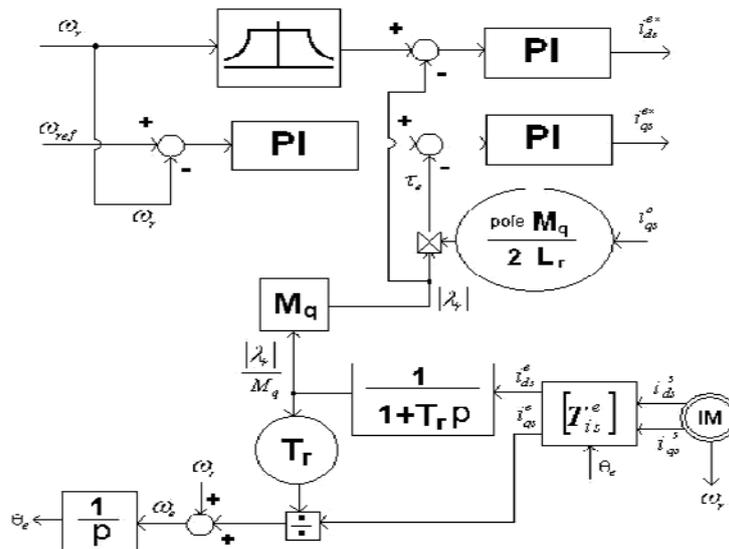Figure 4. Vector Control of Single-phase IM According to Equation (18)

Figure 5. Vector Control of Single-phase IM According to Equation (19)

4. Results and Comparisons
4.1. Performance Evaluation

The proposed controller based on Figure 4 and Figure 5 is applied to a commercial 0.25 hp single-phase IM with the nominal values and parameters as in Table 1. The developed scheme performance is then simulated with different values of rotor speed. Extensive simulation results are presented to evaluate the proposed single-phase IM drive performance.

Figure 6, illustrates the reference and the real rotor speed signals towards two different steady-state rotor speed values (the reference real speed varies from zero to the rated and

rated to zero value. A load torque equal to 1 N.m is introduced at t = 9 s and removed at t = 11 s). It is seen that the real rotor speed signals are so accurate that hardly can be distinguished from the corresponding reference speed signals even after applying load torque (the oscillation of speed is about 0.2 rpm in steady-state and after applying load torque). The motor electromagnetic torque is also shown in Figure 6(b). It can be seen that the electromagnetic torque has a quick response with no pulsations.
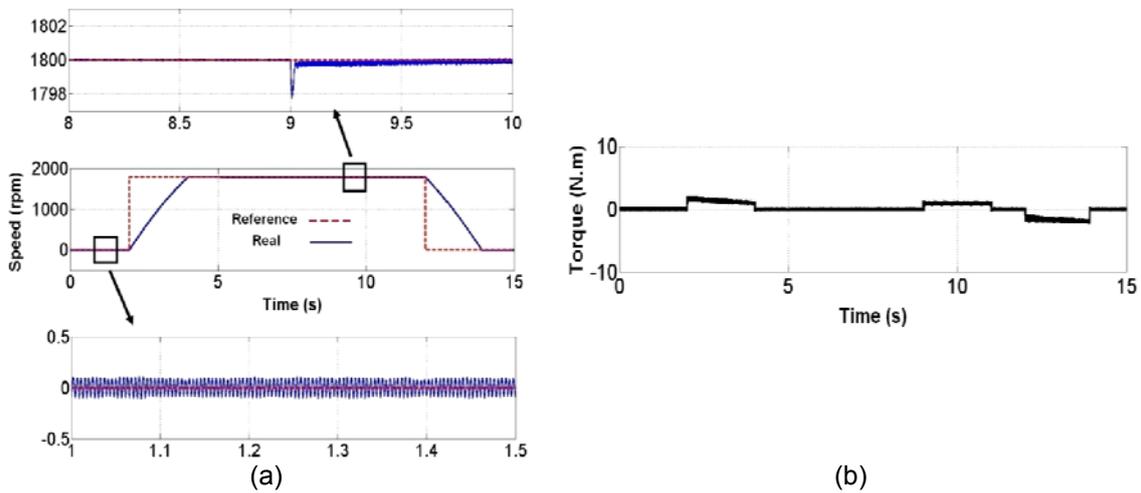

(a)   (b)

