

A New Linear Controller based on PI and PD Controllers to Regulate the Speed and Torque of Induction Motor

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Abstract - In this study, a novel Rotor Flux Oriented Control (FOC) approach for an induction motor (IM) is presented. The method used is based on Filter-type Proportional-Derivative (FPD) and One Plus Proportional Integral (1+PI) Controllers (FPD+(1+PI)) Controllers for Speed, flux and currents control. The FOC-FPD+(1+PI) technique, a proposed control, has the objective to reduce torque ripple, negligibly overshoot, and undershoot. The FOC-FPD+(1+PI) strategy is very good performances because they are robust, precise, simple structure system, and low response dynamic compared traditional FOC-PI strategy. The presented method has been tested with constant and variable speed conditions using Matlab / Simulink software and a 1.5 kW motor. Also, the behavior of the proposed strategy is studied in case the machine parameters change in terms of current quality and ripple ratio. The simulation results showed the effectiveness of the proposed strategy in improving the engine properties.

Keywords - Induction motor, Rotor Flux oriented control, Proportional-Integral, Proportional Integral filter type with proportional derivative plus (One +Proportional Integral controller).

I. INTRODUCTION

Numerous research studies have used various ways to control and modulation strategies in induction motors because induction motors have advantages in terms of simple installation, small size, and high transference of energy capacities [1][2]. If used in conjunction with a dependable simple controller technique, it will have an excellent use. The two vector control methods used in high-performance variable speed drive applications for induction motors are field-oriented control and direct torque control [3].

One of the numerous methods used to control an induction motor is called field-oriented control (FOC), which allows the torque and flux to be separated and controlled independently, much like a DC motor with an independent excited state [4][5]. When decoupling utilizing the control mechanism of the induction motor,

compensation for the coupling impact on the d- and q-axes current dynamics is important [6] [7]. Three fundamental components that constitute a PID controller, whose represent proportional (P), integral (I), and derivative (D) functions, are widely utilized in many industrial control loops because of their simple construction and cost-effectiveness [8].

Conventional Proportional Integral (PI) controllers continue to be utilized in industrial machinery because of their basic simplicity, stability, and suitable performance. An improved two-phase PID controller is suggested for IM in order to improve rapid performance.

A proportional derivative (PD) is used in the first step to hasten the control procedure. To improve the transient characteristics and eliminate the derivative controller-based derivative punch, the term of the derivative is used as a filter.

A 1+PI controller is used in the second step to eliminate steady-state errors from the final result [9][10].

In order to stabilize the rate of rotation in the rapid response time of the induction motor, the steady-state error must be minimized by carefully operating the constructed controller under a number of dynamic conditions. This can be done using a repeated filter type with an absolute derivative (FPD) and one plus a proportional-integral (1 + PI) at an acceptable rate. The key characteristics and features of this work are presented as follows:

- The filter effect types Proportional Derivative with (FPD) cascaded with One plus Proportional Integral (1+PI) is very robust used in as speed controller for induction motor.
- Using FOC to speed regulation for IM, It is recommended to use FPD + (1 + PI) controller; because it works much better compared to PI.
- To verify the efficiency and robustness of the new method PDF+(1+PI) controller, we use MATLAB simulation software by comparing it with the traditional method.

The remainder of this manuscript is organized as follows: Section 2 the model of induction motors a d-q reference frame is presented for of IM. Theoretical principles of FOC for of IM are represented in section 3. In Section 4 gives concise introduction of FPD+(1+PI) controller. In section 5 to use field-oriented control scheme is introduced with the traditional proportional-integral (PI), and FPD+(1+PI) controller, respectively. The simulation results are presented in Section 6. Finally, Section 7 concludes the work.

II. MODELING AND CONTROL (FOC) OF INDUCTION MOTOR

The mathematical model of the induction motor which is built in Simulink is expressed on stator reference frame [11][12].

