iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 **Issue:** X **Month of publication:** October 2023

DOI: https://doi.org/10.22214/ijraset.2023.56039

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue X Oct 2023- Available at www.ijraset.com

Comparative Study of Electric Traction Control Techniques: Application to Motor Vehicles

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Abstract: Climate change and evolution of technology have shown the important of electric vehicles (EV). Its performance strongly depends on the type of control techniques used to control their motor. In this paper, we compare the electric traction control techniques used in motor vehicles.
We consider an electric vehicle with two driving wheels and we model it to bring out the mechanical, electrical and electromechanical equations.
For our obtained road, we develop the control laws of our vehicle using Indirect Flux Oriented Control (IFOC) method, Direct Torque Control (DTC) method and Fuzzy DTC (DTFC) method. A comparative study of these control techniques is made using performance tools such as response-time, static error and ripple rate. Our study shows that DTFC method is better to obtain the motor instruction requested by the driver.
Keywords: Motor vehicles, scalar, IFOC, DTC, DTFC.

I. INTRODUCTION

With global warming, the use of 100% clean electric vehicles is becoming a priority for countries around the world. In recent years, **auto giants** have produced EVs such as Peugeot e – 208, Tesla Model 3, Renault Zoé, etc. But one of the difficulties encountered in this type of vehicle is the strategy for controlling the motors of the traction chain. Nasri *et al* presented a novel studies of sliding mode control applied on four independent wheels electric vehicle systems [3].

In they work, they proposed one propulsion system consists of four induction motors that ensure the driving of back front driving wheels. Bouguenna and collaborators investigated on a robust neuro-fuzzy-sliding mode control with extended state observer technique applied on the traction chain of the electric vehicle [4].

The autors proved that, their control system provided a quick response and robustness in case of fluctuations in the desired output caused by propulsion system load variation. Taibi *et al* analysed a new control structure base on DTC method used for the control of bi-machine traction system of an EV [5].

They studied the robustness of the EV in the presence of the various load cases involved in the electric vehicle traction chain. Ndoumbe and its co-workers developed a DTFC applied to the control of a 2-wheels EV drive utilizing an electronic differential with two induction motor rear drive wheels [6].

Nasri *et al* proposed a new control algorithm of one wheel motor based on backstepping control approach to control independently each in wheel induction motors [7]. Furthermore, the previous authors have not presented a comparative study of EV control techniques. In this article, we compare IFOC, DTC and DTFC steering techniques on a 4-wheel vehicle including 2 front wheel drives in order to identify the best steering technique. The structure of the paper is as follows : section 2 presents the physical description and mathematical modelling of EV with control. Comparative study of electric traction control technique of EV is presented in section 3. The concluding remarks and future work are given in section.

II. PHYSICAL DESCRIPTION AND MATHEMATICAL MODELING OF EV

A. Mechanical Action on EV

This subsection presents the dynamic model of a four-wheeled vehicle. Figure 1 highlights the different forces acting on the tires of the vehicle during its propulsion.

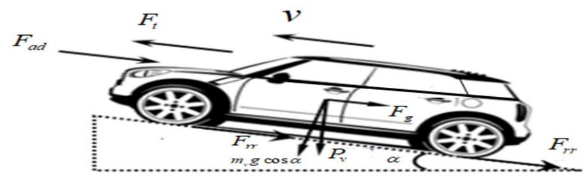

Fig.1 Forces exerted on a 4-wheel vehicle [4, 6]

where P_v : vehicle weight, F_{rr} : rolling resistance, F_{ad} : aerodynamic resistance force, F_g : force due to road profile, F_t : traction force, F_{acc} : force due to acceleration, α : road inclination.

All these forces are given by [6, 7]:

$$P_v = m_v g \,,\; F_{rr} = C_{rr} m_v g \cos\alpha \,,\; F_{ad} = \frac{1}{2}\rho A_f C_d \left(v \pm v_{air}\right)^2 ,\; F_g = m_v g \sin\alpha \,,\; F_{acc} = m_v \frac{dv}{dt} \tag{1}$$

where m_v : vehicle mass, g : gravity acceleration, C_{rr} : rolling resistance coefficient, ρ : air density, A_f : vehicle frontal area, C_d : aerodynamic resistance coefficient, v : vehicle speed, $\pm v_{air}$: air speed (with depends to the air direction).

