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Comparative Analysis of the Dynamic Performance and Energy of the Different Strategies of Control Applied to the Induction Motor for Traction Railway Subject to Disturbance Power

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ABSTRACT

This article presents a comprehensive comparative analysis of the dynamic end energy behavior of a hignt-power induction motor used in railway traction under supply disturbances, such as short power interruption gold transient faults, sudden stator voltage spikes, and steep voltage drops. These disturbances induce rapid changes in magnetic flux, stator current peaks, and electromagnetic torque oscillations, which may increase energy losses and degrade the stability of the traction system.

Four control strategies are investigated: Field-Oriented Control (FOC), Direct Torque Control (DTC), a robust control approach, and an optimized vector control based on Model Predictive Control (MPC). Numerical simulations are carried out using MATLAB/Simulink based on a detailed dq-reference frame model adapted to a real railway traction machine. The analysis focuses on the time-domain responses of transient Toule and iron losses. The results demonstrate the the predictive MPC strategy effectively minimizes electromagnetic oscillations and significantly reduces energy losses, thereby providing the best overall performance.

KEYWORDS: *asynchronous motor, railway traction, control strategies, supply disturbances.*

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1. INTRODUCTION

The asynchronous motors with high power are today one of the most important technologies in systems of rail traction modern due to their robustness, reliability and relatively low cost [1] and [2]. Their integration in systems of variable speed drive controlled by electronic power converters has significantly improved the dynamic performance and the energy efficiency of electric trains [3], [4] and [5].

However, these systems are particularly sensitive to disturbances in the power supply network, in particular:

- the popping of power supplies or faults, often caused by discontinuities of contact between the pantograph and the catenary or by triggering momentary devices, electrical protection.
- the rapid variations of the supply voltage (peak abrupt or voltage dip);

These disturbances can:

- lead, in the case of dropouts, a sudden drop in the supply voltage and cause of transient phenomena in complex traction motors;
- induce, in the case of peaks sudden voltage, over-current, fluctuations of flow and oscillations of the torque, that may degrade the dynamic performance and significantly increase the energy losses;
- alter, in the case of voltage dips, the dynamic behavior and the energy efficiency of systems, rail traction, the asynchronous motor may suffer a disruption in a temporary electromagnetic

coupling, resulting in fluctuations in the flow, over-current and oscillations of the couple. These phenomena result in energy losses are important and can compromise the stability of the traction system.

In this context, we asked ourselves the following question: "What is the strategy of command that would be able to minimize the energy losses and to improve the robustness dynamics of the asynchronous motor of high-power used in the rail traction ? "

This question asked above is the problematic of this article and the answer to this question is the assumption of the article.

This problem opens the way to an in-depth analysis of the dynamic behavior of the induction motor in a transitional regime, to the identification of the boundaries of the control vector classical and the proposed optimization strategies adapted to the specificities of the rail traction.

The hypothesis of the article is defined in the term, a control vector optimized could reduce the energy losses and the mechanical stresses in the applications of rail traction.

To find the solution to our problem, the different control strategies have been proposed in the literature, namely:

- The command vector flow-oriented (FOC), introduced by Blaschke, based on the orientation of the flow in the rotor in the repository dq order to decouple the production of the flux and the torque to finally independently control the flux and torque control PI dq [6] and [7]. It is an industry benchmark.
- The direct torque control (DTC), proposed by Takahashi and Noguchi, based on the direct selection of the voltage vectors applied by the inverter to regulate flow stator and torque and electromagnetic. It acts directly on the couple electromagnetic and flow stator, without loop current by the selection of the voltage vectors of the inverter. It provides a dynamic response fast but oscillatory thanks to the direct regulation of the flux and the torque [8]. It is based on comparators hysteresis.
- The robust control aims to maintain the performance of the system in spite of external disturbances and parametric uncertainties [9], [10] and [11]. It incorporates the parametric uncertainties to improve the stability against disturbances.
- The predictive control uses a dynamic model of the motor to predict the future evolution of the system variables and select the action of optimal control [12] and [13]. It optimizes a cost function in real time, taking into account the constraints and the dynamics of the system.

The main objective of this article is to carry out a detailed comparative analysis of the dynamic performance and energy of the four control strategies applied to an asynchronous motor of rail traction disturbances of power supplies such as cutoff or default fugitive power, peak abrupt and sudden drop in voltage, stator, in order to identify the most suitable solution to these types of disturbances.

The specific objectives of this article are:

- Develop an electromechanical model specific asynchronous motor traction railway;
- To analyze the dynamic behavior and energy of the engine under different control strategies in transitional regime;
- Compare the results obtained with these different control strategies.
- Identify the sources of performance degradation (overruns, swings, loss);
- Choose the control strategy is the most suitable for these types of disturbances.

2. RESEARCH METHODOLOGI THAT

2.1. Modeling of the asynchronous motor

2.1.1. Model repositorydq

The modeling of the motor is carried out in the rotating frame (dq), allowing a decoupling of the flow variables and torque. This representation allows to simplify the equations, dynamic and facilitates the implementation of strategies to control vector.

The equations of electric are written in the form [14]:

$$v_{ds} = R_s.i_{ds} + \frac{d\psi_{ds}}{dt} - \omega_s.\psi_{qs} \qquad (2.1)$$

$$v_{qs} = R_s.i_{qs} + \frac{d\psi_{qs}}{dt} + \omega_s.\psi_{ds} \qquad (2.2)$$

where v_{ds} : voltage stator along the axis " d " (or direct component of Park of the voltage stator);

v_{qs} : voltage stator along the axis " q " (or component in quadrature Park of the voltage stator);

R_s : winding resistance stator per phase (R_s=0,015 Ω for the engine considered in this article);

ω_s : electrical pulse currents in the stator;

ψ_{ds} : magnetic flux stator along the axis " d ";

ψ_{qs} : magnetic flux stator along the axis " q ";

i_{ds} : current stator along the axis " d ";

i_{qs} : current stator along the axis " q ".