A) Stator and Rotor Flux

The flux of dq-axis in terms of equivalent equations is specified as :

$$\begin{cases} \psi_{ds} = L_s i_{ds} + M i_{dr} \\ \psi_{qs} = L_s i_{qs} + M i_{qr} \\ \psi_{dr} = L_r i_{dr} + M i_{ds} \\ 0 = L_r i_{qr} + M i_{qs} \end{cases} \quad (1)$$

B) Stator and Rotor Voltage

$$\begin{cases} v_{ds} = R_s \cdot i_{ds} + \frac{d\psi_{ds}}{dt} - \omega \psi_{qs} \\ v_{qs} = R_s \cdot i_{qs} + \frac{d\psi_{qs}}{dt} + \omega \psi_{ds} \\ 0 = R_r \cdot i_{dr} + \frac{d\psi_{dr}}{dt} - (\omega - \omega_r) \psi_{qr} \\ 0 = R_r \cdot i_{qr} + \frac{d\psi_{qr}}{dt} + (\omega - \omega_r) \psi_{dr} \end{cases} \quad (2)$$

C) Equation of Dynamics

$$\frac{d\Omega_m}{dt} = \frac{1}{J} (T_e - T_L - f \cdot \Omega_m) \quad (3)$$

D) Electromagnetic Torque

$$T_e = \frac{3M}{2L_r} \cdot P (\psi_{dr} i_{qs} - \psi_{qr} i_{ds}) \quad (4)$$

III. PRINCIPE FIELD ORIENTED CONTROL

There are several techniques that can be used to control the induction machine. Field Oriented Control (FOC) will be presented. It was utilized in this work. This control concept presents a simple representation of an induction machine that resembles a direct current machine [13][14]. By the application of a number of constraints to the parameters, this principle aims to simplify the control of IM [15].

The term "rotor field-oriented control" in the present context applies to the direct and quadrature elements that comprise the rotor flux [16][17]:

$$\begin{cases} \psi_{qr} = 0 \\ \psi_{dr} = \psi_r \end{cases} \quad (5)$$

$$\frac{di_{sd}}{dt} = -\left(\frac{1}{\sigma T_s} + \frac{M^2}{\delta L_r T_r}\right) i_{sd} + \omega_s i_{sq} + \frac{M}{\delta L_r T_r} \psi_{rd} + \delta V_{sd} \quad (6)$$

$$\frac{di_{sq}}{dt} = -\left(\frac{1}{\sigma T_s} + \frac{M^2}{\delta L_r T_r}\right) i_{sq} - \omega_s i_{sd} - \frac{M}{\delta L_r} \omega \psi_{rd} + \delta V_{sq} \quad (7)$$

$$\frac{d\psi_{rd}}{dt} = \frac{M}{T_r} i_{sd} - \frac{1}{T_r} \psi_{rd} \quad (8)$$

$$\frac{d\Omega}{dt} = \frac{3pM}{2JL_r} \psi_{rd} i_{sq} - \frac{T_L}{J} - \frac{f}{J} \Omega \quad (9)$$

With:

$$T_s = \frac{L_s}{R_s}; T_r = \frac{L_r}{R_r}; \delta = \frac{1}{\sigma L_s}; \sigma = \frac{M}{L_s L_r}$$

The induction motor is described by two equations in the d-q axes:

$$\begin{cases} \dot{x} = A[x] + B[u] \\ y = C[x] \end{cases} \quad (10)$$

with:

$$\dot{x} = [i_{sd} i_{sq} \psi_{rd} \psi_{rq}]^t ; u = [V_{sd} V_{sq}]^t ; y = [i_{sd} i_{sq}]$$

IV. PROPOSED PI CONTROLLER DESIGN FOR INDUCTION MOTOR

PID controllers are commonly used in a number of industrial control systems. Because of its simple nature, An error is the variation between the defined point and the value of the procedure variable [18]. Fig. 1 presented structure PID controller, and is represented by a formula (10):

$$U_{PID}(t) = K_p \cdot e(t) + K_I \cdot \int_0^t e(t) \cdot dt + K_D \cdot \frac{de(t)}{dt} \quad (11)$$

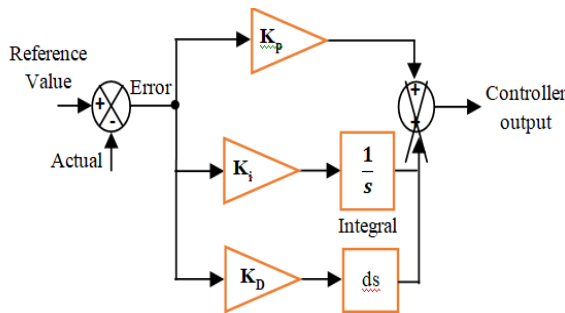


Fig. 1. Structure of the proposed PID controller.

