Improved Rotor Flux Estimating Technique Based on Current Model in FOC method

Tai Thanh Phan[1], *Cuong Dinh Tran* [2,*], *Martin Kuchar*[3], *Phuong Duy Nguyen*[3,4], *Chi Quynh Mai* [1], *Vinh Van Tran* [1], *Thong Tien Nguyen*[1]
[1]Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam.
[2]Power System Optimization Research Group, Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam.
[3]Faculty of Electrical Engineering and Computer Science, VSB – Technical University of Ostrava, Ostrava-Poruba, Czech Republic.
[4]Faculty of Electronics and Telecommunication, Saigon University, Ho Chi Minh City, Vietnam.

*Corresponding Author: Cuong Dinh Tran (email: trandinhcuong@tdtu.edu.vn)
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Abstract. *This paper presents an improved rotor flux estimation algorithm method based on current-voltage signals applied to field-oriented control (FOC) technique in multi-domain motor speed control. This mathematical model is designed to accurately determine the rotor flux vector from the feedback signals of the current and speed sensors. The two steps of converting three-phase current signals in the real-time domain to create spatial vectors in two domains of static coordinates and rotating coordinates corresponding to the rotor flux vector will be presented in detail in the paper. The results are simulated in MATLAB/Simulink environment to demonstrate the feasibility of the typical FOC and the proposed FOC method under different operating and loading conditions of the induction motor drive. The simulation results convincingly illustrate the effectiveness of the proposed induction motor control method.*

Keywords: *Field-oriented control, V/F control, speed control, rotor flux, rotor flux angle.*

1. Introduction

In industrial production and various applications, motors play an important role. When DC motors were first introduced, their ability to precisely regulate speed was widely recognized. However, DC motors have disadvantages such as deterioration of charcoal bristles, need for periodic maintenance, environmental impact, complex structure and limited capacity. In contrast, induction motors (IMs) are powerful, compact, cost-effective and require little maintenance. Induction motor drive (IMD) have overcome the challenges of complex nonlinear control structures to become the most popular machine type and become the first choice in many modern industries [1].

The design and control of IMD for nonlinear loads pose many challenges [2–4]. Recent studies have explored advanced control algorithms to improve the performance and efficiency of induction motor (IM) speed control [5, 6].

A widely used technique is Voltage/Frequency (V/F) control, which maintains throughput by keeping the voltage-to-frequency ratio stable. The torque speed characteristic of V/F control shows a wider speed range, a longer stable operating region for the motor, and a low starting current [7–9]. Advances in electronic technology and the development of high speed microprocessors have made field-oriented control (FOC) theory more feasible. The FOC method ensures smooth and quiet motor operation, providing a wider speed range and better dynamic performance than the V/F speed control method [10]. The FOC method offers several benefits, including precise and efficient management of torque and speed by controlling output voltage and current. FOC systems in IM use current and speed sensors to provide feedback [11, 12]. The typical FOC method is implemented to regulate the speed of the motor using two perpendicular component vectors used as reference values for flux control ix.st, allowing speed regulation, and a component used for torque control iy.st. Integrating data from both sensors is very important in the control process when using the FOC method for the motor control strategy [13, 14]. In an IM system powered by an inverter, it is possible to measure the current frequency and voltage in the rotor and stator circuits. This allows proposing a simple algorithm to estimate two coordinates: the flux to shape the system as a vector and the rotor speed to perform control [15]. The authors in [16,17] present solutions to estimate IMs' speed and rotor current based on their stability in low-speed regions.

Control signals, predefined parameters such as flux, rotor speed and control algorithm. When the reference control signal is converted into a voltage signal [18], switching pulses are generated through the sinusoidal pulse width modulation (SPWM) method, thereby controlling the inverter. This typical FOC controller analyzes this data and generates signals that ensure precise control of motor torque and speed, delivering high performance. However, the problem of error accumulation from the integration algorithm leads to deviations in the rotor flux angle and its value can increase indefinitely, causing some problems when operating the IM feedback beyond the data limit.

Estimation algorithm methods have recently been developed to solve the above problem. In estimators such as observers and Kalman filters, parameter sensitivity can be controlled using appropriate response coefficient design. However, limiting their value is difficult due to stability problems in the closed-loop speed operation of the vector control system of IM, and it is often necessary to adjust to the reference speed value of the motor. In particular, the Kalman filter algorithm has high computational complexity, posing challenges in practical implementation, especially when using observers or extended Kalman filters [19] to reduce rotor flow and speed estimation errors degree. The unscented Kalman filter [20] is a derivative-free estimator for nonlinear systems that has been recently used to estimate rotor speed and flux through the use of current and voltage from sensors. stator, however the method's performance is only similar to Extended Kalman Filter when applying the same model and parameters. Another flux estimation technique is to use a sliding mode observer [21] that uses the estimated speed to correct the flux observation based on the current error and the rotor flux estimate. Thus, the rotor flux plays an important role in the estimation at low speed ranges.

This paper proposes an improved algorithm for the FOC method using the current model (CM) for the IMD system to estimate the rotor flux. This flux estimation method is compared with the typical FOC method presented in Section 2. and Section 3. showing that the rotor flux angle is a periodic function. The simulation results are presented and discussed in Section 4. and Section 5.