The flows are defined by:

$$\psi_{ds} = M.i_{dr} + L_{cys}.i_{ds} \quad (2.3)$$

$$\psi_{qs} = M.i_{qr} + L_{cys}.i_{qs} \quad (2.4)$$

with: L_{cys}: inductance own cycle of the stator ($L_{cys} = L_{as} - M_s$);

M : mutual inductance cyclical between stator and rotor ($M = 3M_{rs}/2$);

L_{as} : inductance of the winding stator phase " a ";

M_s : mutual inductance between two enrolements the stator;

M_{sr} : maximum of the mutual inductance between the winding stator and a

winding in the rotor (reached when their magnetic axes are aligned).

The couple electromagnetic is given by:

$$C_{ém} = \frac{3}{2} p \frac{M}{L_{cyr}} (\psi_{dr}.i_{qs} - \psi_{qr}.i_{ds}) \quad (2.5)$$

The dynamic mechanical:

$$J \frac{d\Omega}{dt} = C_{ém} - C_r - \beta.\Omega \quad (2.6)$$

where J : moment of inertia of all masses rotating;

Ω: angular velocity of the rotor or mechanical speed of the rotor;

$C_{ém}$: torque electromagnetic;

C_r : torque due to the body's driven by the engine;

β : coefficient of friction.

2.1.2. Modeling of losses

The energy losses taken into account are [16]:

- Heat Losses:

$$p_J = 3R_s.i_s^2 \quad (2.7)$$

- Losses:

$$p_{fer} \propto f.\psi^2 \quad (2.8)$$

with: f : power frequency;

ψ : magnetic flux of the motor.

These losses is essential for the assessment of energy system transition.

2.2. Principle of the control vector has flow guides

The command vector to flow in the rotor - oriented, based on the alignment of the axis direct (d) of reference rotating with the flow in the rotor. In this configuration, the torque electromagnetic expressed in a simplified way [17]:

$$C_{ém} = \frac{3}{2} p \frac{L_m}{L_r} \psi_r.i_{qs} \quad (2.9)$$

This relationship shows that the torque depends only on the component quadrature current stator, while the direct component controls the flow. This separation allows independent control of torque and flux, particularly advantageous for applications in traction [18].

3. PRESENTATION, INTERPRETATION AND DISCUSSION OF RESULTS

3.1. Block diagram of the simulation

Regarding the numerical simulation, we used the diagram in figure 3.2 with the three-phase asynchronous motor (figure 3.1), the characteristics of which are the following:

- type of motor: three-phase asynchronous motor with squirrel-cage;
- nominal voltage between phases: 1500 V;
- current to rated current: 700 A;
- rated power factor: 0,87;
- output power rating: 1.5 kW;
- frequency: 50 Hz;
- rated speed: 1480 r/min;
- number of pair of poles: p = 2;
- friction coefficient: β = 0,025 N. m. s/rad.
- resistance stator per phase: R_s = 0,015 Ω;
- resistance in the rotor relative to the stator per phase: $R_r^{'}$ = 0,013 Ω
- leakage inductance of the stator per phase: L_s = 0,030 H;
- leakage inductance of the rotor relative to the stator per phase: $L_r^{'}$ = 0,030 H;
- mutual inductance (magnétisante) stator-rotor: M = 3,8 H;
- moment of inertia of masses rotating: J = 180 kg.m^2;

The moment of inertia is the moment of total inertia reduced to the motor shaft, which leads to the mechanical load.

The simulations have been carried out in MATLAB/Simulink by integrating an inverter with pulse width modulation vector (SVPWM). The scenarios investigated include:

- the brief outage power of the engine,
- the temporary imbalance of voltage of a phase,
- the pic sudden supply voltage,
- the precipitous drop in supply voltage.



Fig. 3.1: Motor, electric rail traction [19]

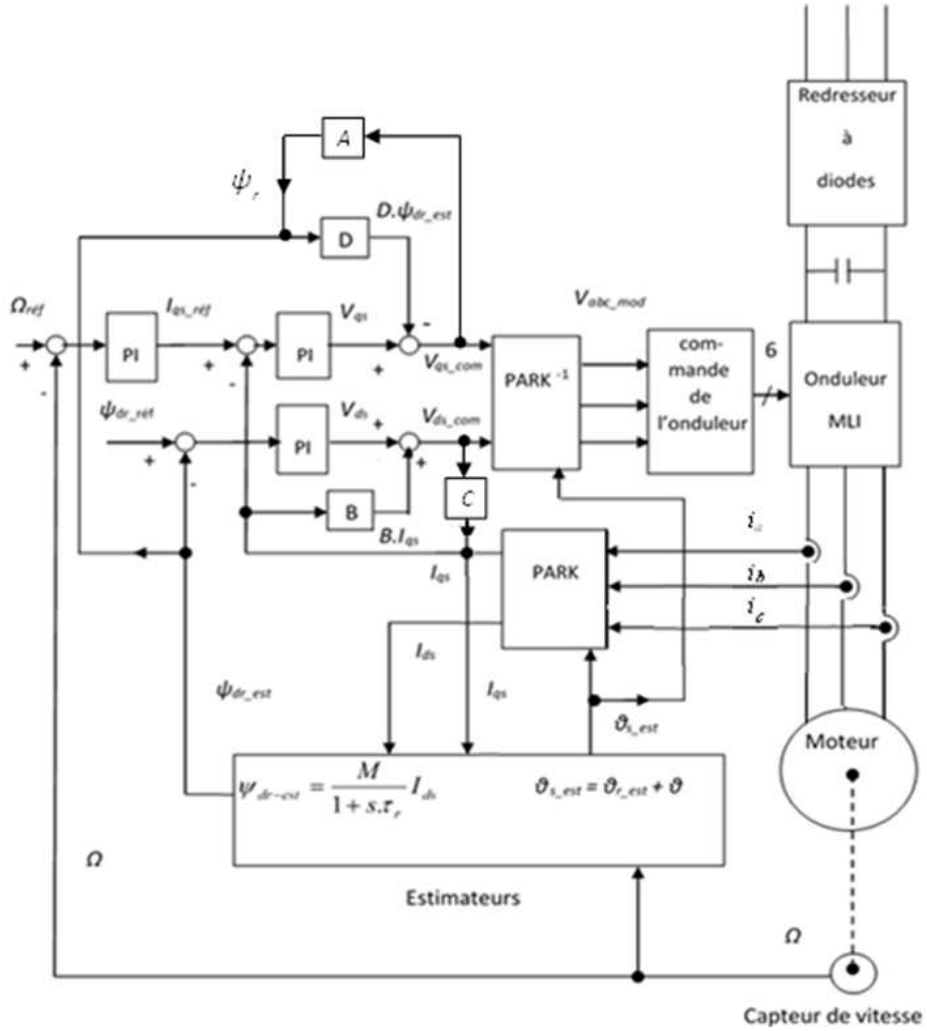


Fig. 3.2: block Diagram of a control flowin the rotor - oriented [20]