The PID controller, as the name implies, is a type of control system that makes use of the gain values in the parameters P, I, and D.

The PI controller is made up of two components: proportional and integral. PI control has historically been an effective and commonly utilized approach to control systems.

The first method can proportionally reduce the deviation quickly, while the second method improves the periodic oscillation and overshoot produced by the proportional connection, bringing it infinitely close to the stated value [19], but its effectiveness depends heavily on proper tuning and careful consideration of its limitations [20].

The conventional PI controller is expressed in the following equation:

$$U_{PI}(t) = K_p \cdot e(t) + K_I \cdot \int_0^t e(t) \cdot dt \quad (12)$$

The problem of any command nonlinear system, in the work FOC strategy, is the robustness, time dynamic, overshoot, and undershoot, current quality (THD), durability, and periodic maintenance. Therefore, a new controller under

the name of based cascade FPD + (1+PI) controller is proposed in the following part, where the mathematical form is given to it with its advantages and disadvantages compared to the traditional controller.

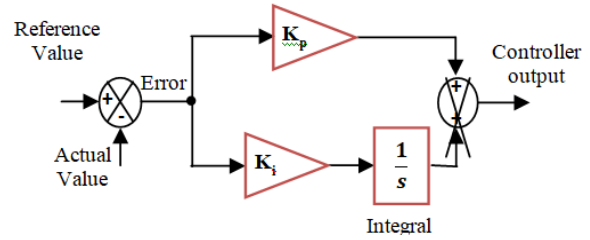


Fig. 2. Structure of the proposed PI controller.

V. PROPOSED FPD +(1+PI) CONTROLLER

When developed for systems that are linear and stable processes, proportional-integral (PI) enhances the system's dynamic response and also gives additional advantages such as simple design, cost-effectiveness, and application [21]. At the same time, conventional PI controllers are generally not efficient when the higher order nonlinear unstable systems.

In this study, an FPD + (1+PI) controller for IM utilizing a PWM inverter is proposed in order to obtain improved results. A PD controller with a filter and a one-plus PI controller make up the two components of the controller FPD + (1+PI). The error signal is used as a parameter by the PDF controller, whose output has been approved by the PI controller, in order to function.

The formula used can be used to represent the FPD + (1+PI) controller.

$$\begin{cases} U_{FPD}(t) = K_D \cdot \frac{d.N.e(t)}{N+dt} + K_p \cdot e(t) + K_I \cdot \int_0^t e(t) \cdot dt \\ U_{1+PI}(t) = 1 + K_p \cdot e(t) + K_I \cdot \int_0^t e(t) \cdot dt \end{cases} \quad (13)$$

where, K_P , K_I , K_D and N represents constant gains, and e represents error:

$$e = X_{reference} - X_{Actual}.$$

Figure 3 depicts the structure of the proposed FPD + (1+PI) controller.

The FOC method develops an effective controller for IM because it offers precise control of the induction motor with a fast dynamic response. The FOC method has become a prominent control technique for induction motors due to its effectiveness in achieving high-

speed control and torque. However, FOC strategies are more expensive than conventional

controller strategies and call for complicated controller strategies in Fig. 4.