2. Mathematical modelling of induction motor

This section concisely explains the mathematical model and the FOC strategy used for IM. The mathematical representation of an IM can be described by a system of differential equations that depicts the relationship between its electrical parameters and nonlinear characteristics:

$$\begin{cases} \frac{\mathrm{d}\,\overrightarrow{\mathrm{F}}_{\mathrm{s.st}}}{dt} = \tilde{\mathrm{u}}_{\mathrm{s.st}} - \mathrm{R_s}\tilde{\mathrm{i}}_{\mathrm{s.st}};\ \frac{\mathrm{d}\,\overrightarrow{\mathrm{F}}_{\mathrm{r.st}}}{dt} = -\mathrm{R_r}\tilde{\mathrm{i}}_{\mathrm{r.st}} + \mathrm{j}\Omega_\mathrm{r}\overrightarrow{\mathrm{F}}_{\mathrm{r.st}} \\ \tilde{\mathrm{i}}_{\mathrm{s.st}} = \frac{1}{\mathrm{L_s}}\overrightarrow{\mathrm{F}}_{\mathrm{s.st}} - \frac{\mathrm{L_m}}{\mathrm{L_s}}\tilde{\mathrm{i}}_{\mathrm{r.st}};\ \tilde{\mathrm{i}}_{\mathrm{r.st}} = \frac{1}{\mathrm{L_r}}\overrightarrow{\mathrm{F}}_{\mathrm{r.st}} - \frac{\mathrm{L_m}}{\mathrm{L_r}}\tilde{\mathrm{i}}_{\mathrm{s.st}} \end{cases} \quad (1)$$

where: Ω_{rt} is the rotor speed; $\tilde{i}_{s.st}$,$\tilde{u}_{s.st}$ are the stator current and voltage vectors; $\overrightarrow{F}_{s.st}$ is the stator flux vector; $\overrightarrow{F}_{r.st}$,$\tilde{i}_{r.st}$ is the rotor flux and the current rotor vectors; R_s,R_r are the stator and rotor resistance. L_s,L_r,L_m are the stator, rotor, and magnetizing inductances. The IM's torque can be stated as shown in Eq. 2.

$$T_e=\frac{3}{4}.p.Im(\tilde{i}_{s.st}.\overrightarrow{F}_{r.st}) \tag{2}$$

3. The rotor flux estiamtion

In this section, part 3.1. presents a typical FOC method. Part 3.2. is to apply the new current model to the FOC method.

3.1. The typical FOC framework with the sinusoidal pulse width modulation technique

The typical FOC method is implemented to regulate the speed of the motor using two perpendicular component vectors used as reference values for flux control ($i_{x.st}$), allowing speed regulation, and a component used for torque control ($i_{y.st}$) [12]. Figure 1 illustrates the classic FOC controller structure. The Clarke transformation

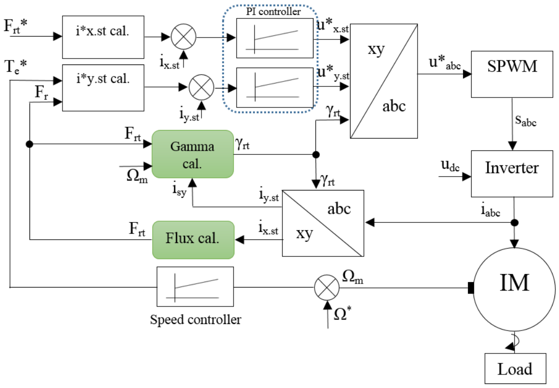

Fig. 1: The structure of FOC technique.

is applied to convert stator current into a rotating coordinate system and this process is carried out as in Eq 3:

$$\begin{cases} i_{x.st}=\frac{2}{3}\left[i_a.\cos(\text{fl}_{rt})+i_b.\cos(\text{fl}_{rt}-2\pi/3)+i_c.\cos(\text{fl}_{rt}+2\pi/3)\right] \\ i_{y.st}=-\frac{2}{3}\left[i_a.\sin(\text{fl}_{rt})+i_b.\sin(\text{fl}_{rt}-2\pi/3)+i_c.\sin(\text{fl}_{rt}+2\pi/3)\right] \end{cases} \tag{3}$$

The rotor flux and slip speed of the motor are expressed in terms of current elements $i_{x.st}$ and $i_{y.st}$ as follows, with $T_r=L_r/R_r$ is rotor time constant.

$$\begin{cases} F_{rt}=L_m\frac{1}{1+T_r.s}.i_{x.st} \\ \Omega_{slip}=L_m\frac{1}{T_r.F_{rt}}.i_{y.st} \end{cases} \tag{4}$$

The rotor flux angle fl_{rt} is calculated based on the measured rotor speed and slip speed.

$$\text{fl}_{rt}=\int(p.\Omega_m+\Omega_{slip})dt \tag{5}$$

The reference component $i^*_{x.st}$ is estimated from the rotor flux presented by the formula below:

$$i^*_{x.st}=\frac{1}{L_m}.F^*_{rt} \tag{6}$$

The rotor flux and slip speed of the motor are expressed in terms of current elements $i_{x.st}$ and $i_{y.st}$ as follows, with $T_r=L_r/R_r$ is rotor time constant.