The traction force is responsible for vehicle moving. It is defined by:

$$F_t = F_{rr} + F_{ad} + F_g + F_{acc} \tag{2}$$

This traction force create the torque propulsion with is given by :

$$C_{pv} = F_t R_w \tag{3}$$

where R_w : vehicule wheel radius.

The rotation speed of the vehicle wheel is defined by:

$$\Omega_w = \frac{v}{R_w} \tag{4}$$

B. *Electromechanical Modelling of two Wheels EV*

An EV is an assembly made up of electrical components and mechanical components. A two-wheel drive electric vehicle has two identical electric motors in their traction chain. These two motors are linked by the controller.

1) *Traction Motor*

Squirrel induction motor is used as the traction motor of the EV. This choice is justified by its robustness, easy control, etc. To model the squirrel induction motor, we consider the following assumptions [8, 9]:

- the magnetic circuit of the induction motor is not saturated;
- iron losses by hysteresis and eddy current, skin effect, teeth effect, notches effects are neglected;
- The distribution of the magnetic field in the air gap of the machine is sinusoidal;
- the inductances of motor are constant.

By using the Park and Concordia transformations (Figure 2), we obtain the three-phase and two-phase models of the induction motor defined respectively by:

$$\frac{d}{dt}\begin{bmatrix} i_{sd} \\ i_{sq} \\ \phi_{rd} \\ \phi_{rq} \end{bmatrix} = \begin{bmatrix} -\left(\frac{1}{\sigma\tau_s}+\frac{1-\sigma}{\sigma\tau_r}\right) & \omega_s & \frac{1-\sigma}{\sigma M\tau_r} & \frac{(1-\sigma)\omega_r}{\sigma M} \\ \omega_s & -\left(\frac{1}{\sigma\tau_s}+\frac{1-\sigma}{\sigma\tau_r}\right) & -\frac{(1-\sigma)\omega_r}{\sigma M} & \frac{1-\sigma}{\sigma M\tau_r} \\ \frac{M}{\tau_r} & 0 & -\frac{1}{\tau_r} & (\omega_s-\omega_r) \\ 0 & \frac{M}{\tau_r} & -(\omega_s-\omega_r) & -\frac{1}{\tau_r} \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \\ \phi_{rd} \\ \phi_{rq} \end{bmatrix} + \begin{bmatrix} \frac{1}{\sigma L_s} & 0 \\ 0 & \frac{1}{\sigma L_s} \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} \tag{5}$$

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$$\frac{d}{dt}\begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \\ \phi_{s\alpha} \\ \phi_{s\beta} \end{bmatrix} = \begin{bmatrix} -\left(\frac{R_s}{\sigma L_s}+\frac{R_r}{\sigma L_r}\right) & -\omega_r & \frac{1}{\sigma L_s \tau_r} & -\frac{\omega_r}{\sigma L_s} \\ \omega_r & -\left(\frac{R_s}{\sigma L_s}+\frac{R_r}{\sigma L_r}\right) & \frac{\omega_r}{\sigma L_s \tau_r} & \frac{1}{\sigma L_s \tau_r} \\ -R_s & 0 & 0 & 0 \\ 0 & -R_s & 0 & 0 \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \\ \phi_{s\alpha} \\ \phi_{s\beta} \end{bmatrix} + \begin{bmatrix} \frac{1}{\sigma L_s} & 0 \\ 0 & \frac{1}{\sigma L_s} \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix} \quad (6)$$

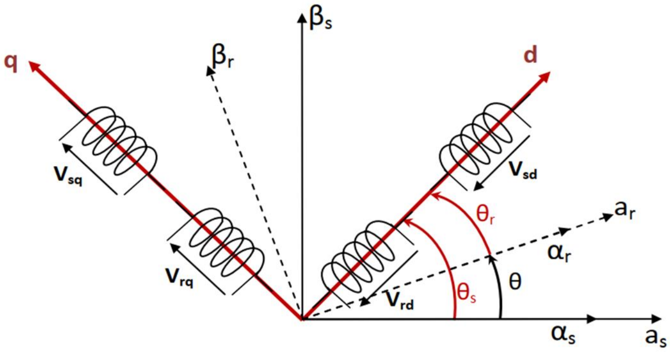

Fig. 2 Two-phase structure of the asynchronous machine in the benchmarks dq and $\alpha\beta$

2) DC/AV Converter

DC/AC converters or inverters are static converters that adjust the transfer of energy between a direct power supply (DC) and an alternating electrical load (AC). In this article, we use a three-phase voltage inverter which attacks the electric machine used in the traction chain of the electric vehicle. This choice is justified by the fact that voltage inverters are used in both fixed frequency and variable frequency applications. They allow the implementation of safety power supplies.