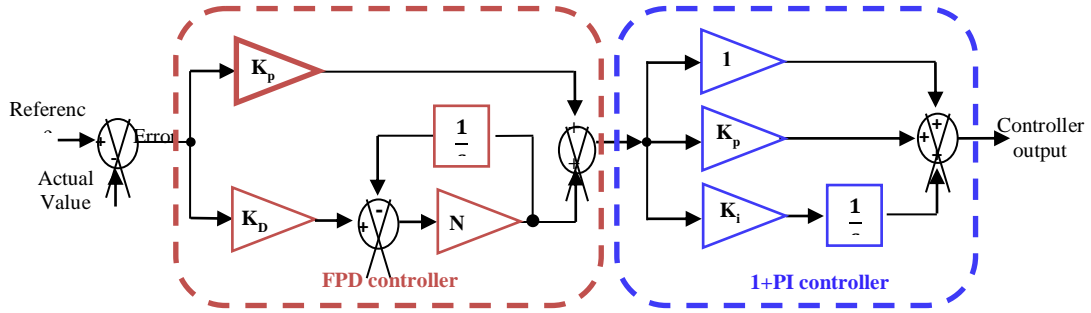


Fig. 3. Structure of the proposed a cascaded FPD+ (1+ PI) controller.

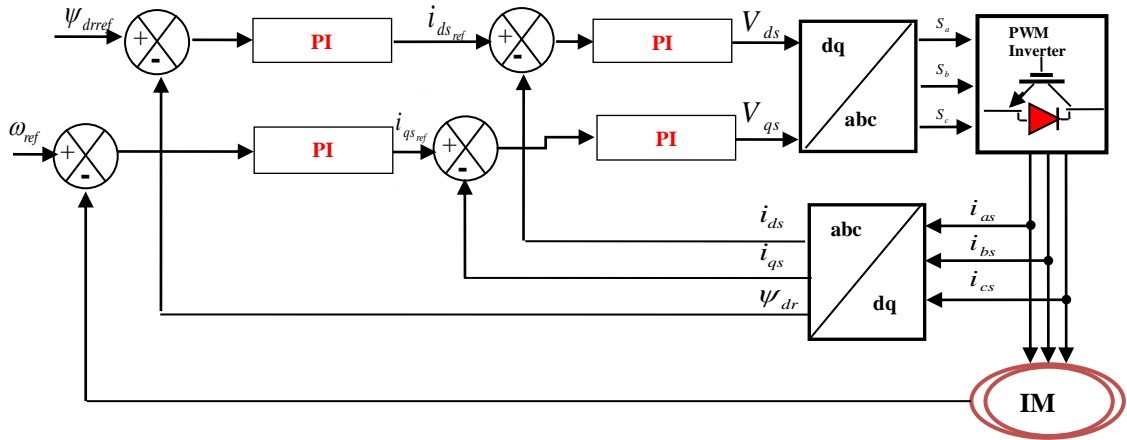


Fig. 4. Bloc diagram FOC-PI technique of the IM.

VI. RESULTS

The results of the behavior of the IM control are presented comparatively, using the classic PI controller, FDP+(1+PI) controller. The induction motor that used in this work is a 1.5kW. Nominal parameters presented in Table 1.

Table 1. Nominal parameters of induction motor.

Parameters	Numerical values
R_s	5.35 Ω
R_r	4.05 Ω
L_s	0.5763 H
L_r	0.5763 H
L_m	0.556 H

f	0 N.m.s
F_s	50 Hz
J	0.0498 Kg.m ²
p	2

A) Test 1: No Load Torque

Figure 6 presents the results of the simulation the FOC strategy an IM, where the speed, currents controllers is classical FOC-PI-type and FOC-FDP+(1+PI) type, respectively. For a speed reference of 157rad/sec , with no load torque. After this case. FDP+(1+PI) controller shows good performance than classic PI controller. Torque response of FDP+(1+PI) controller and classic PI controller are presented in Fig. 6(a).