3.2. Presentation of the results of the simulation

3.2.1. Brief outage of the power of the engine

1° Framework and scenario simulation

In point 3.2.1 of this article, a comprehensive comparative analysis of the dynamic behavior of an induction motor traction was performed using numerical simulations in MATLAB / Simulink. The objective is to evaluate the dynamic performance and energy of different control strategies applied to the induction motor traction railway subjected to a brief outage of its power**,** in order to choose the control strategy best suited to this type of disturbance.

The disturbance studied corresponds to a cutoff power is characterized by:

- sudden drop of the voltage stator;
- transition from 100% to 0% of the rated voltage (100 % → 0 % → 100%)
- time default: 30 ms;
- recovery instant of the voltage.

The performance of four control strategies, namely, the command vector classic (FOC), the direct torque control (DTC), robust control and model predictive control, model-based (MPC) are compared on the basis of the answers temporal currents, flow, torque, and speed, as well as Heat losses and iron transitional.

2° the Results of the simulation on the brief outage of the power of the engine

The results are obtained by simulations in MATLAB / Simulink using a model dq realistic (integrating the actual settings of the engine).

The results are presented for the temporal evolution of the quantities of electromagnetic and mechanical following:

- the voltage stator phase-to-phase.
- the rotation speed of the engine;
- the current stator phase "$\mathbf{i_{have}}$ ";
- the currents in the stator "$\mathbf{i_{ds}}$" and "$\mathbf{i_{qs}}$ " in the repository dq;
- the flow stator"$\boldsymbol{\psi}_{\mathbf{ace}}$";
- the components of flow in the rotor "$\boldsymbol{\psi}_{\mathbf{dr}}$" and "$\boldsymbol{\psi}_{\mathbf{qr}}$ " in the repository dq;
- the couple electromagnetic "$\mathbf{C_{ms}}$";
- the Heat losses and iron transitional.

An energy analysis add-in is also conducted from the Heat losses and losses of iron transitional.

This simulation gave us the following results (figure 3.3 to 3.12):
Legend Blue: Field-Orinted Control (FOC);
Orange: Direct Torque Command (DTC);
Green: Field-Orinted Control Robust (Robust);
Red: Model Predictive Control (MPC).

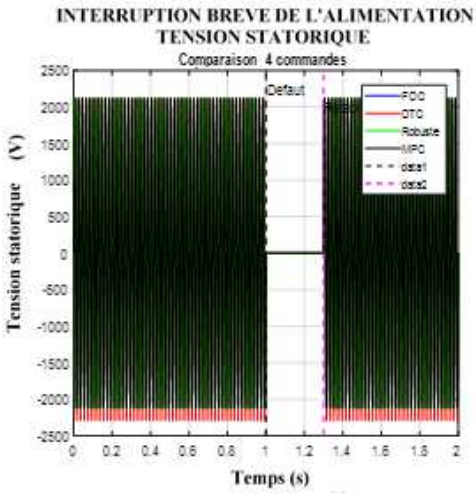


Fig. 3.3: Voltage stator

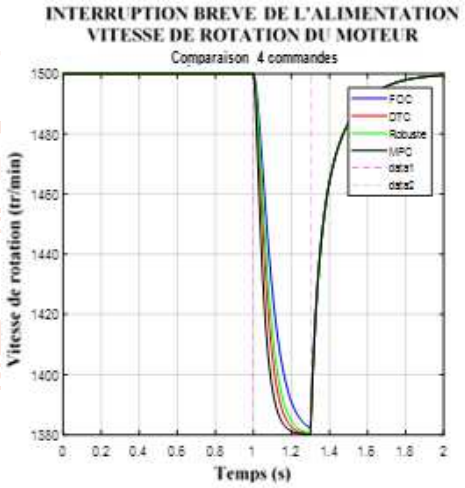


Fig. 3.4: Speed of rotation

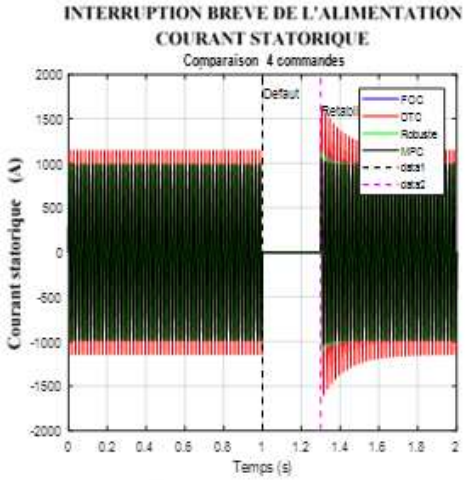


Fig. 3.5: Current stator

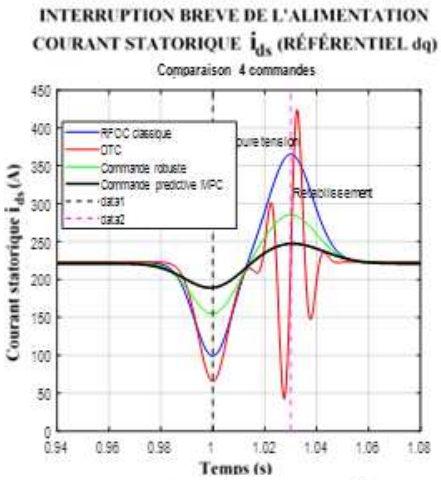
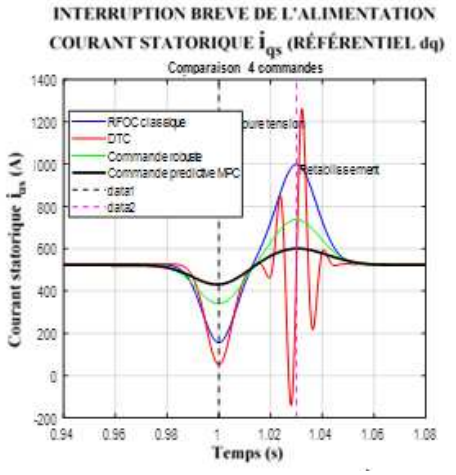