3) Electric Traction Control Techniques

To control the electric motor used in this paper, we used IFOC, DTC and DTFC methods described respectively by figures 3, 4, and 5. The IFOC method is an induction motor control technique that does not use too much sensors. It uses the estimators to approximate the components of the flux and their position [10](and references therein). The DTC method maintains the electromagnetic torque and the stator flux within two predefined hysteresis bands. It uses Takahashi's control table to develop the inverter control law that will drive the induction motor [9, 11]. The DTFC consists to replace the hysteresis comparators and the selection table of DTC method by a controller based on a fuzzy inference system [9, 12].

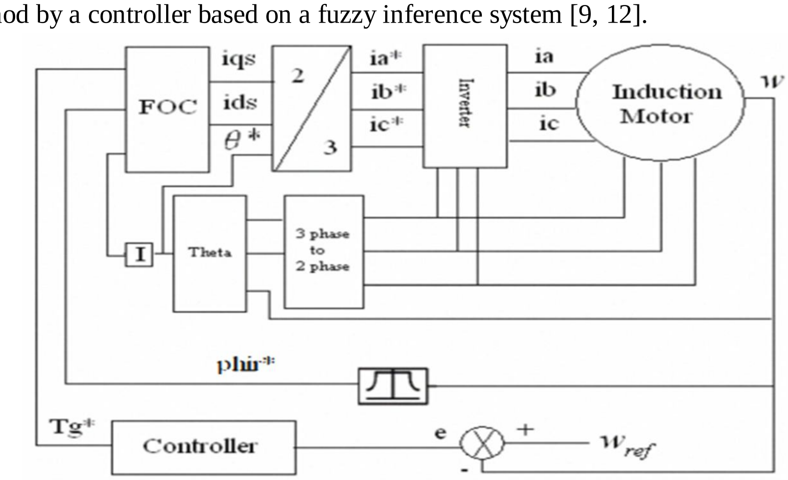

Fig. 3 Synoptic of the IFOC command

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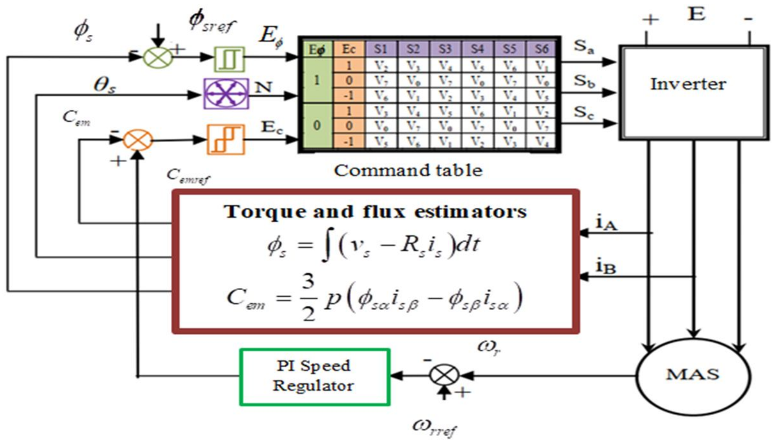