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The rotor flux angle fl_{rt} is calculated based on the measured rotor speed and slip speed.

$$\text{fl}_{rt}=\int(p.\Omega_m+\Omega_{slip})dt \tag{8}$$

The reference component $i^*_{x.st}$ is estimated from the rotor flux presented by the formula below:

$$i^*_{x.st}=\frac{1}{L_m}.F^*_{rt} \tag{9}$$

The reference torque component is generated from comparing the measured speed and the set speed via the PI controller. The reference current $i^*_{y.st}$ is estimated from the rotor torque and flux as follows:

$$i^*_{y.st}=\frac{2}{3}\frac{1}{p}\frac{L_r}{L_m}\frac{1}{F_{rt}}T^*_e \tag{10}$$

The estimated currents $i^*_{x.st}$, $i^*_{y.st}$ are compared with $i_{x.st}$, $i_{y.st}$ to produce an error, this error will be passed through the PI error corrector to produce the voltage $u^*_{x.st}$, $u^*_{y.st}$. The voltage will be converted to become u^*_{abc}. The reference phase stator voltages are converted, shown as:

$$\begin{cases} u^*_a = u^*_{x.st}\cos(\text{ﬂ}_{rt}) - u^*_{y.st}\sin(\text{ﬂ}_{rt}) \\ u^*_b = u^*_{x.st}\cos(\text{ﬂ}_{rt} - 2\text{ß}/3) - u^*_{y.st}\sin(\text{ﬂ}_{rt} - 2\text{ß}/3) \\ u^*_c = u^*_{x.st}\cos(\text{ﬂ}_{rt} + 2\text{ß}/3) - u^*_{y.st}\sin(\text{ﬂ}_{rt} + 2\text{ß}/3) \end{cases} \tag{11}$$

The reference voltage u^*_{abc} are converted into the inverter's switching impluses Sabc signal sequence through sinusoidal pulse width modulation (SPWM) technique. The SPWM technique compares the reference signal's value with that of the 10 kHz triangle waves to generate the switching impulses for controlling inverter. This comparison determines the states of openness and closure for the switches in the control circuit. This process guarantees that the actual voltage remains within the designated sensitivity range, as illustrated in Figure 2. The S_{abc}

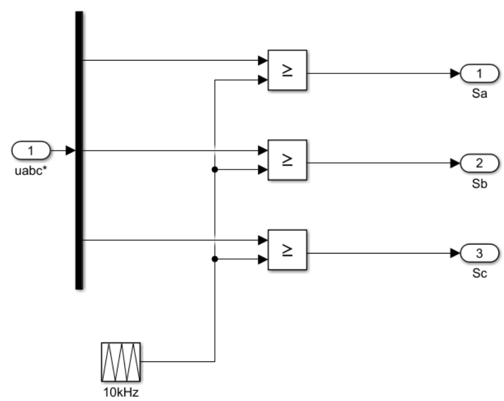

Fig. 2: The switching pulse generation of the SPWM technique.

signal is fed to the inverter for control and is used to create a 3-phase voltage corresponding to the desired frequency.

3.2. The rotor flux estimation by applying a current model based on the FOC framework

For FOC, estimating the flux linkage space phasor position is essential. Therefore, it is necessary to model the rotor flux linkages for the FOC technique. A new current model (CM) is applied in the proposed structure of the FOC technique to determine the rotor flux's magnitude and rotation angle, as shown in the block diagram of Figure 3.

Clarke's transformations convert the stator voltage in [a, b, c] coordinate system into $[\alpha, \beta]$ stationary coordinate system.

$$\begin{cases} i_{\text{ﬀ}.st} = \frac{2}{3}i_a - \frac{1}{3}i_b - \frac{1}{3}i_c \\ i_{\text{ﬁ}.st} = -\frac{\sqrt{3}}{3}i_b - \frac{\sqrt{3}}{3}i_c \end{cases} \tag{12}$$

The current components in the $[\alpha, \beta]$ coordinate

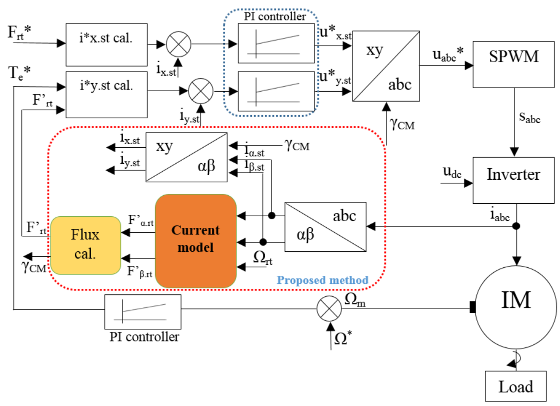

Fig. 3: A New Current Model based on FOC technique.

system are transformed into the rotating coordinate system $[x, y]$ with rotor flux angle by curent model ﬂ_{CM} , the Park transformation as bellow:

$$\begin{cases} i_{x.st} = i_{\text{ﬀ}.st}\cos(\text{ﬂ}_{CM}) + i_{\text{ﬁ}.st}\sin(\text{ﬂ}_{CM}) \\ i_{y.st} = -i_{\text{ﬀ}.st}\sin(\text{ﬂ}_{CM}) + i_{\text{ﬁ}.st}\cos(\text{ﬂ}_{CM}) \end{cases} \tag{13}$$

The current model block receives the current signals $i_{\text{ﬀ}.st}, i_{\text{ﬁ}.st}$ and the rotor electrical speed to estimate the rotor flux in $[\alpha, \beta]$ the coordinate system in Eq. 14, where $T_r = L_r/R_r$ is the rotor time constant.

