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Control of variable reluctance machine (8/6) by artificiel intelligence techniques

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ABSTRACT

The non-linearity of variable-Reluctance Machine (8/6) and the dependence of machine inductance on rotor position and applied current complicate the development of the control strategies of drives using variable-Reluctance Machine variable-Reluctance Machine (VRM). The classical-control algorithms for example of derived full proportional action may prove sufficient if the requirements on the accuracy and performance of systems are not too strict. In the opposite case and particularly when the controlled part is submitted to strong nonlinearity and to temporal variations, control techniques must be designed which ensure the robustness of the process with respect to the uncertainties on the parameters and their variations. These techniques include artificial-intelligence-based techniques constituted of neural networks and fuzzy logic. This technique has the ability to replace PID regulators by nonlinear ones using the human brain's reasoning and functioning and is simulated by using MATLAB/Simulink software. Finally, by using obtained waveforms, these results will be compared.

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1. INTRODUCTION

VRMs have the particularity of not having conductors on the rotor. This simplicity allows them to operate at high speed as at low speed. These machines have become a powerful competitor in the sectors of variable speed. Variable reluctance machines combine the qualities of synchronous machines and those of brushless DC machines. The advantages of such machines are numerous. In addition to being simple to build, the rotor often has low inertia. The stator is also simple to build and the phases operate almost independently of each other (mutual inductances are weak). The unipolar converters associated with them are inexpensive and easy to control. In the event of a fault, the open circuit voltage and the short-circuit current are very low. The starting torque can be high without causing an excessive rise in current (in the case of conventional motors). Thus, their performance associated with their low manufacturing costs reserve them a place of choice in several applications [1-3].

The motor is highly non-linear and works in saturation to maximize torque. The motor torque is a non-linear function of the rotor position and current, the coupling of their internal variables (torque and flux), makes the structure of the VRM complex and makes the controller design difficult. The reduction of the high torque ripple and the sensitivity of these machines to disturbances [4] ,as well as the degradation of their performances when their parameters varies with the temperature or the presence of noise due to the static converter, but also the uncertainties due to modeling errors as well as to the variation of the parameters of the system, represent for us a considerable challenge since in addition to having strongly non-linear characteristics, the parameters are often unknown. It is therefore necessary to design efficient comands that are less sensitive to these parametric variations and to these disturbances. A current direction of research is essentially based on the comparison of advanced commands that use the tools of artificial intelligence: fuzzy logic, artificial neural networks [5]. We will demonstrate the utility of applying different robust comands with fuzzy logic or neural networks that will at best enable the prosecution of position trajectories with great accuracy and, on than the others, significantly reduce the ripples of torque of VRM [6].

2. EQUIVALENT CIRCUIT AND ELECTROMAGNETIC EQUATIONS

The parameters used for the variable reluctance motor 8/6 cited in Figure 1 are as follows: 4 phases, P_N=3000 W, U_N=230 V, ω_n=1920 rad/sec, T=12 N.m, R_s=1,3Ω, L_{max}=120 mH, L_{min}=90 mH, J=0,0013 kg.m^2, B=0,0183T et $\beta_r=\beta_s=30^\circ$. The equivalent circuit of a phase of the VRM is composed of a resistor R_s, an inductance L(θ) and an electromotive force e, connected in series, as shown in Figure 2.

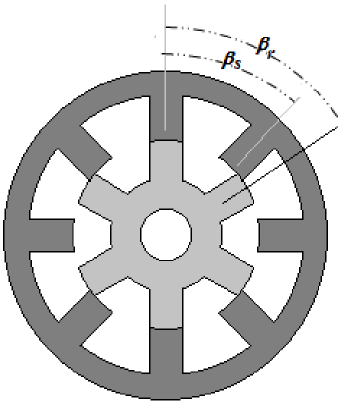

Figure 1. Four-phase variable reluctance motor (8/6)

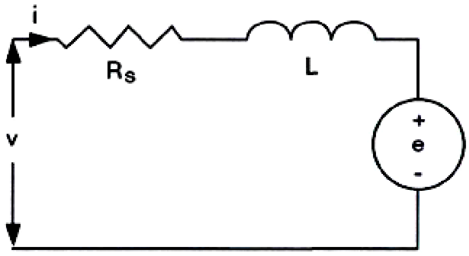

Figure 2. Equivalent circuit of a VRM phase

By neglecting the mutual inductance between the phases of the stator, the voltage applied across a phase is equal to the sum of the resistive voltage drop and the variation of the coupled flow [7-10]. This tension is given by the following equation:

$$V = R_s i + \frac{d\Psi}{dt} = R_s i + \frac{d\left[L(\theta,i)i\right]}{d\theta} \tag{1}$$

knowing that

θ : Rotor position
Ψ: The flow
ω: The rotation speed.

$$\Psi = \theta\left(i\ ,\ \right)\times$$

$$\omega = \frac{d\theta}{dt}$$

R_s is the resistance of a single phase. Equation (1) can be written in the following form:

$$V = R_s i + L(\theta,i)\frac{di}{dt} + \frac{dL(\theta,i)}{d\theta}\omega i \tag{2}$$

The three terms on the right side of the Equation (2) represent respectively the resistive voltage drop, the inductive voltage drop and the emf induced. This equation is similar to that of the DC motor with series excitation. The induced electromotive force e is obtained by the following equation:

$$e = \frac{dL(\theta,i)}{d\theta}\omega \times i = K_b \omega \times i \tag{3}$$

e : is the expression of the electromotive force.

The multiplication by the instantaneous current on both sides of the (2) gives:

$$P_i = V \times i = R_s i^2 + L(\theta,i) \times i\frac{di}{dt} + \frac{dL(\theta,i)}{d\theta}\omega \times i^2 \tag{4}$$

Where P_i is the instantaneous input power.

