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Control DTC associated with different technics of observation (KUBOTA and MRAS observers) of an induction motor.

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Abstract: In this article, we present the construction of observers of rotor flux and mechanical speed needed for robust control of the asynchronous machine. Two observers will be developed for comparison. The first is based on the techniques MRAS and the second is observer of KUBOTA, with the enhanced DTC, "sensorless DTC", The validity of the proposed strategies of observation are confirmed by the simulation results.

Keywords: Asynchronous machine, DTC,KUBOTA,MRAS.

1. Introduction

Getting high performance with an asynchronous machine, requires complex control including requiring reliable information from process control, this information can reach the sensors, they dedicated the weakest link in the chain, so it tries to fill their functions by calculation algorithms reconstructing the machine states, such tools are the name of estimators and observer [1]for reasons of cost or technological reasons, it is sometimes too restrictive measure some quantities of the system. However these quantities may represent an important information for control or monitoring. It is necessary to reconstruct the evolution of these variables that are not directly from the sensors. We must therefore carry out an indirect sensor. For this, the estimators are used or as appropriate, observers [2].

In this work, our main objective is to exploit artificial intelligence tools namely: networks of artificial neurons on the DTC control, In this work, our main objective is to exploit artificial intelligence tools namely: artificial neural networks on the DTC control, we use the adaptive observer of Kubota to estimate the flow and we express the estimation error then THD of stator current is evaluated.

2. DTC control

Since Depenbrock and I. Takahashi proposed DTC control of the asynchronous machine in the mid-1980s, it has become increasingly popular. The DTC command makes it possible to calculate the control quantities that are the stator flux and the electromagnetic torque from the only quantities related to the stator and this without the intervention of mechanical sensors [3].

The principle of control is to maintain the stator flux in a range. The block diagram of the DTC control is shown in Fig.1

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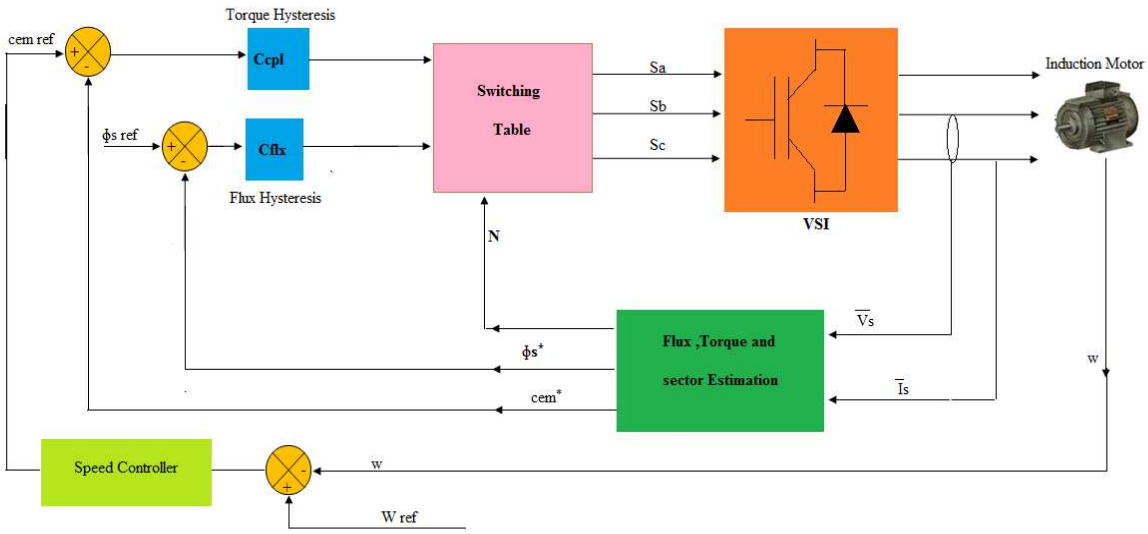


Fig. 1 Structure of classical DTC.