$$\begin{cases} F'_{\text{ﬀ}.rt} = \int [\frac{L_m}{T_r} i_{\text{ﬀ}.st} - \frac{1}{T_r} F'_{\text{ﬀ}.rt} - \Omega_{rt} F'_{\text{ﬁ}.rt}]dt \\ F'_{\text{ﬁ}.rt} = \int [\frac{L_m}{T_r} i_{\text{ﬁ}.st} - \frac{1}{T_r} F'_{\text{ﬁ}.rt} + \Omega_{rt} F'_{\text{ﬀ}.rt}]dt \end{cases} \tag{14}$$

The flux calculation block is used to generate improved magnetizing current F'_{rt} and the rotor flux angle γ_{CM}, by Eq. 15.

$$\begin{cases} \text{Amplitude}: F'_{rt} = \sqrt{F'^2_{\text{ﬀ}.rt} + F'^2_{\text{ﬁ}.rt}} \\ \text{Phaseangle}: \text{ﬂ}_{CM} = \tan^{-1}(\frac{F'_{\downarrow.rt}}{F'_{\uparrow.rt}}) \end{cases} \tag{15}$$

The estimated rotor flux and rotor flux angle are used to generate the reference stator current for the FOC method, as presented in Section 3.1.

4. Simulation results

The parameter of studies selects the following values for the IM: P_n = 3500 W, V_{sn} = 308 V, n_{rate} = 1420 rpm, p =2, Ψ_{sn} = 1.23 Wb, R_s = 3.179 Ω, R_r = 2.118 Ω, L_m = 0.192 H, L_s = 0.209 H, and L_r = 0.209 H. The simulation results included both models' rotor speed, electrical torque, stator current, and rotor flux responses.

The IM simulation model is fully displayed in Figure 4, and the proposed simulation model is based on the CM in Figure 5.

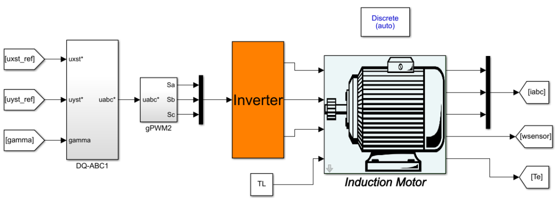

Fig. 4: The induction motor simulink model.

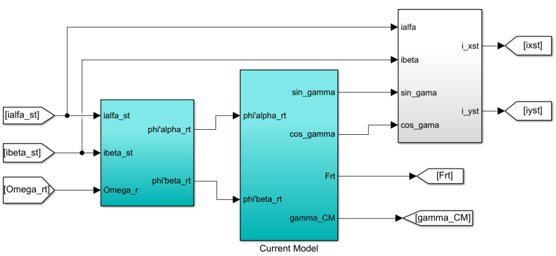

Fig. 5: The current Simulink model.

The IM's control simulation is shown below. The IM's response is displayed in two distinct cases:

Case study 1: The reference speed of the IM is kept at a low speed, increased from 0 to 350 rpm (25% of rated value) in 1.5 seconds, then increased to 710 rpm (about 50% of rated value) at 2.0 seconds and remains constant until the end of the operating cycle. The load torque is maintained at 0 Nm. Figure 6 illustrates the performance of a typical FOC method when the IM is operating at no load. Figure 6(a) shows that the motor speed quickly reaches 350 rpm in about 0.5 seconds, and overdrive occurs, after which the speed remains constant. At 1.5 seconds to 2.0 seconds, the speed increases to about 50% of the rated value (710 rpm). Although there is an overspeed phenomenon, the speed quickly reaches the set value and operates stably until the end of the cycle. Figure 6(b) shows the balance between electrical and load torque despite the strong torque fluctuations produced by the typical FOC method to ensure system performance and stability. Figure 6(c) shows the compatibility between the x-axis and y-axis currents to ensure the performance and stable operation of the IM. Figure 6(d) depicts the rotor flux angle increasing infinitely due to the integration algorithm. When the rotor flux angle value exceeds the data limit, the value may be zero, affecting the IMD's performance.

The performance of the proposed FOC method using a current model (CMFOC), operating under the same conditions as a typical FOC, is shown in Figure 7. Figure 7(a, b, c) depicts the proposed method's speed, torque characteristics, and x, y axis currents. These values are equivalent to typical FOC. Figure 7d shows that the rotor flux angle is variable in the range $[-\pi, \pi]$. Simulation results have demonstrated the effectiveness of the proposed method.

Case study 2: Perform motor reversal at low speed; the motor accelerates from 0 to 1/4 of the rated speed value (355 rpm), and after 1.0 seconds, the motor rotates back at the same speed. The load torque is maintained at a value of 3 Nm throughout the operation. Figures 8 and 9 show the results when the motor reverses. The IMD systems both demonstrate stable and reliable performance by applying the typical FOC method and the proposed FOC method. The motor's speed, torque, and xy-axis current values operate as required, strictly following the set values, as shown in Figure 8(a, b, c), 9(a, b, c). Figures 8(d), and 9(d) show that the magnetic flux angle also changes direction when the motion reverses the direction of rotation. The typical FOC method still shows that the flux angle is a nonlinear function. It is easy to see that the rotor flux angle in the proposed FOC method is