Fig. 4 Synoptic of the DTC command

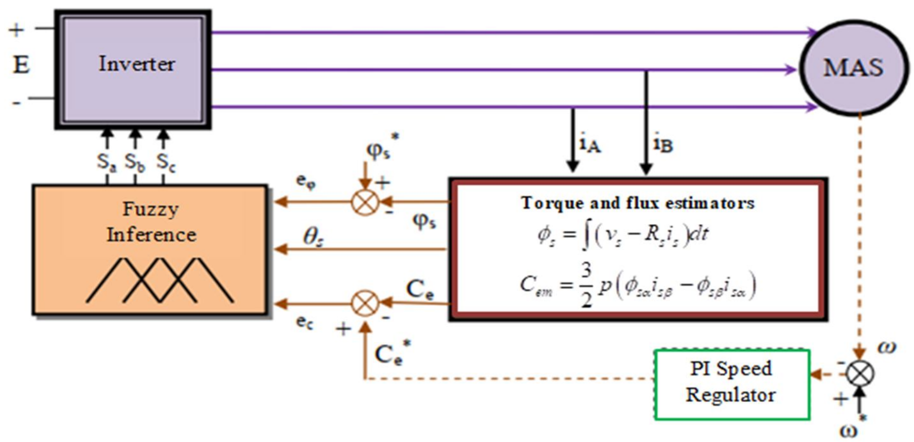

Fig. 5 Synoptic of the DTFC command

4) Electrical Sources for EV

To supply the motors of electric vehicles while they are moving, it is necessary to use energy storage in DC form. We can cite for example the fuel cell, batteries, supercapacitors, etc. This stored energy is then transformed to supply the induction motor [13-16].

5) Electronic Differential

Electronic differential (Figure 6) allows the speed management of the driving wheels of the EV. On a straight path, it keeps both drive wheels at the same speed. For a curvilinear trajectory, depending on whether we are going left or right, it allows the outer wheel of the curvature to go faster than the inner wheel.

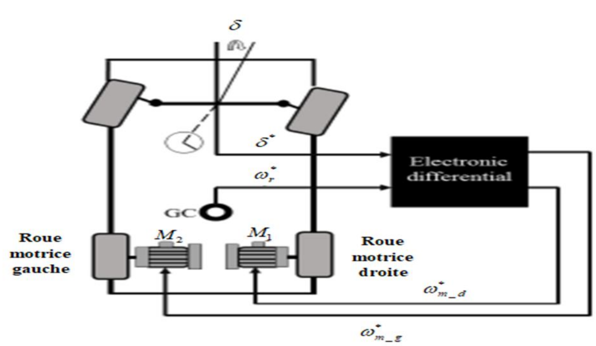

Fig. 6 Electronic differential

The steering condition of the vehicle is given by [6]:

$$\begin{cases} \delta > 0 & \text{for a right turn} \\ \delta = 0 & \text{for straight movement} \\ \delta < 0 & \text{for a left turn} \end{cases} \quad (7)$$

The rotation speed of the right wheel (ω_w^r) and the left wheels are given respectively by:

$$\omega_w^r = \left(\frac{v}{R_w} - \frac{\Delta\omega}{2} \right) \quad (8)$$

$$\omega_w^l = \left(\frac{v}{R_w} + \frac{\Delta\omega}{2} \right) \quad (9)$$

where $\Delta\omega = \frac{d_\omega.\tan(\delta)}{L_\omega}\frac{v}{R_w}$: difference between the speed of the left drive wheel and the right drive wheel, d_ω : distance between the two drive wheels, L_ω : distance between a drive wheel and this non-drive wheel on the same side.

The reference speeds of the right wheel and the left wheel are given by:

$$\begin{cases} \omega_{ref}^r = K_e \omega_w^r \\ \omega_{ref}^l = K_e \omega_w^l \end{cases} \quad (10)$$

where K_e is an multiplier coefficient.

All these elements are grouped together to form an electric vehicle traction chain which is shown in figure 7.

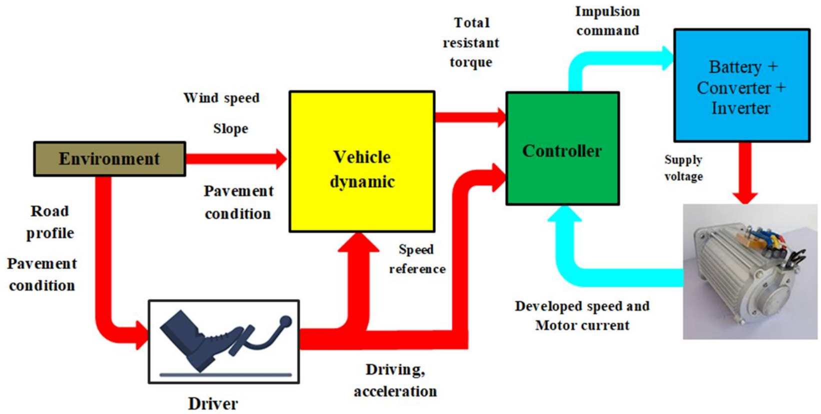

Fig. 7 Structure of the traction chain of an EV

III. COMPARISON STUDY OF ELECTRIC TRACTION CONTROL TECHNIQUE OF EV

This section presents the numerical results (rotation speed of the vehicle wheel, torque, flux, etc.) of VE control with four wheels that two wheels are driving, by IFOC, DTC and DTFC methods. These results, obtained on MATLAB – SIMULINK, are then compared in order to choosing the best EV control technique among those cited. The results of this section are obtained by using the parameters of table 1.