$$\begin{cases} \Phi_{s\alpha} = \int_0^t (v_{s\alpha} - R_s i_{s\alpha})dt \\ \Phi_{s\beta} = \int_0^t (v_{s\beta} - R_s i_{s\beta})dt \end{cases} \quad (1)$$

$$T_e = \frac{3}{2} p \left[\Phi_{s\alpha} i_{s\beta} - \Phi_{s\beta} i_{s\alpha} \right] \quad (2)$$

The DTC control method allows direct and independent electromagnetic torque and flux control, selecting an optimal switching vector. The Fig. 2 shows the schematic of the basic functional blocks used to implement the DTC of induction motor drive. A voltage source inverter (VSI) supplies the motor and it is possible to control directly the stator flux and the electromagnetic torque by the selection of optimum inverter switching modes [4].

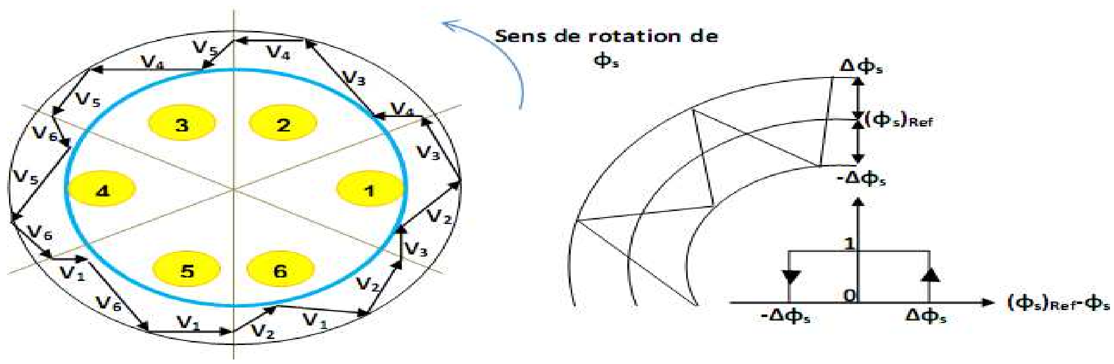


Fig. 2 Voltage vectors.

The switching table allows to select the appropriate inverter switching state according to the state of hysteresis comparators of flux (cflx) and torque (ccpl) and the sector where is the stator vector flux (φ_s) in the plan (α, β), in order to maintain the magnitude of stator flux and electromagnetic torque inside the hysteresis bands. The above consideration allows construction of the switching table [5].

Table.1
The selection of electric tension

$\Delta\varphi_s$	ΔCe	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6
0	**1**	V_3	V_4	V_5	V_6	V_1	V_2
	0	V_5	V_6	V_1	V_2	V_3	V_4
1	**1**	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_6	V_1	V_2	V_3	V_4	V_5

3. Adaptative system with reference model'MRAS'

This technics is designed on the basis of an adaptive system using two estimators flow, the first not introducing speed is called the reference model (or voltage model). The second, which is a function of speed is called adjustable model (or current model), the error produced by offset between the outputs of the two pilot estimators an adaptation algorithm that generates the estimated speed [6].Fig. 3

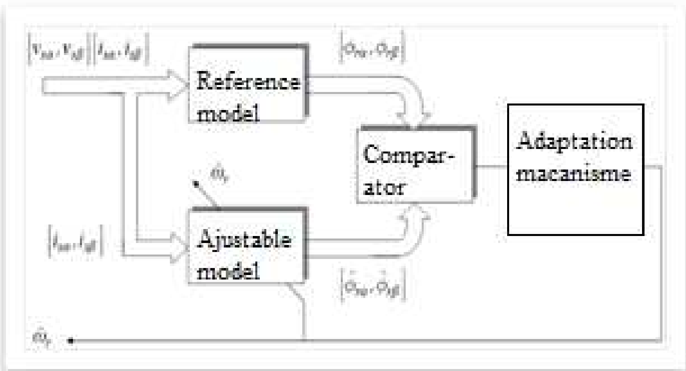


Fig. 3 Structure of the MRAS observer

- **The basic model:**

from stator and rotor equations of the an asynchronous machine, we have:

- **Reference model :**

$$\begin{cases} \dfrac{d\varphi_{r\alpha}}{dt} = \dfrac{L_r}{M}\left(V_{s\alpha} - R_s \cdot I_{s\alpha} - \sigma L_s \cdot \dfrac{dI_{s\alpha}}{dt}\right) \\ \dfrac{d\varphi_{r\beta}}{dt} = \dfrac{L_r}{M}\left(V_{s\beta} - R_s \cdot I_{s\beta} - \sigma L_s \cdot \dfrac{dI_{s\beta}}{dt}\right) \end{cases} \quad (3)$$

- **Adjustable model:**

$$\begin{cases} \frac{d\tilde{\varphi}_{r\alpha}}{dt} = -\frac{1}{T_r}\tilde{\varphi}_{r\alpha} - P.\tilde{\Omega}.\tilde{\varphi}_{r\alpha} + \frac{M}{T_r}I_{s\alpha} \\ \frac{d\tilde{\varphi}_{r\beta}}{dt} = -\frac{1}{T_r}\tilde{\varphi}_{r\beta} + P.\tilde{\Omega} + \frac{M}{T_r}I_{s\beta} \end{cases} \quad (4)$$

The algorithm of adaptation is chosen so as to converge the adjustable model to the reference model thus minimizing the error and have the stability of the model. For this, the algorithm parameters are defined according to the criterion of hyperstability said Popov.

The error between the states of the two models can be expressed in matrix form by [7]:

$$\begin{bmatrix} \varepsilon_\alpha \\ \varepsilon_\beta \end{bmatrix} = \begin{bmatrix} \varphi_{r\alpha} - \tilde{\varphi}_{r\alpha} \\ \varphi_{r\beta} - \tilde{\varphi}_{r\beta} \end{bmatrix} \quad (5)$$

$$\frac{d}{dt}\begin{bmatrix} \varepsilon_\alpha \\ \varepsilon_\beta \end{bmatrix} = \begin{bmatrix} -\frac{1}{T_r} & -\omega \\ \omega & -\frac{1}{T_r} \end{bmatrix} \bullet \begin{bmatrix} \varepsilon_\alpha \\ \varepsilon_\beta \end{bmatrix} - \begin{bmatrix} \tilde{\varphi}_{r\alpha} \\ \tilde{\varphi}_{r\beta} \end{bmatrix} \bullet (\omega - \tilde{\omega})$$

$$\frac{d}{dt}[\varepsilon] = [A] \bullet [\varepsilon] - [W]$$

Schauder offers an adaptation law that meets the criterion of Popov and given by the equation:

$$\tilde{\omega} = Q_2(\varepsilon) + \int_0^t Q_1(\varepsilon)\,d\tau \quad (6)$$

The criterion of Popov requires satisfaction of the following integral:

$$\int_0^t \varepsilon^T \bullet W dt \geq -\gamma^2, \gamma \succ 0 \quad (7)$$

Using equation (7), while replacing ε and w by their values, we obtain:

$$\int_0^t \left\{ \left[\varepsilon_\alpha \cdot \tilde{\varphi}_{r\beta} - \varepsilon_\beta \cdot \tilde{\varphi}_{r\alpha} \right] \bullet \left[\omega - Q_2(\varepsilon) - \int_0^t Q_1(\varepsilon) d\tau \right] \right\} dt \geq -\gamma^2 \quad (8)$$

The solution of equation (8) can be found using the following relation:

$$\int_0^t k \bullet \left(\frac{df(t)}{dt} \right) f(t)dt \geq -\frac{1}{2}kf(0)^2, k \geq 0 \quad (9)$$

Using the latter equation for solving Popov of the integral, the following functions are obtained:

$$\begin{cases} Q_1 = k_i(\varphi_{r\beta} \cdot \tilde{\varphi}_{r\alpha} - \varphi_{r\alpha} \cdot \tilde{\varphi}_{r\beta}) \\ Q_2 = k_p(\varphi_{r\beta} \cdot \tilde{\varphi}_{r\alpha} - \varphi_{r\alpha} \cdot \tilde{\varphi}_{r\beta}) \end{cases} \quad (10)$$