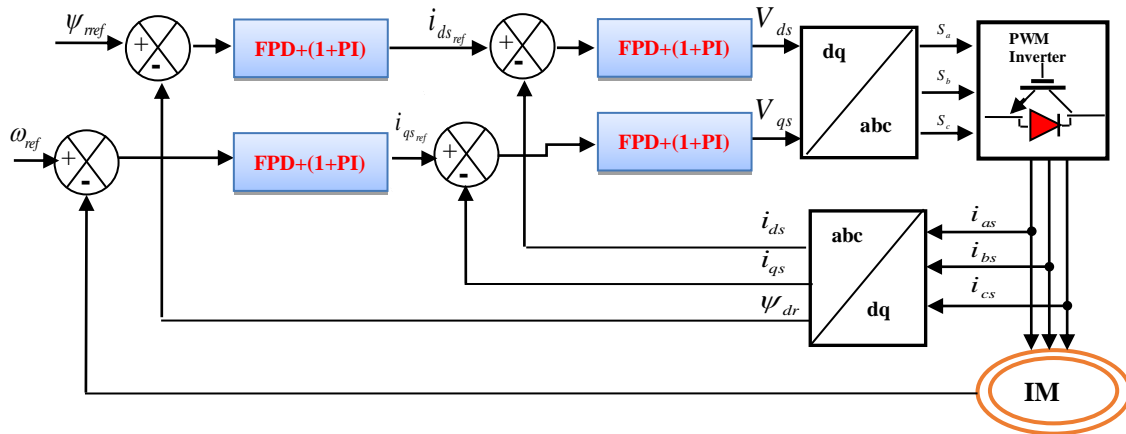
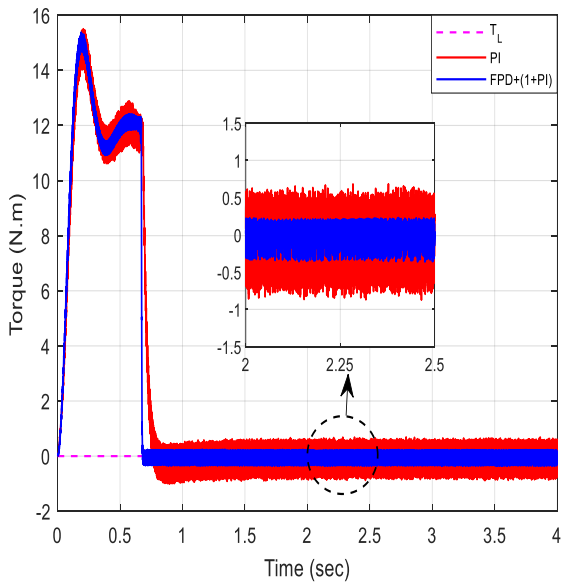
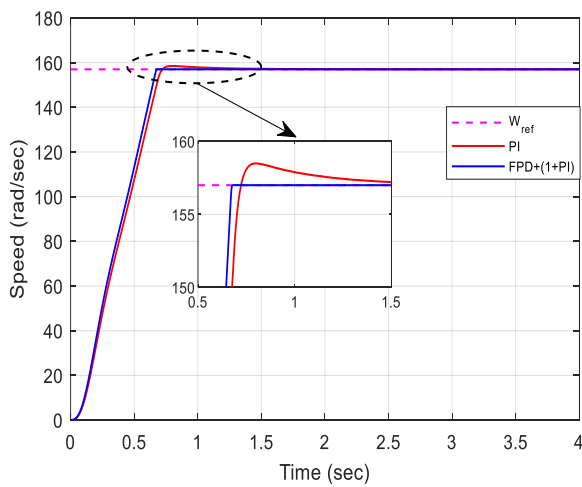


Fig. 5. The bloc diagram FOC-PI technique of the IM.



(a)



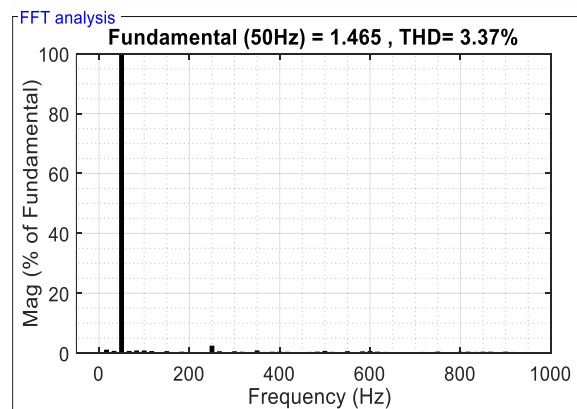
(b)

Fig. 6. Electromagnetic Torque and Rotor Speed in case 1 : (a)Electromagnetic Torque, (b) Rotor Speed.