Tableau 1 : Induction motors parameters

$P_n = 4KW$	$V_n = 220V$	$p = 2$	$R_s = 1,2\Omega$	$R_r = 1,8\Omega$	$L_s = 0,1554H$
$M = 0,15H$	$J = 0,07kgm^2$	$f_s = 50Hz$	$f = 0SI$	$L_r = 0,1568H$	

The route profile used in this paper is presented in Figure 8.

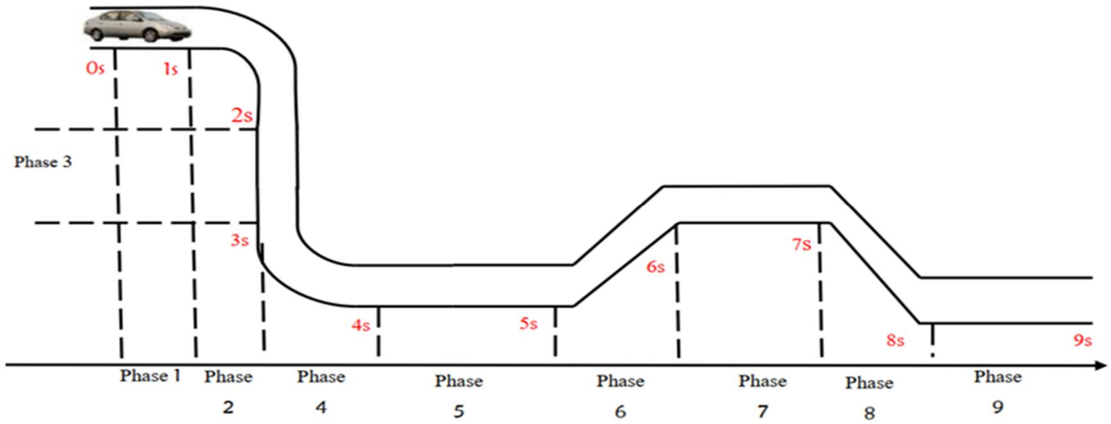

Fig. 8 Road profile

Our route profile is broken down into nine phases as shown in Figure 8; each phase for 1s. The speed of the VE is assumed to be constant and equals to $v = 70km/h$. When steering the wheels (phase 2 and 3), the steering angle is defined by $|\delta| = \frac{\pi}{2}$.

To analyze the dynamics of the EV, we plot the evolution of the stator flux in the traction motors by the DTC method (Fig.9). To analyze the dynamics of the EV, we trace the evolution of the stator flux in the traction motors by the DTC method.

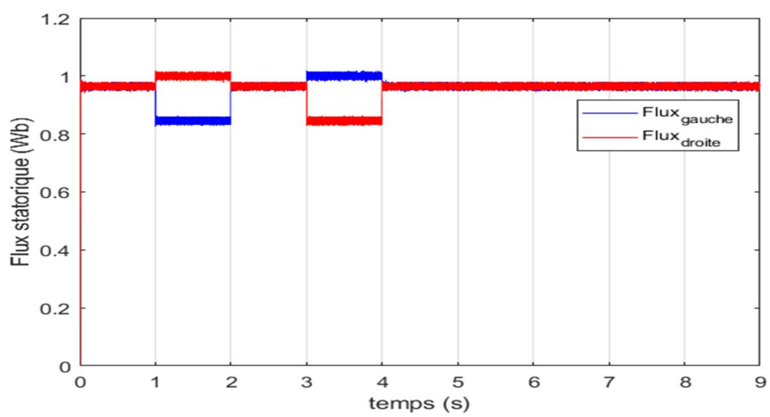

Fig. 9 Stator flux developed in traction motors

We have plotted the stator flux of the right wheel (Fig. 10). From this figure, we can observe the drop in torque ripples.