By replacing this system of equations in equation (10) yields the value estimated by the following adaptation law:

$$\tilde{\omega} = k_p(\varphi_{r\beta}\cdot\tilde{\varphi}_{r\alpha} - \varphi_{r\alpha}\cdot\tilde{\varphi}_{r\beta}) + k_i\int_0^t(\varphi_{r\beta}\cdot\tilde{\varphi}_{r\alpha} - \varphi_{r\alpha}\cdot\tilde{\varphi}_{r\beta}) \qquad (11)$$

4. Design of the Kubota observatory

The estimators used in open loop, based on the use of a copy of a model representation of the machine. This approach led to the implementation of simple and fast algorithms, but sensitive to modeling errors and parameter variations during operation.

Is an estimator operating in a closed loop and having an independent system dynamics. It estimates an internal physical quantity of a given system, based only on information about the inputs and outputs of the physical system with the feedback input of the error between Estimated outputs and actual outputs, using the K matrix gain to thereby adjust the dynamic convergence error [8].

The structure of the adaptive observer of KUBOTA is illustrated in Fig. 5, when the rotational speed of the machine is not measured, it is considered as an unknown parameter in the observer's system of equations based on the state model. This state model is given below [9].

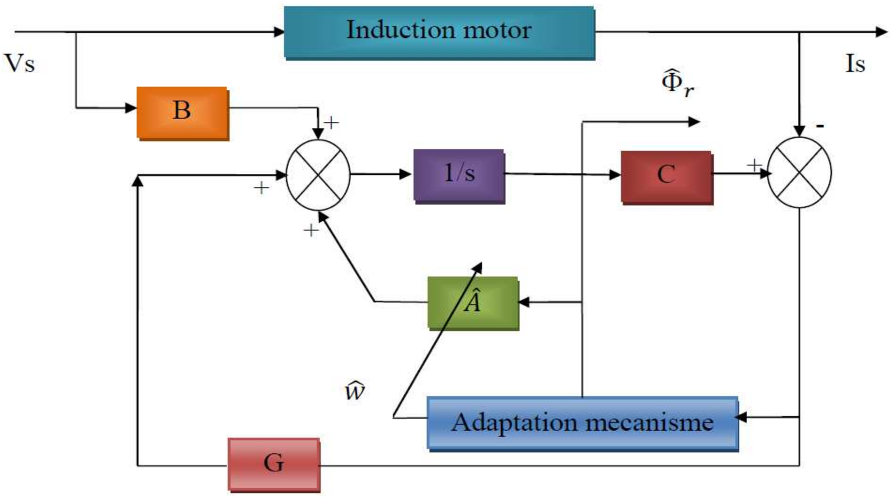


Fig.4 Structure of the adaptive Kubota observer.

The modeling the observer KUBOTA

- **State model**

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx \end{cases} \quad [A] = \begin{bmatrix} A11 & A12 \\ A21 & A22 \end{bmatrix} \quad x = \begin{bmatrix} I_s \\ \varphi_r \end{bmatrix} \qquad (12)$$

So the observatory associated with this model is written as:

$$\frac{d\tilde{x}}{dt} = \tilde{A}\tilde{x} + B_{us} + G(I_s - \tilde{I}_s) \qquad G = \begin{vmatrix} g_1 & g_2 & g_3 & g_4 \\ -g_2 & g_1 & -g_4 & g_3 \end{vmatrix}^T \qquad (13)$$

By asking that $e = x - \tilde{x}$ estimation error between the model and the observer:

- **Estimation error**

$$\frac{de}{dt} = (A - GC)e - \Delta A\tilde{x} \; ; \Delta A = A - \tilde{A} = \begin{bmatrix} 0 & \Delta kwJ \\ 0 & \Delta wJ \end{bmatrix}, \Delta w = w - \tilde{w} \quad (14)$$