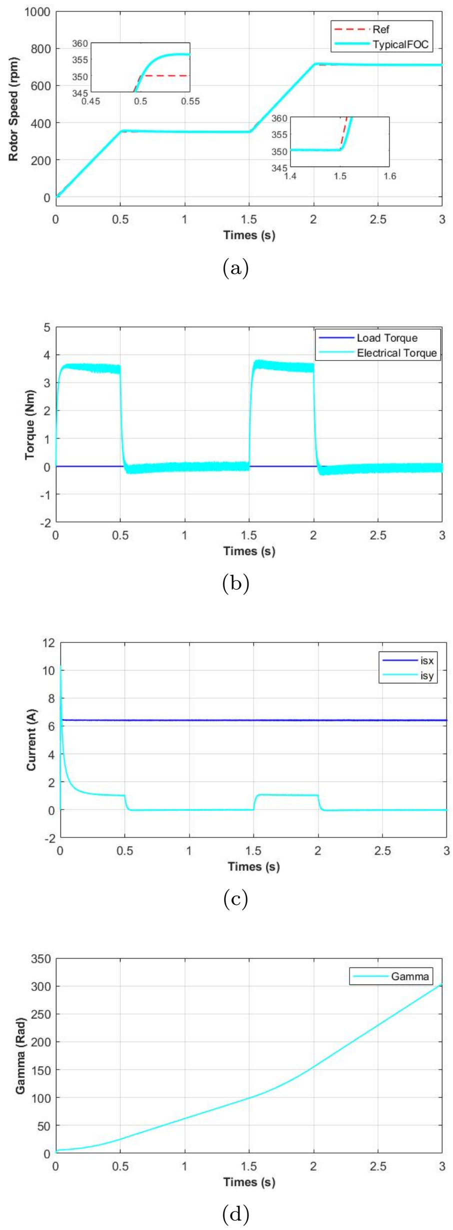

Fig. 6: Performance of typical FOC method at no-load condition: (a) Reference and real rotor speed, (b) Torque, (c) Current, (d) Rotor flux angle.

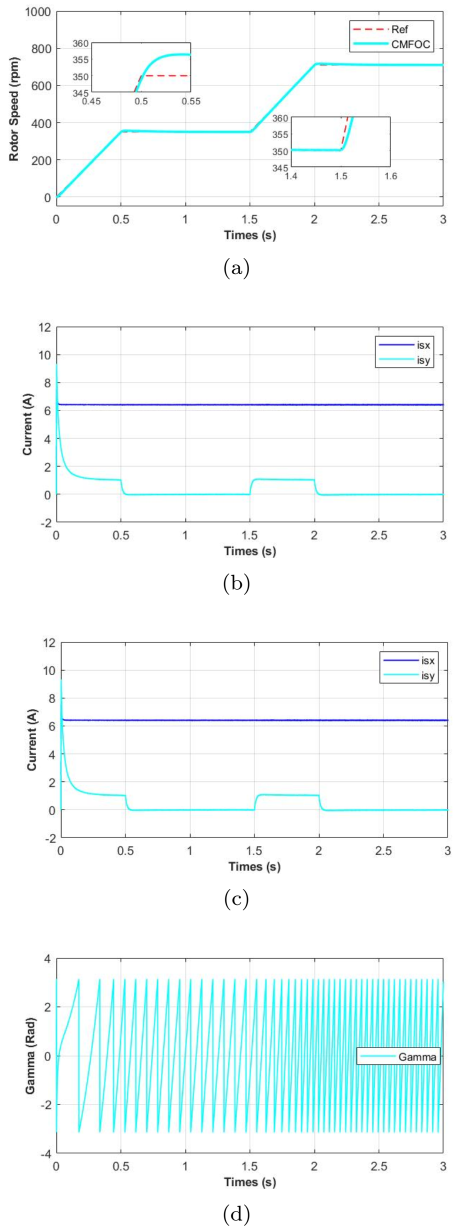

Fig. 7: Performance of the proposed FOC method at no-load condition: (a) Reference and real rotor speed, (b) Torque, (c) Current, (d) Rotor flux angle.

still limited to a limited range that the IM stable motor operation.

Case study 3: The reference speed of IM increases as a step function, in the first 0.5 seconds the speed is zero, at 0.5 seconds the motor speed is 200 rpm, after 1.5 seconds and 2.5 seconds, the motor speed increases 400 rpm and 600 rpm respectively and kept at this speed until the end of the process. Load torque is maintained at 3 Nm. Figures 10 and 11 show the results of the motor when the speed changes as a step function. The IMD system both exhibits stable