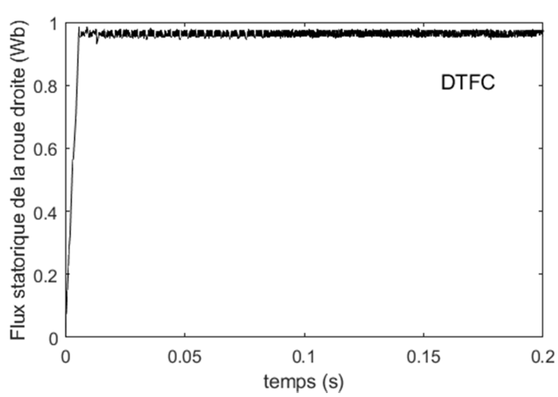

Fig. 10 Stator flux developed in the right traction motor controlled by the DTFC

In order to make the choice of the best pilot technique of the traction chain of an EV among the techniques IFOC, classic DTC and DTFC, we evaluated the stator flux of the right wheel of the EV over time (Fig. 11). From figure 11, we observe that the flux commanded by the DTFC is closer to the flux set point required by the driver.

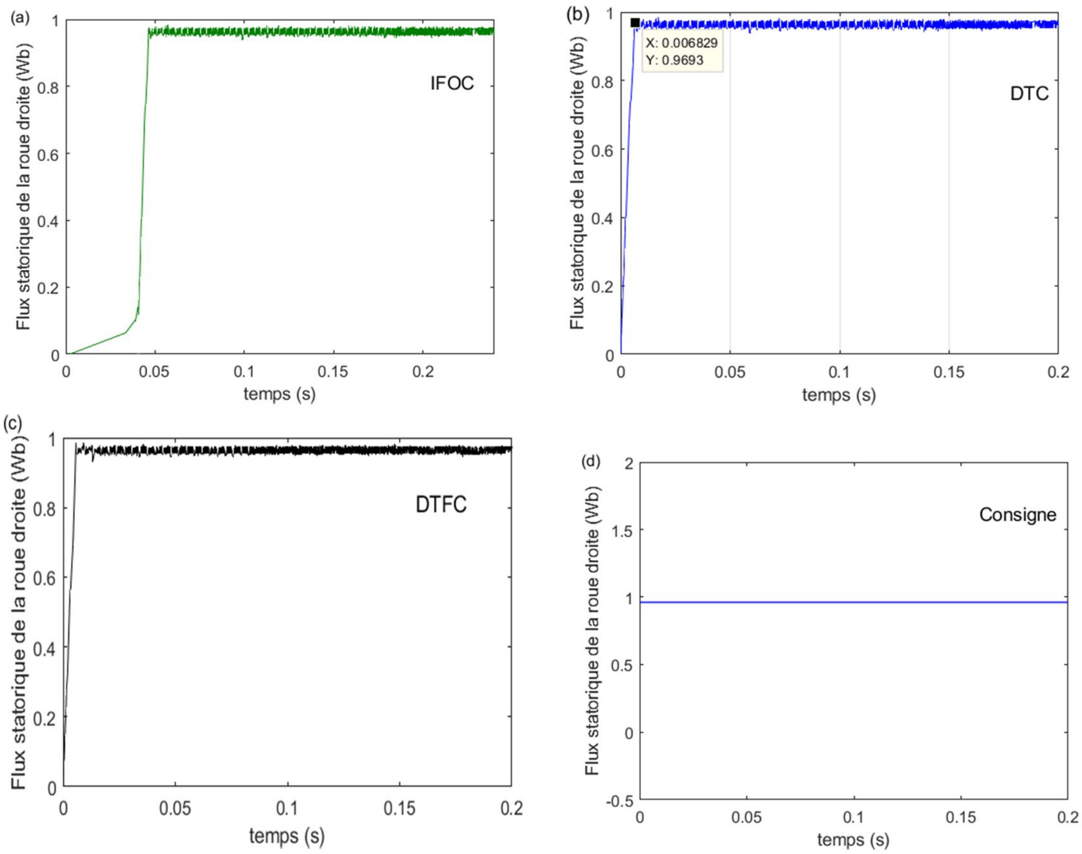

Fig. 11 Evolution of electromagnetic torque in the right wheel of the VE by using IFOC (a), DTC (b), DTFC (c) and reference (d).

In addition, we present in Table 2 the speed response time, the static error and the ripple rate for the different electric traction control techniques presented in the chapter. From this table, we see that the DTFC has better performance (lower ripples) when controlling.