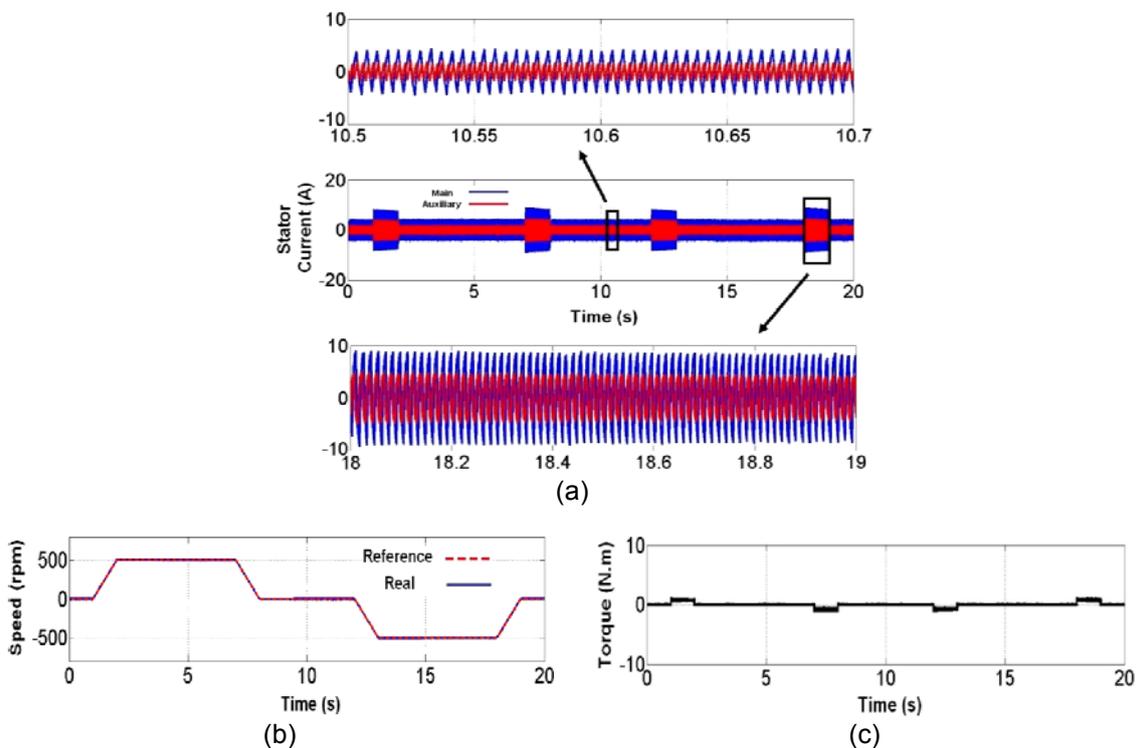Figure 6. Simulation Results of RFOC at Zero and Nominal Command Speed; (a) Speed, (b) Torque

Figure 7. Simulation Results of RFOC for a Trapezoidal Command Speed; (a) Stator currents, (b) Speed, (c) Torque

Figure 7 shows simulation results of the command and actual rotor speed according to proposed method for a trapezoidal command speed from 500rpm to -500rpm. It is evident from Figure 7(b) that the real speed follows the command speed. The auxiliary and main stator currents and electromagnetic torque for trapezoidal command speed are shown in Figure 7(a) and Figure 7(c) respectively. In this case, as can be seen in Figure 7(b), by using proposed controller, the speed oscillation at steady-state is ~ 0.07rpm at rotor speed of 500rpm.

Figure 8 and Figure 9 shows the good performance of the proposed drive system for controlling single-phase IM in the difference values of speed (±500rpm, ±1000rpm and ±1700rpm) and at very low speed operation respectively. It can be seen from Figure 6-9 that the dynamic performance of the proposed drive system for vector control of single-phase IM is extremely acceptable.
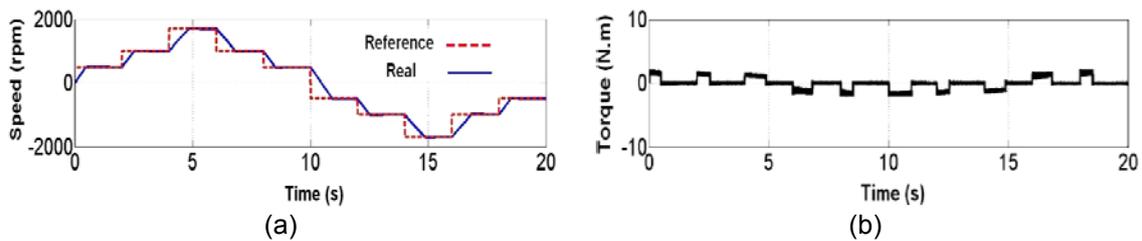