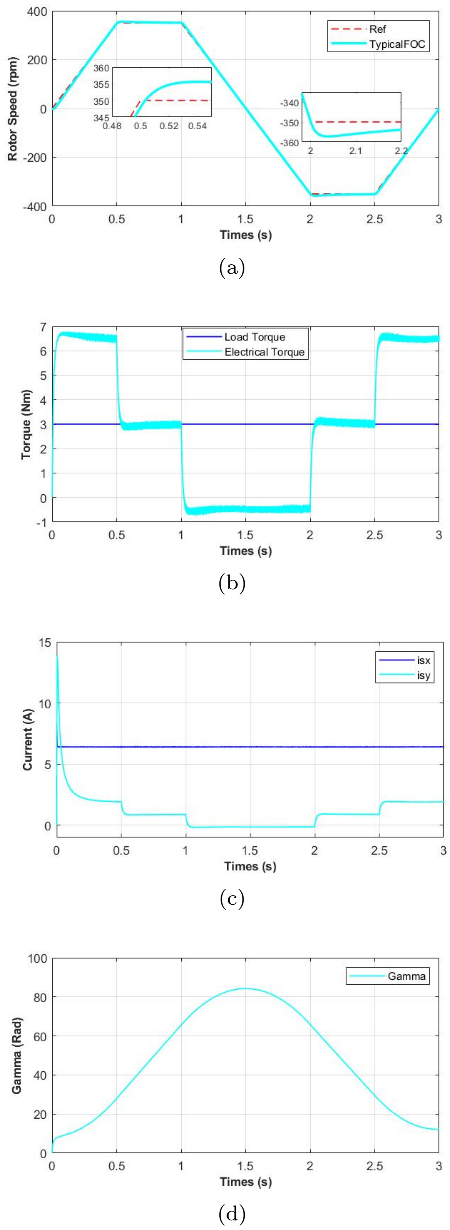

Fig. 8: Performance of typical FOC method at a load of 3 Nm condition: (a) Reference and real rotor speed, (b) Torque, (c) Current, (d) Rotor flux angle.

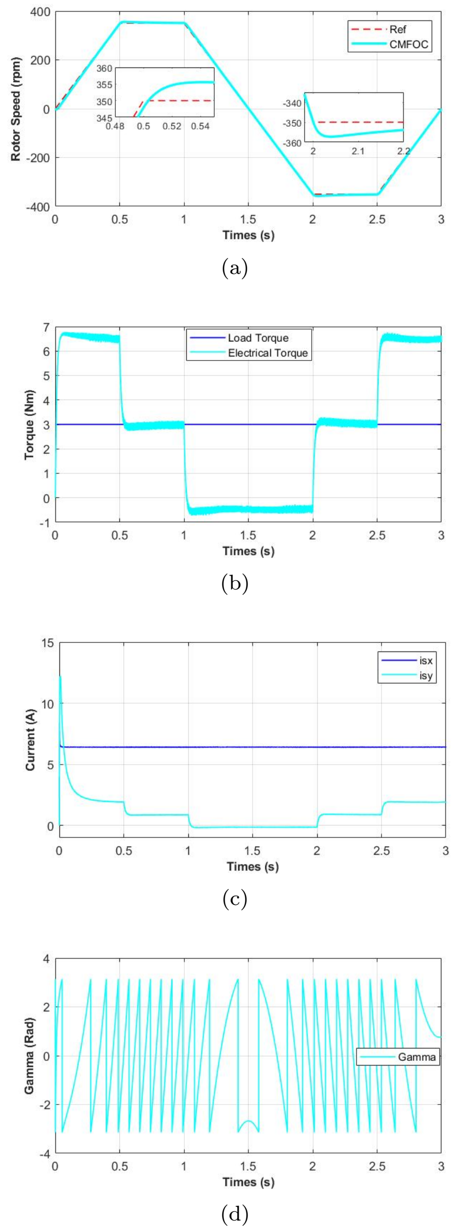

Fig. 9: Performance of the proposed FOC method at a load of 3 Nm condition: (a) Reference and real rotor speed, (b) Torque, (c) Current, (d) Rotor flux angle.

and reliable performance by applying the typical FOC method and the proposed FOC method. Figures 10(a, b, c), 11(a, b, c) show the values of speed, torque and xy axis current of the motor operating as required. Figures 10(d) and 11(d) show different flux angles similar to study case 1.

The simulations illustrated the speed control of the IM, demonstrating its response in three specific situations. Simulation results confirm the stability and robustness of the proposed IM control system. In the first case, the motor operation is observed as a step change in both reference speed. The second case explores the IM's response to speed and torque reversals, and case 3 shows that the system remains stable when speed is a step function.

5. Conclusions

This paper presents an improved method using a current model to estimate the rotor flux based on the FOC strategy to control the motor speed. The effectiveness of this innovative technique was confirmed using simulations performed under various operating conditions, including varying loads. A typical FOC method is compared with a proposed FOC method using a current model (CMFOC), which produces equivalent values of speed, torque, and current. However, the proposed method has the rotor flux angle varied within a specific range and has demonstrated its effectiveness in simulation results. The main benefit of the proposed method is reduced fluctuation amplitude and stable operation. In addition, the rotor resistance of the current model can significantly affect the accuracy of prediction and control. This problem can be solved in the future by using intelligent and flexible algorithms to adapt to fluctuations in IM parameters and ensure stable system performance.