Fig. 3.6: Current stator i_{ds} Repository dq



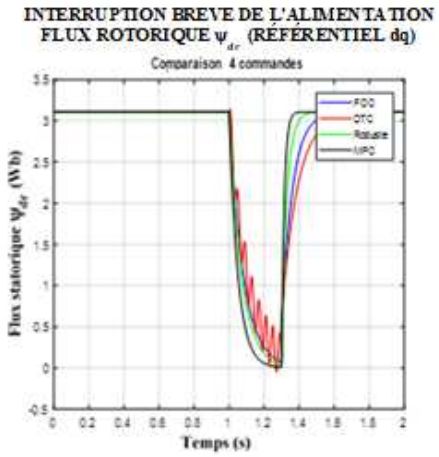
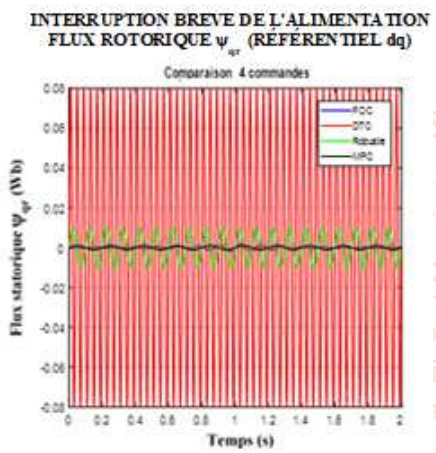


Fig. 3.7: Current stator i_{qs} (Repository dq) *Fig. 3.8: rotor Flux ψ_{ds} (Repository dq)*



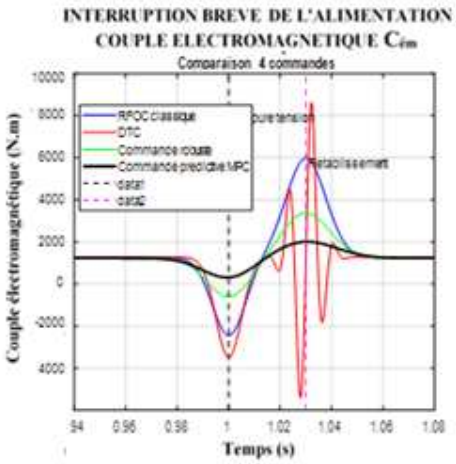
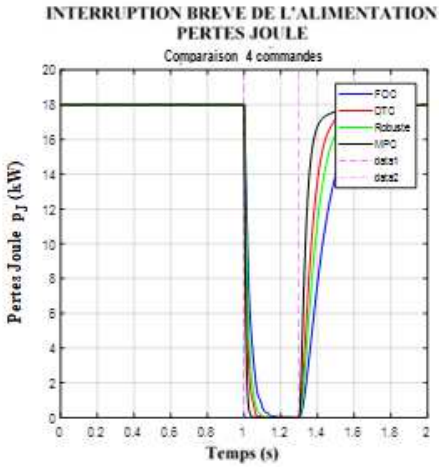


Fig. 3.9: rotor Flux ψ_{ds} (Repository dq) *Fig. 3.10: Couple életromagnétique*



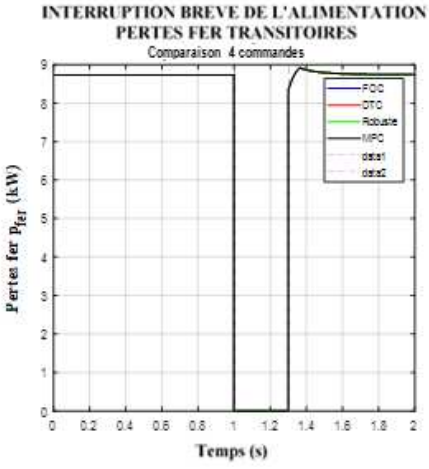


Fig. 3.11: Heat Losses P_j *Fig. 3.12: Loss iron P_{iron}*

Discussion of the simulation on the brief outage of the power of the engine

During the cutoff, the voltage stator becomes zero (figure 3), which leads to a dampening of the flow in the rotor ψ_{dr} (figure 3.8).

During the recovery of the voltage, transients and large, appear in the current (figures 3.5, 3.6 and 3.7) and the couple electromagnetic (figure 10); the Heat losses reach their maximum.

The results show that:

- the command DTC generates the most strong oscillations of the flux and the torque, the losses are maximum;

- the command JIB enhances the stability of the flow, the losses are intermediaries;
- vector drive robust reduces the oscillations of the current, the losses are reduced;
- the command MPC presents the dynamic response, more stable, and the losses are minimal.

The losses are primarily influenced by the variations of the magnetic flux and remain below the Heat losses during the transitional regimes.

3.2.2. Pic sudden stop of the supply voltage (increase of very short duration followed bya recovery)

1° Framework and scenario simulation

The objective of part of the article is to evaluate the dynamic performance and energy of different control strategies applied to the induction motor traction railway subjected to a peak in sudden stop of the supply voltage (increase of very short duration followed by a recovery)**,** in order to choose the control strategy best suited to this type of disturbance.

The scenario studied:

- nominal operation;
- at time t = 0.4 s: peak voltage +20% for 200 ms;
- return to the rated voltage.