- **Adaptation mechanism**

The speed adjustment mechanism is derived from the application of Lyapunov theorem on system stability. Let Lyapunov function defined positive:

$$V = e^T e + \frac{(w - \tilde{w})^2}{\lambda} \quad (15)$$

Otherwise, the derivative of this function with respect to time is negative:

$$\frac{dV}{dt} = e^T Qe - 2\Delta w\left[k(e_{is\alpha}\tilde{\varphi}_{r\beta} - e_{is\beta}\tilde{\varphi}_{r\alpha} - \frac{d\tilde{w}}{\lambda dt})\right] \quad (16)$$

With:

$$e_{is\alpha} = i_{s\alpha} - \tilde{i}_{s\alpha}, e_{is\beta} = i_{s\beta} - \tilde{i}_{s\beta}$$

$$Q = (A - GC)^T + (A - GC) \quad (17)$$

Equation (8) must be set negative according to the Lyapunov stability theory. Therefore, by careful selection of the gain matrix G, the matrix Q must be a negative definite matrix and the adaptation mechanism for estimating the speed will be reduced by cancellation of the 2 nd term of the equation (9).

The estimate of the speed is done by the following law:

$$\tilde{\omega} = k\lambda . \int (e_{is\alpha}\tilde{\varphi}_{r\beta} - e_{is\beta}\tilde{\varphi}_{r\alpha})dt \quad (18)$$

To improve the speed of dynamic observation, propose to use PI instead of a pure integrator:

$$\tilde{\omega} = k_p . (e_{is\alpha}\tilde{\varphi}_{r\beta} - e_{is\beta}\tilde{\varphi}_{r\alpha}) + k_i \int (e_{is\alpha}\tilde{\varphi}_{r\beta} - e_{is\beta}\tilde{\varphi}_{r\alpha})dt \quad (19)$$

5. Simulation results

The simulation is performed by MATLAB-Simulink environment, where the reference speed w_{ref} = 150 rad / s and t_3=2s, applied to the load t_1=1s and eliminated to t_2=1.5 s.