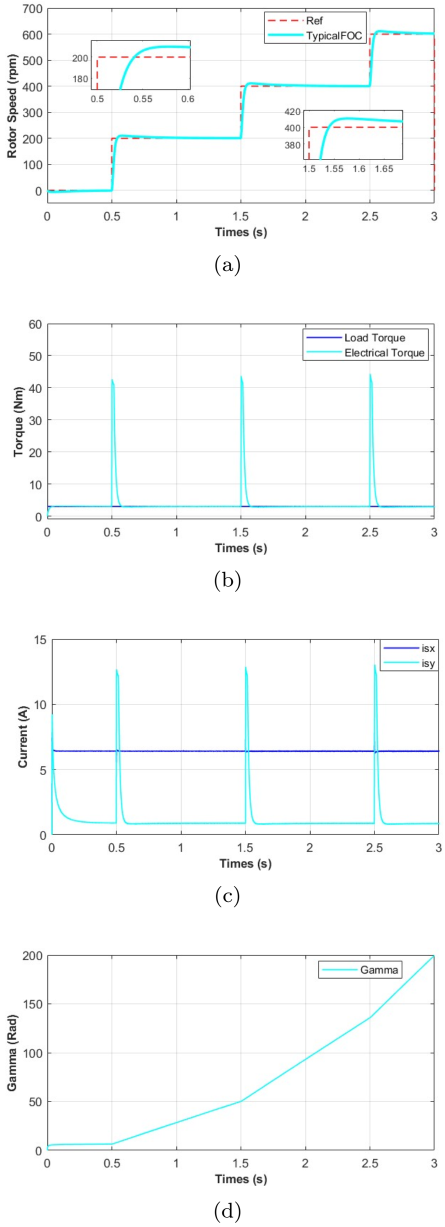

Fig. 10: Performance of typical FOC method at speed step function under 3 Nm load condition: (a) Reference and real rotor speed step function, (b) Torque, (c) Current, (d) Rotor flux angle.

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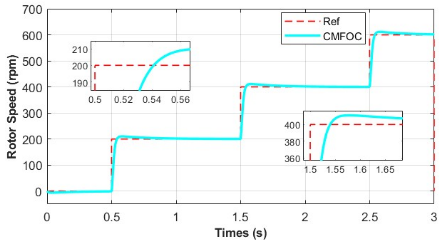
References

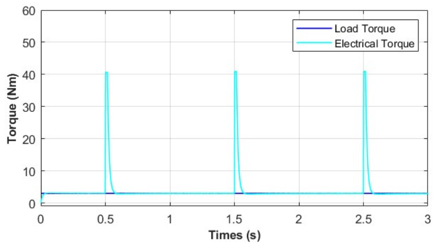
[1] T. F. Chan and K. Shi. Applied intelligent control of induction motor drives. *John Wiley & Sons*, 2011.

[2] I. Neborak, V. Sladecek, and M. Kuchar. Modelling and simulation of induction machine and frequency converter considering power losses. *16th Int. Sci. Conf. on Electr. Power Eng.*, pages 251–255, 2015.

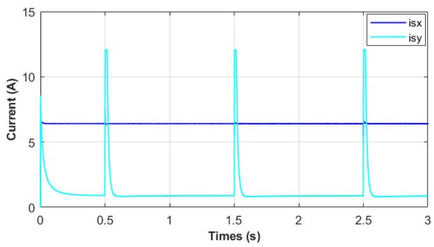
[3] T. L. Le and V. Q. Nguyen. A robust control for five-level inverter based on integral



(a)



(b)



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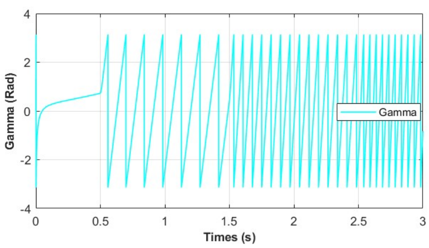

(d)

Fig. 11: Performance of the proposed FOC method at speed step function under 3 Nm load condition: (a) Reference and real rotor speed step function, (b) Torque, (c) Current, (d) Rotor flux angle.

sliding mode control. *Int. J. Integr. Eng.*, 15(4):177–192, 2023.

[4] V. Q. Nguyen, T. L. Le, N. B. Nguyen, and M. T. Nguyen. A robust adaptive control for multilevel inverters based on sliding mode control. *6th Int. Conf. on Green Technol. Sustain. Dev.*, pages 1132–1138, 2022.

[5] A. Consoli, G. Scarcella, and A. Testa. Speed- and current-sensorless field-oriented induction motor drive operating at low stator frequencies. *Trans. on Ind. Appl.*, 40(1):186–193, 2004.

[6] M. Ghanes and G. Zheng. On sensorless induction motor drives: Sliding-mode observer and output feedback controller. *Trans. on Ind. Electron.*, 56(9):3404–3413, 2009.

[7] K. B. Hunasikatti, R. L. Naik, and B. V. Hiremath. Implementation of fpga based closed loop v/f speed control of induction motor employed for industrial applications. *Second. Int. Conf. on Adv. Electron. Comput. Commun.*, pages 1–6, 2018.

[8] W. Chen, D. Xu, R. Yang, Y. Yu, and Z. Xu. A novel stator voltage-oriented v/f control method capable of high output torque at low speed. *Int. Conf. on Power Electron. Drive Syst.*, pages 228–233, 2009.

[9] Y. Q. Xiang. Instability compensation of v/hz pwm inverter-fed induction motor drives. *Conf. Rec. IEEE IAS Annu. Meet.*, 1:613–620, 1997.

[10] E. S. Sergaki, N. Essounbouli, K. C. Kalaitzakis, and G. S. Stavrakakis. Fuzzy logic control for motor flux reduction during steady states and for flux recovery in transient states of indirect-foc ac drives. *The XIX Int. Conf. on Electr. Mach.*, pages 11–6, 2010.

[11] H. Haq, M. H. Imran, H. I. Okumus, , and M. Habibullah. Speed control of induction motor using foc method. *Int. J. Eng. Res. Appl.*, 5(3):154–158, 2015.

[12] C. D. Tran, P. Brandstetter, B. H. Dinh, S. D. Ho, and M. H. C. Nguyen. Current-sensorless method for speed control of induction motor based on hysteresis pulse width modulation technique. *J. Adv. Eng. Comput.*, 2(4):271–280, 2018.