2° the Results of the simulation on the pic sudden stop of the supply voltage (increase in very short period of time followed by a recovery)

This simulation gave us the following results (3.13 to 3.22):

Legend Blue: Field-Orinted Control (FOC);
Orange: Direct Torque Command (DTC);
Green: Field-Orinted Control Robust (Robust);
Red: Model Predictive Control (MPC).

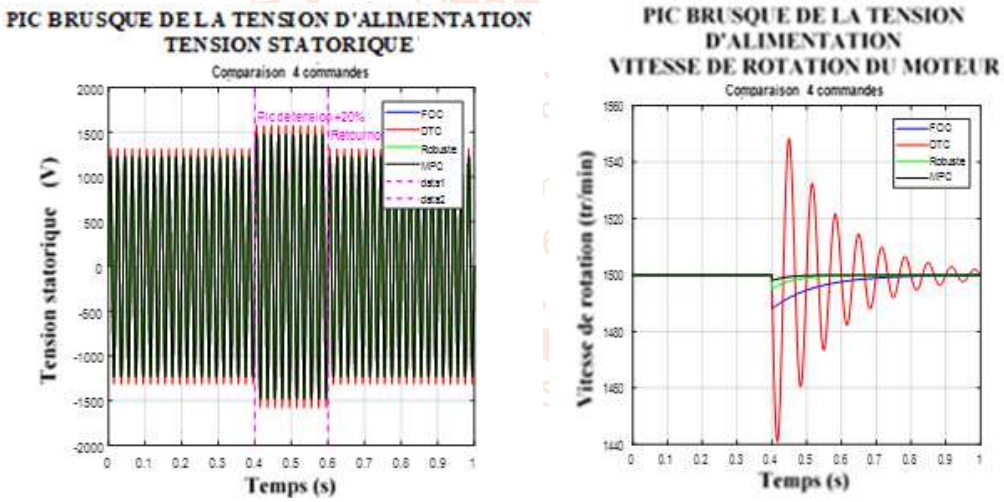


Fig. 3.13: Voltage stator Fig. 3.14: Speed of rotation

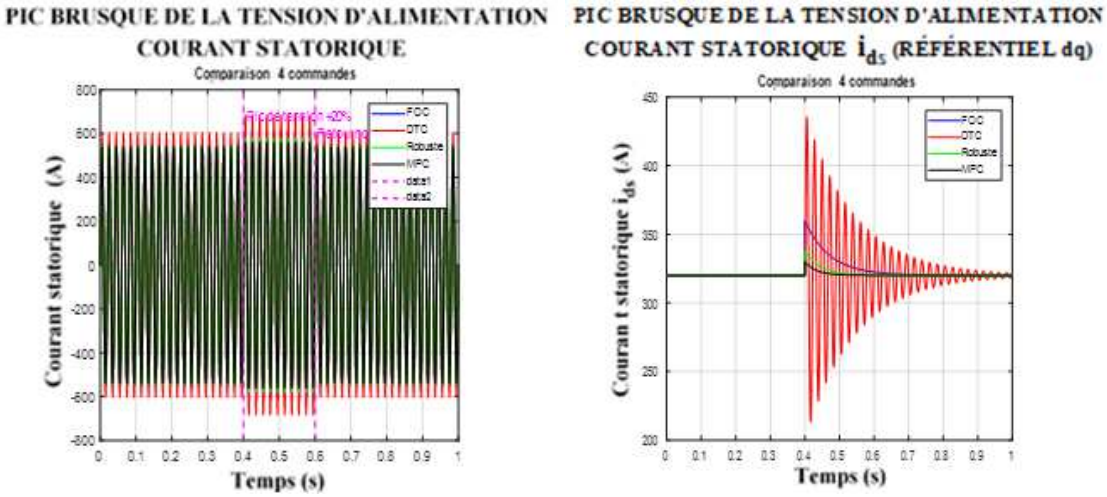


Fig. 3.15: Current stator Fig. 3.16: Current i_{ds}(Repository dq)

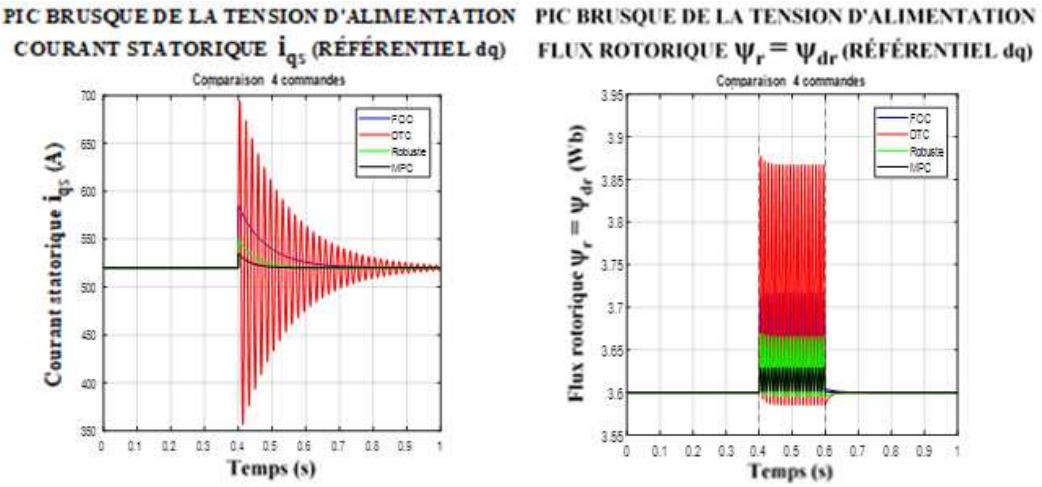


Fig. 3.17: Current i_{qs} (Repository dq) Fig. 3.18: rotor Flux $\psi_r = \psi_{dr}$ (Repository dq)