Normal operation with load variation

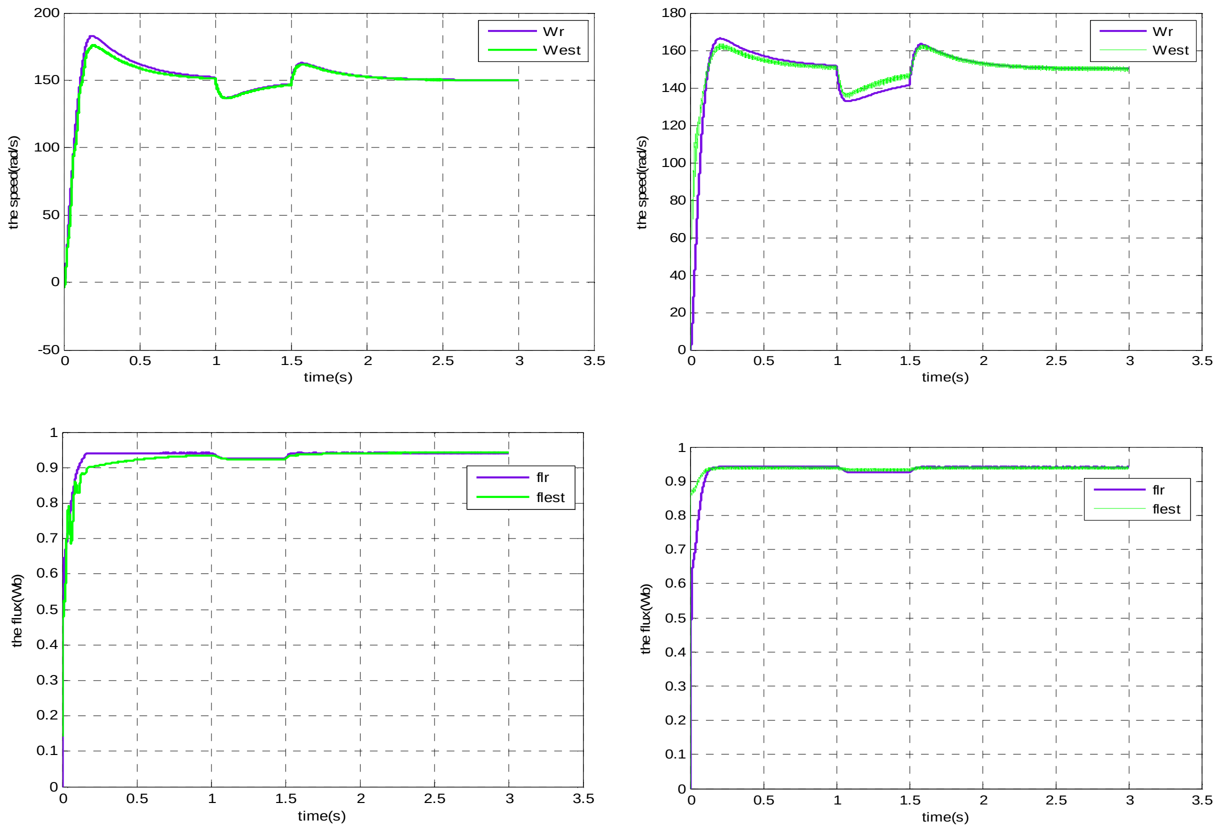


Figure. 5 error estimation of speed and of flux by Kubota(left), Mras (right).

Testing the robustness of low speeds (50-15 rad / s):

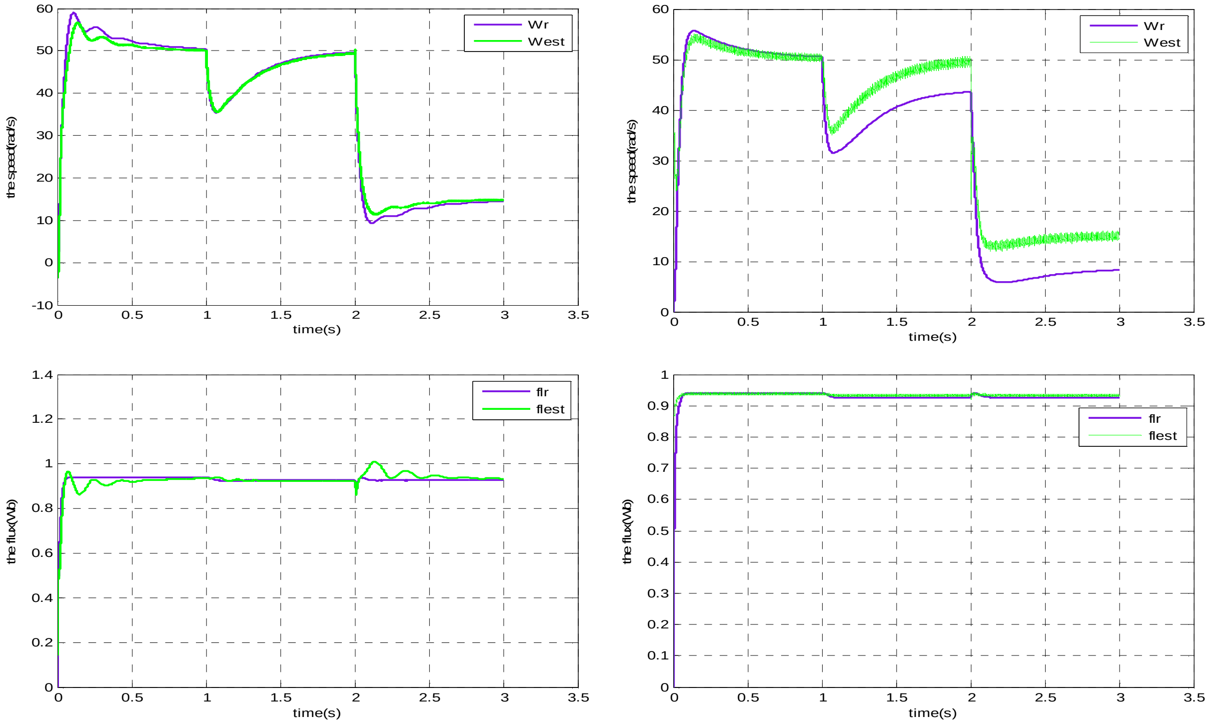


Figure. 6 Speed and flux estimate by Kubota (left), Mras (right).