Table 2. Comparative analysis of speed.

No Load Torque			
Controller	Rise Time (sec)	Response Time (sec)	Overshoot (%)
PI	0.289	0.67	0.94
FPD+(PI+1)	0.27	0.64	0.0003
RATION (%)	6.57	4.47	99.96

Figure 7 show the THD value of stator current in phase a for IM. Note that the THD value is reduced for FOC-FDP+(1+PI) strategy when compared to FOC-PI strategy. Through this table, we find that the proposed FOC-FDP+(1+PI) strategy minimized the THD value of stator current by about 84.86% compared to the FOC-PI technique.



(a)

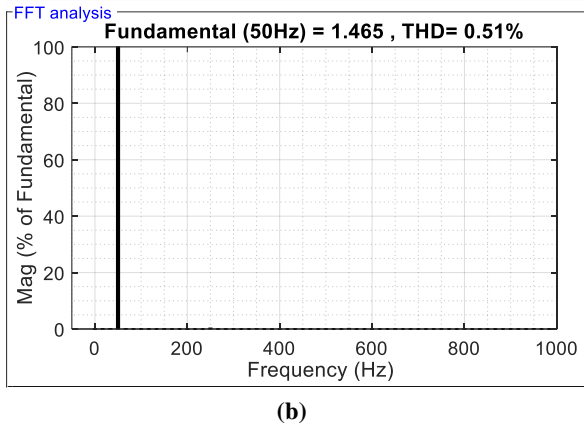


Fig. 7. THD current phases I_{sa} : (a) FOC-PI, (b) FOC-FPD + (1+PI).

B) Test 2: at Variation Load Torque

In the case, the results captured in Fig. 8 illustrate the constant speed under load torque variation of the IM. Torque response comparing curves are shown in Fig. a.8. See figure the torque ripple is significantly reduced when the FOC-FDP+(1+PI) strategy is in use. FOC-FDP+(1+PI) takes very less time to reach its reference value, this technique is very fast and dynamic response is also very good performance and static results are obtained, but with an obvious advantage of the FOC-PI controller.

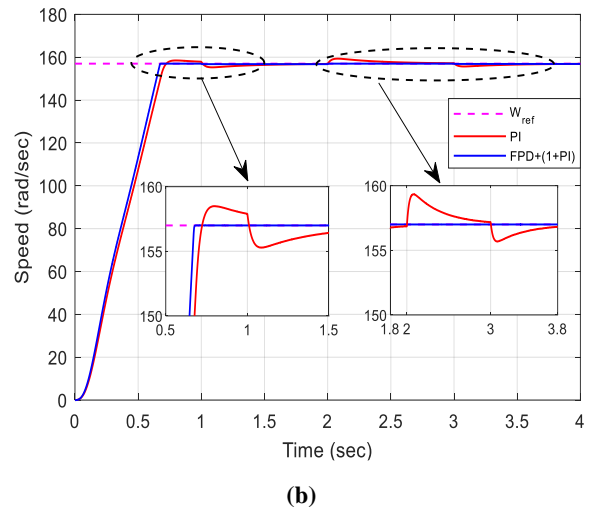
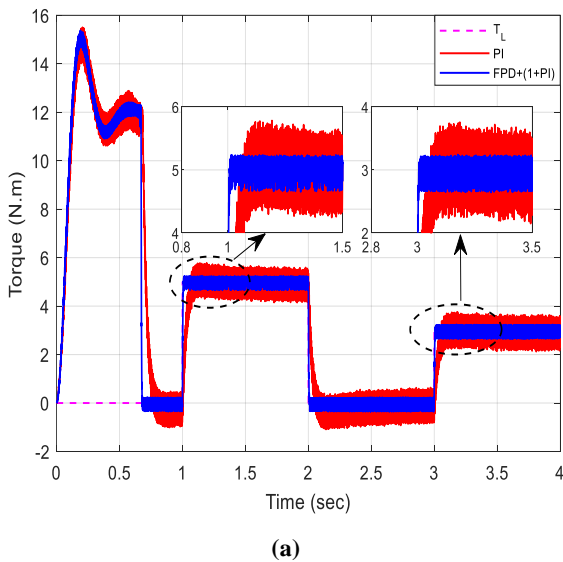