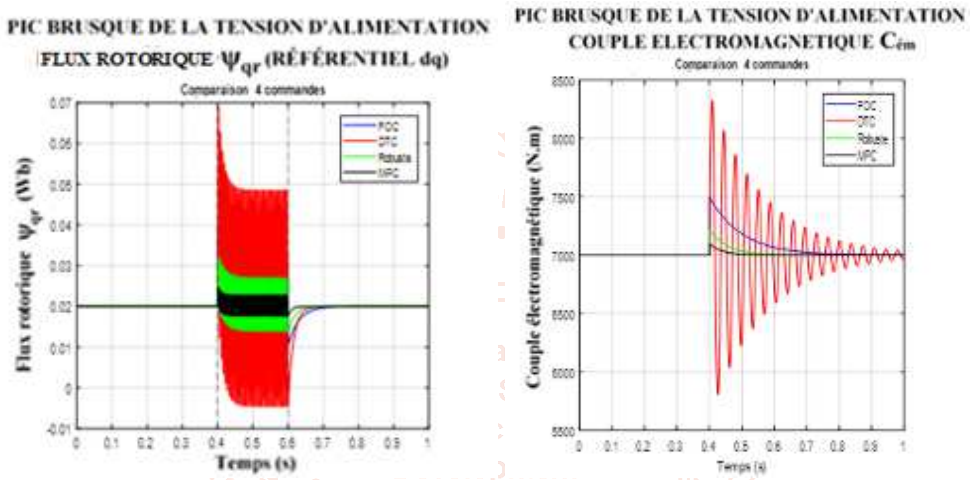


Fig. 3.19: rotor Flux ψ_{qr} (Repository dq) Fig. 3.20: Couple electromagnetic

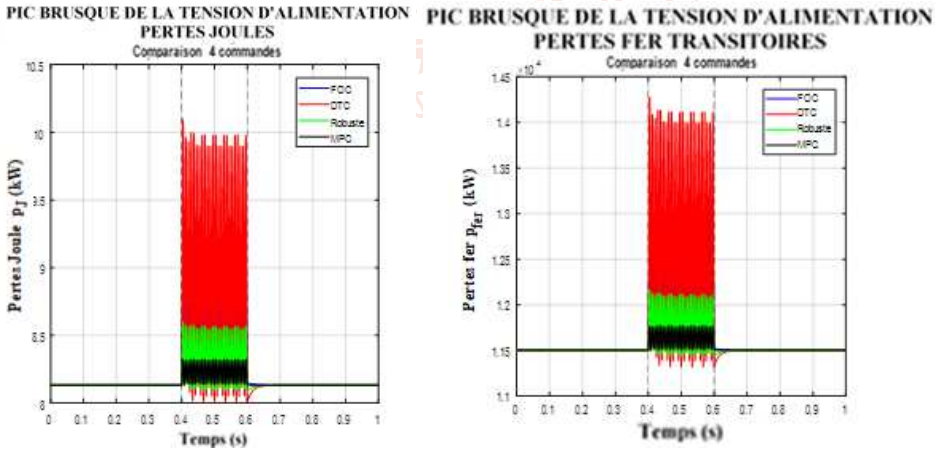


Fig. 3.21: Heat Losses p_j Fig. 3.22: Losses iron transitional p_{iron}

2° Discussion of the simulation on the pic sudden stop of the supply voltage (Increase in very short period of time followed by a recovery)

A. Response currents

The results show that the DTC generates peak power of the most high (figures 3.15, 3.16 and 3.17), reflecting a strong sensitivity to disturbance. The FOC limit partially these effects, while the control vector sturdy significantly improves the stability. The MPC allows to minimize the inrush current thanks to its pre-emptive nature.

B. Flow behaviour

The fluctuations of the flow (figures 3.18 and 3.19) are particularly important in DTC, leading to losses of iron high. The JIB and the robust control to improve stability, but only the MPC ensures an optimal control of the flow.

C. Torque and speed

The DTC has large fluctuations of the torque (figure 20), causing variations in speed (figure 14). The FOC improves damping, the robust control enhances stability, while the MPC guarantees a response, quasi-aperiodic.

D. Energy analysis

Energy losses to confirm that (figures 3.21 and 3.22):

- DTC: maximum losses,
- JIB; high losses,
- Robust: reduced losses,
- MPC: minimum losses.

The reduction of losses under MPC reaches up to 50% compared to the DTC, which is an energy gain significant.

3.2.3. Sudden drop of the supply voltage (down to a very short duration followed by a recovery)

1° Framework and scenario simulation

The objective is to evaluate the dynamic performance and energy of different control strategies applied to the induction motor traction railway subjected to a sudden drop in the supply voltage (falling very short period of time followed by a recovery)**,** in order to choose the control strategy best suited to this type of disturbance.

The engine works initially to:

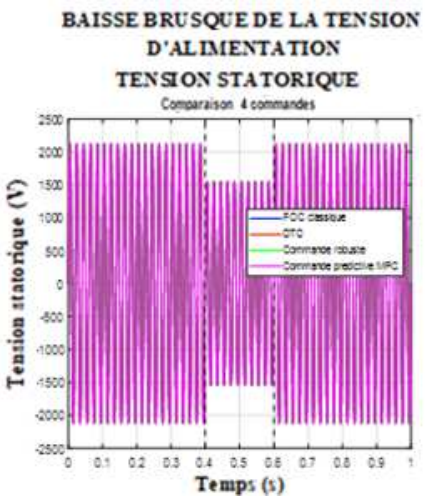
- Rated speed: 1500 r/min,
- Rated load
- Rated voltage: 1500 V

At time t = 0.4 s, a sudden drop in voltage (27%) is applied for a short duration (200 ms), followed by a return to the nominal value.

2° the Results of the simulation on the sudden drop of the supply voltage (falling very short period of time followed by a recovery)

This simulation gave us the following results:

Legend Blue: Field-Orinted Control (FOC);
Orange: Direct Torque Command (DTC);
Green: Field-Orinted Control Robust (Robust);
Red: Model Predictive Control (MPC).