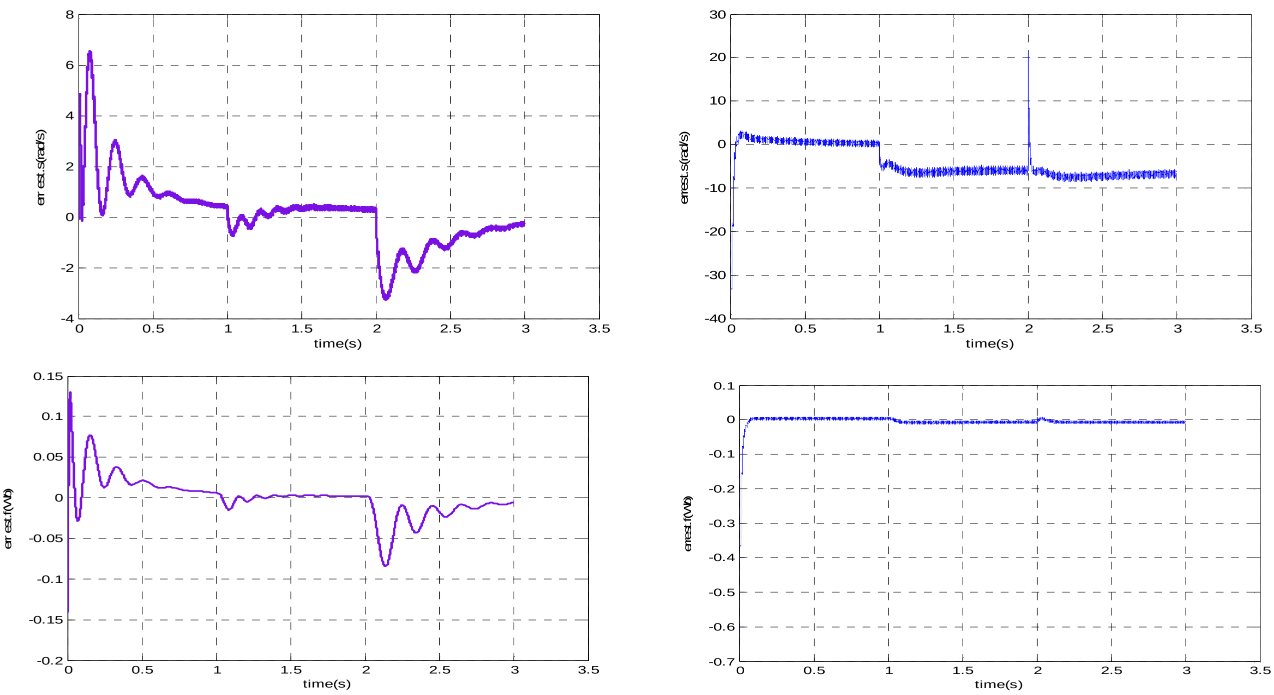
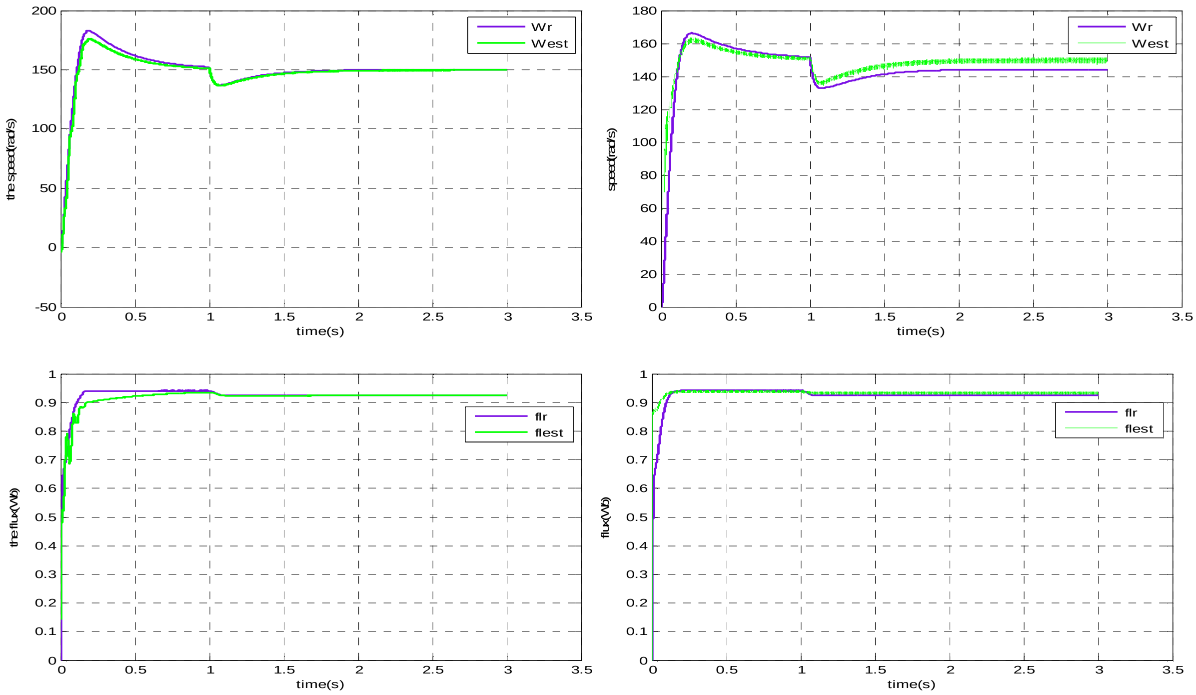