Fig. 8. Electromagnetic Torque and Rotor Speed in case 2: (a) Electromagnetic Torque, (b) Rotor Speed.

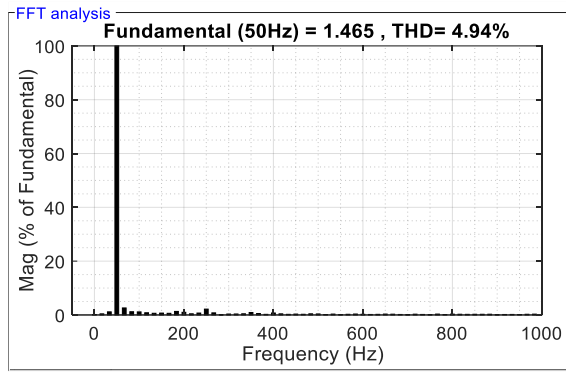
Table 3. Comparative analysis of performance in electromagnetic torque.

Variation Load Torque T_e (N.m)			
	Response time	Undershoot	Ripples
PI	0.2	0.67	0.8
FPD+(1+PI)	0.17	0	0.014
Ratios (%)	15	100	98.25

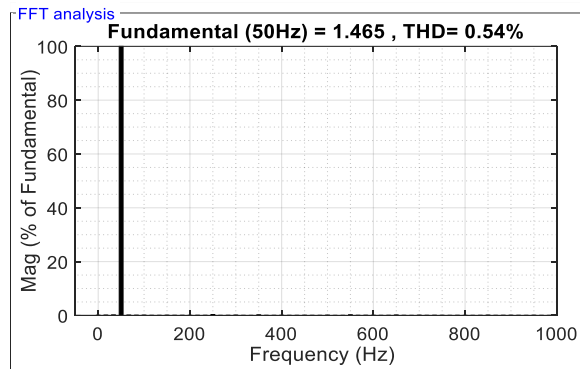
Table 4. Comparative analysis of performance in speed.

Speed W_r (rad/sec)				
	Response time	Overshoot	Undershoot	Error static
PI	0.67	1.15	0.90	0.109
FPD+(1+PI)	0.64	0.00006	0.0003	0.064
Ratios (%)	4.47	99.99	99.96	41.28

The THD of current in the FOC-FDP+(1+PI) technique has been reduced significantly (Fig.9. a and Fig.9. b). we find that the proposed FOC-FDP+(1+PI) technique reduced the THD value by about 89.06% compared to the FOC-PI strategy. Based on the results presented here, it can be concluded that the designed FOC-FDP+(1+PI) strategy is more robust than the traditional FOC-PI method.



(a)



(b)

Fig. 9. THD current phases I_{sa} : (a) FOC-PI; (b) FOC-FPD + (1+PI).

Table 5. Comparative analysis of performance in PI and FPD+(1+PI)

	FOC-PI	FOC-FPD+(1+PI)
Overshoot	High	Negligible
Undershoot	High	Negligible
Steady-state error	High	Low
Response time	Slow Fast	Very Fast
Torque response	Slow	Very fast
Torque ripples	High	Low
Simplicity	Simple	Simple

VII. CONCLUSION

In this present study, FPD+(1+PI) controller is proposed for the FOC technique for The dynamic performances of the considered IM system.

The efficiency of the developed technique has been supported by the results of Matlab/Simulink. As a comparison, the traditional PI controller and proposed controller were tested under the variation torque load conditions. The results showed that the proposed

FPD+(1+PI) controller for an IM allows high performances.

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