Figure 8. Simulation Results of RFOC in the Difference Values of Command Speed; (a) Speed, (b) Torque
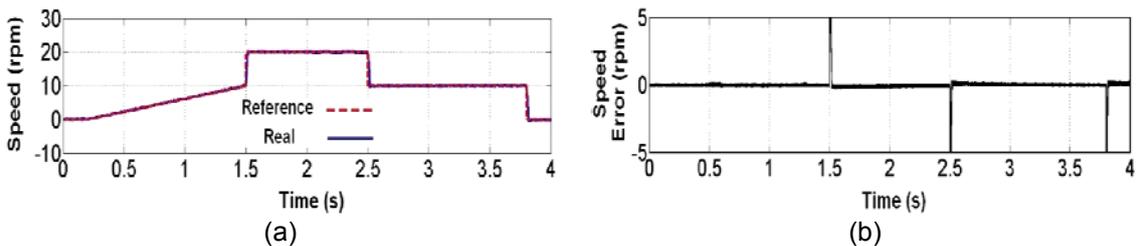

Figure 9. Simulation Results of RFOC at Low Speed Operation; (a) Speed, (b) Speed Error

4.1. Comparisons

Based on Equation (15), the difference in the d and q stator voltages between the conditions in which the supposition of $(M_q/M_d)^2 = L_{qs}/L_{ds}$ is considered (e.g., [2-3], [6-10], [14-16]) and otherwise is as following equation:

$$\begin{bmatrix} \Delta v_{ds}^e \\ \Delta v_{qs}^e \end{bmatrix} = \begin{bmatrix} (\frac{M_q^2}{M_d^2}L_{ds} - L_{qs})\frac{d}{dt} & -\omega_e(\frac{M_q^2}{M_d^2}L_{ds} - L_{qs}) \\ \omega_e(\frac{M_q^2}{M_d^2}L_{ds} - L_{qs}) & (\frac{M_q^2}{M_d^2}L_{ds} - L_{qs})\frac{d}{dt} \end{bmatrix} \begin{bmatrix} i_{ds}^{-e} \\ i_{qs}^{-e} \end{bmatrix}$$

(20)

An evaluation between the steady-state rotor speed response of the RFOC with considering of $(M_q/M_d)^2 = L_{qs}/L_{ds}$ and with no considering of $(M_q/M_d)^2 = L_{qs}/L_{ds}$ is demonstrated in Figure 10. Small magnitude of oscillations at the rated reference rotor speed can be observed in the speed responses when the supposition $(M_q/M_d)^2 = L_{qs}/L_{ds}$ is employed. As can be seen in Figure 10, by using conventional controller (supposition $(M_q/M_d)^2 = L_{qs}/L_{ds}$), the speed oscillation at steady-state is ~ 0.2rpm at rotor speed of 1800rpm but by using proposed controller the speed oscillation reduced ~ 0.08rpm at rotor speed of 1800rpm.

It is concluded in comparison with the previous proposed schemes for FOC of single-phase or two-phase IMs (e.g., [2-3], [6-10], [14-16]),the proposed controller in this research produces fewer ripples in the torque and speed.
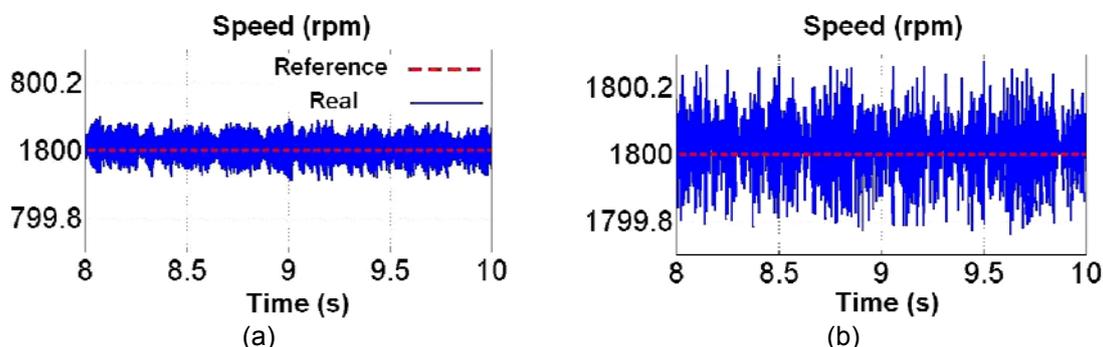