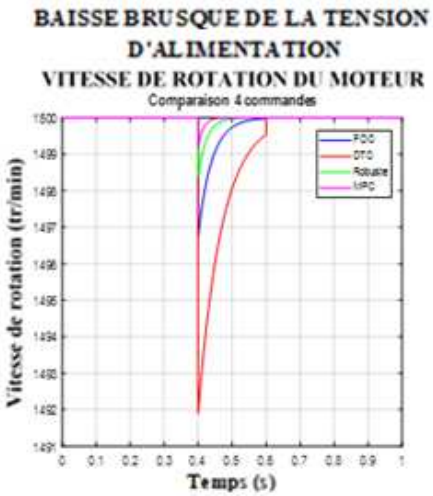
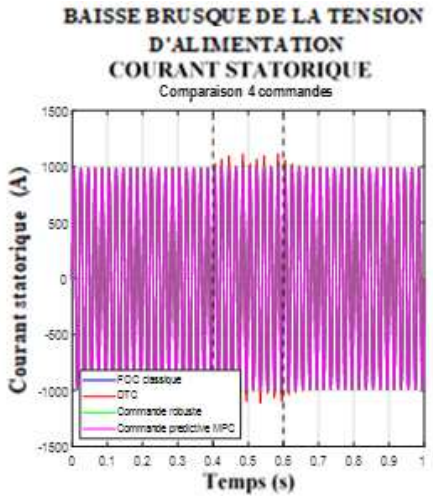


Fig. 3.23: Voltage stator Fig. 3.24: Speed of rotation



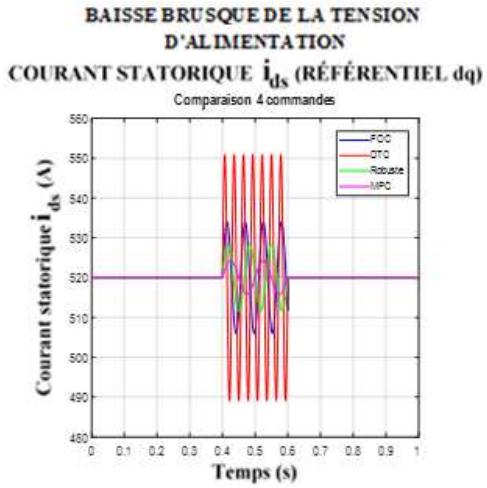
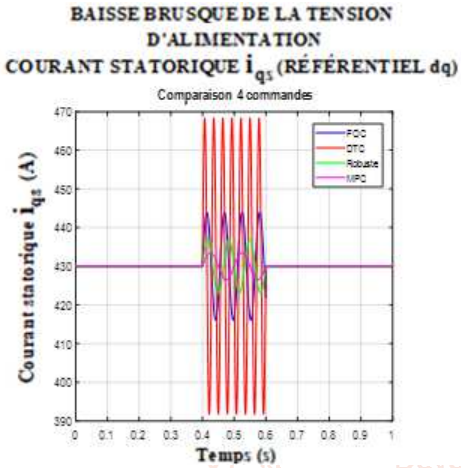


Fig. 3.25: Current stator Fig. 3.26: Current i_{dc} (Repository dq)



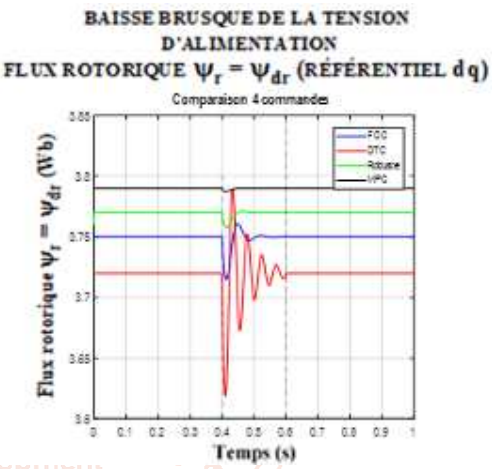
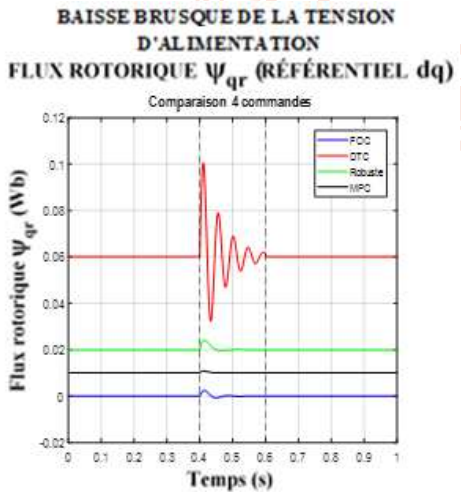


Fig. 3.27: i_{qs} (Repository dq) Fig. 3.28: rotor Flux $\psi_r = \psi_{dr}$ (Repository dq)

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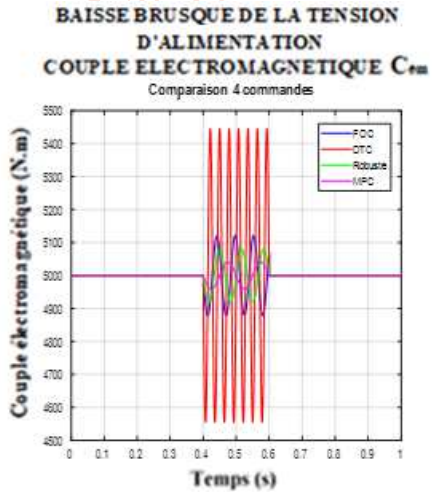
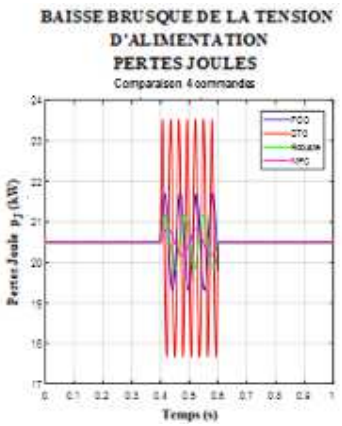


Fig. 3.29: rotor Flux ψ_{qr} (Repository dq) Fig. 3.30: Couple electromagnetic



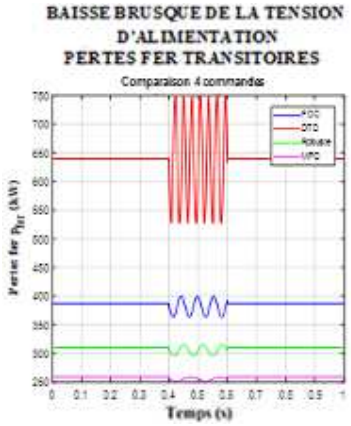


Fig. 3.31: Heat Losses p_j Fig. 3.32: Losses transient p_{iron}

2° Discussion of the simulation on the sudden drop of the supply voltage (increase of very short duration followed by a recovery)

A. Response currents

The results show an increase of the currents (figures 3.25, 3.26 and 3.27).