Tableau 2 : Comparative study of classic DTC, DTFC and classic IFOC techniques for an electric vehicle torque response

Controller	Time de response (s)	Static error	modulation rate
DTC	0,007	0,102	5,87%
DTFC	0,0061	0,062	4,43%
IFOC	0,010	0,142	6,02%

IV. CONCLUSION

In this paper, we investigated and compared the electric traction control techniques used in motor vehicles. An electric vehicle with two driving wheels was used to apply the control techniques of electric traction. We modeled the electromechanical dynamic of EV with two driving wheels.

We developed the control laws of our vehicle using IFOC, DTC, DTFC) method. A comparative study of these control techniques was made using performance tools such as response-time, static error and ripple rate. Our study shows that DTFC method was better to obtain the motor instruction requested by the driver.

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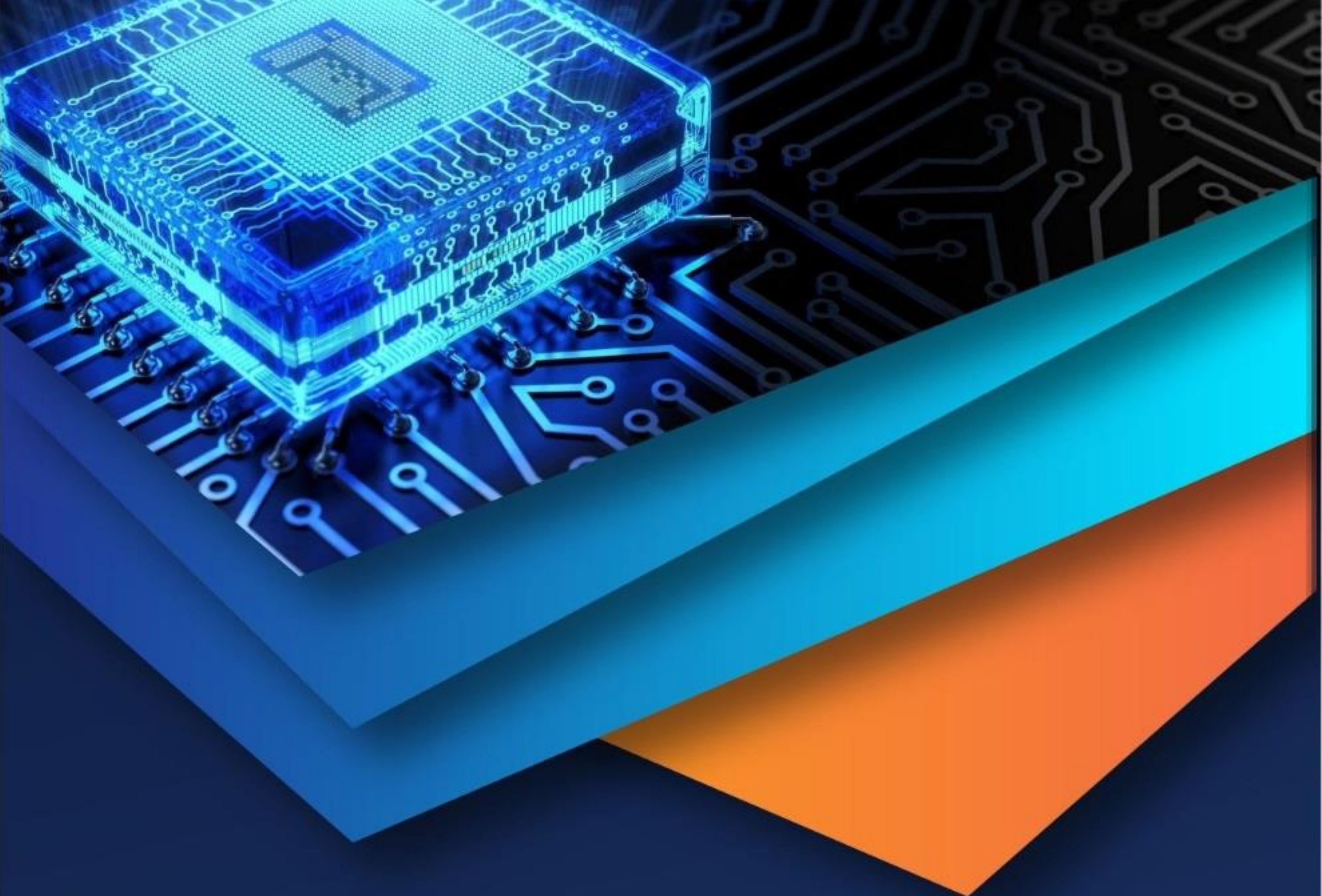

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