Figure. 7 Error estimation of speed and of flux by Kubota(left), Mras (right)

Case of variation of R_s(-50%)

Figure. 8 Speed and of flux estimate by Kubota(left), Mras (right).



5.1 Comparison and interpretation

Table.1 Comparison between the performances of KUBOTA and MRAS

	Precision	**swiftness**	**Oscillation**	**Low speed**
MRAS	Accurate	Fast	Existing	Good
KUBOTA	More accurate	Fast below	Missing	Excellent

This table shows that the simulation results using artificial intelligence techniques (neural hysteresis) show that the tracking of the set point is perfect. We note that the ripple of electromagnetic torque and stator flux reduces perfectly compared to conventional DTC without neural hysteresis comparator It is more apparent through the trajectory of the stator flux In addition to a large decrease in THD as shown in the table above , We were able to conclude that the DTC control by neural hysteresis showed good performance than the classical DTC control.

Simulation results show that using the observer is important in the control of the machine, the estimation error as zero in the steady state, The major advantage for KUBOTA observation technique it's insensitivity to the machine settings.

6. Conclusion

In this paper, we mainly presented the estimation of the rotor flux by the KUBOTA adaptive state observer, then we evaluated the estimation error of the flux, we also devoted to improve the performances of the direct control of the torque of the asynchronous two-level UPS powered machine based on artificial intelligence techniques by neural hysteresis, The simulation results show that the use of both estimators is important in the control of the MAS, the transient and very short regime and the error between the flows estimated and measured to zero in the steady state, the robustness tests of the estimator are also verified. According to the simulation results too, we notice that the estimation by MRAS technique performance (a little overflow, short response time, no oscillations, robust), but the observer KUBOTA also play its role, and give good result and almost similar by contribution to the 1st observer The major disadvantage of the speed estimation based on MRAS is its high sensitivity to the parameters of the machine For this, several works have proposed online adaptation techniques the stator resistance and also rotor resistance.

Finally we can say the use of the estimator brings a clear improvement to the looped structure.

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