- DTC: peaks of high currents during the fault;
- JIB: peak currents lower during the default compared to those of the control DTC;
- Robust control: peak currents lower during the default compared to those of the control JIB;
- MPC: peak currents lower during the default compared to those of previous orders.

The MPC minimizes the inrush current and reduces the stabilization time.

B. Flow behaviour

The voltage dip causes a drop of the magnetic flux (figures 3.28 and 3.29):

- DTC: fluctuations (up to -40% of the flow before the default);
- JIB: fall moderate (-25% of the flow before the default);
- Robust control: significant improvement (-15% of the flow before the default);
- MPC: better regulation of the flow (-10% of the flow before the default).

The flow in the rotor lags dynamic (≈ 40 to 60 ms), accentuated by DTC and attenuated in the MPC.

C. Response of the couple to electromagnetic

Figure 3.30 shows a high sensitivity of the couple:

- DTC: fast response, but highly oscillatory (waves up to ±40%);
- JIB: initial fall (-30%), followed by a tolerance (+20%);
- Robust control: oscillations moderate (±15%)
- MPC: response stable, without overflow significant (<5%).

The quality of the couple is essential in rail traction to prevent slippage wheel-rail and the mechanical constraints.

D. Response of the speed of rotation

The speed (figure 3.24) is relatively unaffected grace inertia:

- DTC: the fall maximum bit near – 6% of speed before the default,
- JIB: the fall of the speed of light near – 4% of speed before the default,
- Robust: the fall of the speed at approximately 2 to -3% of the speed before the default,
- MPC: the fall of the speed of less than -2% of speed before the default.

E. Analysis of Heat losses

The Heat losses (figure 3.31) are strongly influenced by the over current protection:

- DTC: maximum increase (+80% of the Heat losses before the default),
- JIB: (+40% of Heat losses before the default),
- Vector drive Robust: (+30% of the Heat losses before the default),
- MPC: (+20% of the Heat losses before the default).

The energy dissipated during the transient is minimal in MPC, confirming its energy efficiency.

F. Impact on the losses of iron

Compared (figure 3.32):

- DTC: high peak (+30% of losses before the default),
- JIB: +15% of losses before the default,
- Vector drive Robust: +10% of the losses before the default,
- MPC: pic of less than +10% of the losses before the default.

4. CONCLUSION

This article has presented a comparative analysis of the performance and dynamic energy of an asynchronous motor traction railway subject to the flaws in the power of short duration, such as cutoff or default fugitive power, peak sharp and a sharp decrease of the voltage stator.

The results show that the control strategies for advanced play an essential role in the improvement of the robustness and the effectiveness of the systems of traction.

The command vector predictive MPC appears as the more powerful solution to reduce disturbances dynamic and reduce the loss of energy transients.

REFERENCES

[1] **F. Blaschke**, (1972). "The principle of field orientation as applied to the new TRANSVECTOR closed-loop control system for rotating-field machines, "*Siemens Review*, vol. 39, no. 5, pp. 217-220;

[2] **P. Vas,** (1990). *Vector Control of AC Machines*, Oxford, U. K.: Oxford Univ. Press;

[3] **B. K. Bose**, (2002).*Modern Power Electronics and AC Drives*, Upper Saddle River, NJ, USA: Prentice-Hall;

[4] **H. Abu-Rub et al**., (2021). High Performance Control of AC Drives**;**

[5] **J. Holtz, (2002)**. "Sensorless control of induction motor drives," *Proc. IEEE*, vol. 90, no. 8, pp. 1359-1394, Aug;

[6] **D. Casadei et al**., (2020). "JIB vs DTC: A comparison study," IEEE Trans. Power Electronics;

[7] I**. Takahashi and T. Noguchi**, "A new quick-response and high-efficiency control strategy of an induction motor, "*IEEE Trans. Ind. Appl.*, vol. IA-22, no. 5, pp. 820-827, Sept. 1986.

[8] **S. Vazquez, J. Rodriguez, M. Rivera, L. Garcia, and M. Norambuena**, (2017)."Model predictive control for power converters and drives: Advances and trends, " *IEEE Trans. Ind. Electron.*, vol. 64, no. 2, pp. 935-947, Feb;

[9] **J. Rodriguez, et al,** (2022). "Model predictive control of power converters," IEEE Trans. IE.

[10] **S. Kouro et al.,** (2021). "Model predictive control – A simple and powerful method," IEEE Trans. IE.

[11] **S. Bolognani**, (2023)."Robust control of induction motor drives," IEEE Trans. IE.

[12] **R. Krishnan**, (2001). *Electric Motor Drives: Modeling, Analysis, and Control*, Upper Saddle River, NJ, USA: Prentice-Hall;

[13] **J. Holtz**, (2017). "Advanced PWM techniques," IEEE;

[14] **R. Kennel**, (2009)."Predictive torque control of induction machines," IEEE;

[15] **P. Cortés**, (2019). "Predictive control in power electronics," IEEE;

[16] **M. Kazmierkowski**, (2018). Control in Power Electronics**,** Elsevier;

[17] **T. Geyer**, (2021). Model Predictive Control of High Power Converters**,** Wiley;

[18] **J. Rodriguez**, (2011). Predictive Control of Power Converters and Electrical Drives**,** Wiley;

[19] **L. Harnefors**, (2016). "Control of variable-speed drives," IEEE;

[20] **H. Toliyat**, (2012) Handbook of Electric Motors, CRC Press.