Figure 10. Simulation Results of Comparison between Speed Response in Single-phase IM (a) not assuming $(M_q/M_d)^2 = L_{qs}/L_{ds}$ (b) assuming $(M_q/M_d)^2 = L_{qs}/L_{ds}$

5. Conclusion

An accurate technique for speed control of single-phase IMs based on RFOC has been presented. The proposed method employs rotational transformations that transform the unbalanced single-phase IM equations into equations of RFOC that has the same structure as the balanced motor. Unlike other RFOC method implemented for the single-phase IMs, the proposed technique does not utilize the supposition $(M_q/M_d)^2 = L_{qs}/L_{ds}$. Simulation results proved the technique validity.

References
[1] MR Correa, CB Jacobina, ERCD Silva, AMN Lima. Vector control strategies for single-phase induction motor drive systems. *IEEE Trans. Ind. Electron.* 2004; 51(5): 1073-1080.
[2] MBR Correa, CB Jacobina, AMN Lima, ERC da Silva. Rotor Flux Oriented Control of a Single Phase Induction Motor Drive. *IEEE Transactions on Industrial Electronics*. 2000; 47(4): 832-841.
[3] M Jemli, HB Azza, M Boussak, M Gossa. Sensorless Indirect Stator Field Orientation Speed Control for Single-Phase Induction Motor Drive. *IEEE Transaction on Power Electronics*. 2009; 24(6): 1618-1627.
[4] Zicheng Li, Zhouping Yin, Youlun Xiong, Xinzhi Liu. Rotor Speed and Stator Resistance Identification Scheme for Sensorless Induction Motor Drives. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2013; 11(1): 503-512.
[5] T Sutikno. The Preliminary Research for Implementation of Improved DTC Scheme of High Performance PMSM Drives. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2008; 6(3): 155-166.
[6] M Jannati, E Fallah. *A New Method for Speed Sensorless Vector Control of Single-Phase Induction Motor Using Extended Kalman Filter*. Conf. Proc. Of ICEE. 2011.
[7] Sh Reicy Harooni, S Vaez-Zadeh. *Decoupling Vector Control of Single-Phase Induction Motor Drives*. Power Electronics Specialists Conference. 2005; 733-738.
[8] S Vaez-Zadeh, A Payman. Design and analysis of sensorless torque optimization for single phase induction motors. *Int. J. Energy Conver. Manag*. 2006; 47: 1464-1477.
[9] HB Azza, M Jemli, M Boussak, M Gossa. High performance sensorless speed vector control of SPIM Drives with on-line stator resistance estimation. *J. Simulat. Practice Theory*. 2011; 19: 271-282.
[10] HB Azza, M Jemli, M Boussak, M Goss. Implementation of Sensorlee Speed Control for Two-Phase Induction Motor Drive Using ISFOC Strategy. *IJST, Transactions of Electrical Engineering*. 2011; 35(E1): 63-74.
[11] MB Correa, CB Jacobina, AMN Lima, ERC da Silva. A Three-Leg Voltage Source Inverter for Two-Phase AC Motor Drive Systems. *IEEE Trans. on Power Electronics*. 2002; 17(4): 517-523.
[12] AE Fitzgerald, C Kingsley, SD Umans. Electric Machinery. McGraw-Hill. 2003.
[13] M Jannati, NRN Idris, MJA Aziz. *A new method for RFOC of Induction Motor under open-phase fault*. In Industrial Electronics Society, IECON. 2013; 2530-2535.

[14] M Jannati, NRN Idris, Z Salam. *A New Method for Modeling and Vector Control of Unbalanced Induction Motors*. IEEE Energy Conversion Congress and Exposition. 2012; 3625-3632.

[15] M Jannati, A Monadi, NRN Idris, MJA Aziz, AAM Faudzi. Vector Control of Faulty Three-Phase Induction Motor with an Adaptive Sliding Mode Control. *Prz Elektrotech*. 2013; 89(12): 116-120.

[16] M Jannati, E Fallah. *Modeling and Vector Control of Unbalanced induction motors (faulty three phase or single phase induction motors)*. 1st. Conference on Power Electronic & Drive Systems & Technologies (PEDSTC). 2010; 208-211.