[13] E. S. de Santana, E. Bim, and W. C. Amaral. A predictive algorithm for controlling speed and rotor flux of induction motor. *Trans. on Ind. Electron.*, 55(12):4398–4407, 2008.

[14] D. C. Tran, B. Pavel, K. Martin, and S. D. Ho. A novel speed and current sensor fault-tolerant control based on estimated stator currents in induction motor drives. *Int. Rev. Electr. Eng.*, 15(5):344–351, 2020.

[15] M. Bobrov and G. Tutaev. Flux estimation algorithms for double-fed induction motor drive field-oriented control. *Int. Conf. on Electr. Power Drive Syst.*, pages 1–6, 2018.

[16] M. Korzonek, G. Tarchala, and T. Orlowska-Kowalska. A review on mras-type speed estimators for reliable and efficient induction motor drives. *ISA transactions*, 93:1–13, 2019.

[17] M. Popescum, A. Bitoleanu, and C. V. Suru. Estimation of the rotor flux in the traction systems with induction motors and field-oriented control. *Int. Conf. on Electromechanical Energy Syst. n*, pages 1–6, 2023.

[18] M. Tran, C. D. Tran, B. H. Dinh, T. T. Phan, T. H. C. Nguyen, H. T. Nguyen, G. T. T. Lai, , and H. X. Phan. Speed control applying hysteresis current combining sine pulse width modulation for induction motor drive. *J. Adv. Eng. Comput.*, 6(1):45–59, 2022.

[19] M. Hilairet, F. Auger, and E. Berthelot. Speed and rotor flux estimation of induction machines using a two-stage extended kalman filter. *Automatica*, 45(8):1819–1827, 2009.

[20] B. Akin, U. Orguner, and A. Ersak. State estimation of induction motor using unscented kalman filter. *Proc. 2003 IEEE Conf. on Control. Appl.*, 2:915–919, 2023.

[21] Kun Zhao and Xiaojie You. Speed estimation of induction motor using modified voltage model flux estimation. *6th Int. Power Electron. Motion Control. Conf.*, pages 1979–1982, 2009.

About Authors

Tai Thanh PHAN was born in Vietnam in 1995. He received a Master degree in Electrical Engineering from Ton Duc Thang University, Ho Chi Minh City, Vietnam, in 2020. Now, he is a lecturer at the Faculty of Electrical and Electronics Engineering at Ton Duc Thang University, Ho Chi Minh City, Vietnam. His research areas are the application of optimization algorithms in the power system, renewable energy, and control engineering. Email: phanthanhtai@tdtu.edu.vn.

Cuong Dinh TRAN is the deputy head of the Electrical Engineering Department, Faculty of Electrical-Electronics Engineering at Ton Duc Thang University. He received his B.E, M.E degrees from Ho Chi Minh City University Of Technology, Vietnam, and Ph.D. degree from VSB-Technical University of Ostrava, the Czech Republic, in 2005, 2008, and 2020. His research interests include modern control methods and intelligent algorithms in motor drives. Email: trandinhcuong@tdtu.edu.vn.

Martin KUCHAR was born in Ostrava, Czech Republic, in 1977. He received the M.Sc. and Ph.D. degrees in Electrical Machines, Apparatus, and Drives from VSB-Technical University of Ostrava, Czech Republic, in 2000 and 2003, respectively. He worked as an R&D Engineer in practice for almost 10 years. Now, he is an Associate Professor in Electrical Engineering and Deputy Head of the Department of Electronics, Faculty of Electrical Engineering and Computer Science, VSB-Technical University of Ostrava. His research interests include DSC-based control systems, sensorless and sensor fault tolerant control of AC drives, applications of observers, estimators, and soft computing methods in the control of electrical drives. Email: martin.kuchar@vsb.cz.

Phuong Duy NGUYEN is a lecturer in the Electrical Engineering Department, Faculty of Electronics and Telecommunications at Saigon University. He received B.E degree from Ho Chi Minh City University of Technology and Education and M.E degree from Ho Chi Minh City University Of Technology in 2010 and 2014. He is a PhD student researching at the Faculty of Electrical Engineering & Computer Science, VSB – Technical University of Ostrava, Czech Republic. His research interests include modern control methods, intelligent algorithms in motor drives, and power systems. Email: phuong.nd@sgu.edu.vn, phuong.nguyen.duy.st@vsb.cz.

Chi Quynh MAI is an undergraduate student in the Faculty of Electrical-Electronics Engineering at Ton Duc Thang University. Her domain of concentration in research is the application of modern control methods and intelligent algorithms in induction motor drives. She participates in the student research group that studies "modern control methods of AC machines." Email: 42101176@student.tdtu.edu.vn.

Vinh Van TRAN is an undergraduate student in the Faculty of Electrical-Electronics Engineering at Ton Duc Thang University. His research interests are the application of modern control methods and intelligent algorithms in induction motor drives. He is a member of the student research group on "modern control methods of AC machines." Email: 42101276@student.tdtu.edu.vn.

Tien Thong NGUYEN was born in Vietnam in 1998. He received a Bachelor degree in Electrical Engineering from Ton Duc Thang University, Ho Chi Minh City, Vietnam, in 2021. He is currently a researcher in the Electrical Motor Field. His research mainly concerns induction motor drive control methods and machine learning algorithms. Email: nguyentienthong.electric@gmail.com.