The last term is not physically interpretable. For it to have a physical meaning, it must be according to known variables.

$$\frac{d}{dt}\left(\frac{1}{2}L(\theta,i)i^2\right) = L(\theta,i)i\frac{di}{dt} + \frac{1}{2}i^2\frac{dL(\theta,i)}{dt} \tag{5}$$

Replacing in (5) and simplification:

$$P_i = R_s i^2 + \frac{d}{dt}\left(\frac{1}{2}L(\theta,i)i^2\right) + \frac{1}{2}i^2\frac{dL(\theta,i)}{dt} \tag{6}$$

This equation clearly shows that the instantaneous input power is equal to the sum of the resistive losses given by $R_s i^2$, the rate of change of the electromagnetic energy is given by $\frac{d}{dt}\left(\frac{1}{2}L(\theta,i)i^2\right)$ and the power P_i in the air gap given by the term $\frac{1}{2}i^2\frac{dL(\theta,i)}{dt}$ .Setting the time according to rotor position and speed

$$t = \frac{\theta}{\omega} \tag{7}$$

The power P_a in the gap becomes:

$$P_a = \frac{1}{2}i^2\frac{dL(\theta,i)}{dt} = \frac{1}{2}i^2\frac{dL(\theta,i)}{d\theta}\frac{d\theta}{dt} = \frac{1}{2}i^2\frac{dL(\theta,i)}{dt}\omega \tag{8}$$

The power in the air gap is equal to the product of the electromagnetic torque and the speed of the rotor

$$P_a = T_e \omega \tag{9}$$

Whence comes the equation of the electromagnetic torque:

$$T_e = \frac{dL(\theta,i)}{d\theta}\frac{i^2}{2} \tag{10}$$

$$\frac{dL(\theta,i)}{d\theta} = \left.\frac{L(\theta_2,i)-L(\theta_1,i)}{\theta_2-\theta_1}\right|_{i=cons\tan t} \tag{11}$$

This variation of the inductance is considered as the constant of the torque, and is expressed in N.m/A^2. The (12) leads to the following conclusions:

- The torque is proportional to the square of the current, so the current can be unidirectional. The advantage of using a unidirectional current is distinguished by the use of a single switch controlled in each phase. This would minimize the number of switches that make up the converter and make it more economical
- It will thus be possible to use a unidirectional current converter to power our machine. Thus, the direction of the produced torque does not depend on the direction of the current in the coils, but only on the slope of variation of the permeance
- The torque constant is given by the slope of the characteristic of the inductance as a function of the position of the rotor Figure 3, but the inductance depends on the current and the position of the rotor, which makes this non-linear characteristic. This non-linearity makes the development of a simple equivalent circuit of the variable reluctance machine.

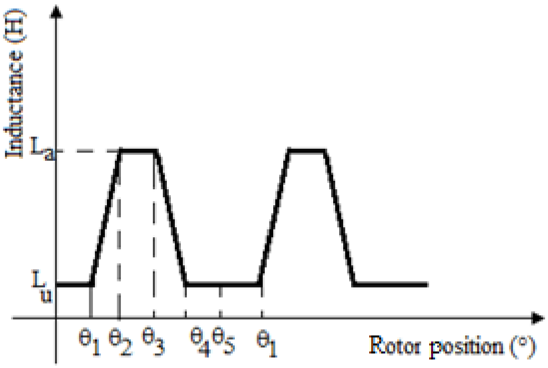

Figure 3. Characteristic of the inductance as a function of the position of the rotor

3. FEEDING THE VARIABLE RELUCTANCE MACHINE

The power supply by rectangular currents allows a gain in torque and the use of a simple and robust power converter [11-14]. The most commonly used inverter for supplying the variable reluctance motor is the asymmetric half-bridge inverter Figure 4. An inverter arm is formed by two semiconductor switches and two freewheel diodes. The major advantage of this circuit is the independent phase control it offers and the implicit protection given by the presence of the motor winding between the two semiconductor components.

4. CONTROL OF THE VRM WITH A CONVENTIONAL PID

The closed-loop control of the DC drive system is shown in Figure 5. The power circuit consists of an asymmetric converter which drives the variable reluctance motor [15-19]. The circuit has an internal current control loop and an external loop for speed control. The variable speed drive is designed to follow the load variation. The current loop is used to generate the motor control signal $V_{d.}$

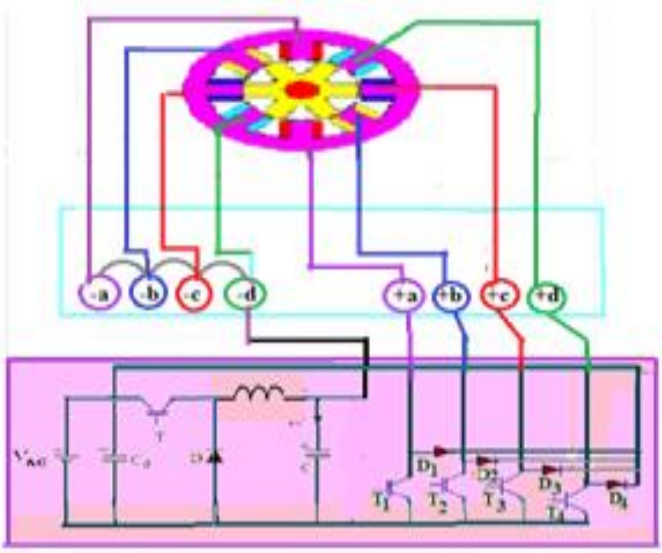

Figure 4. Supply of the VRM with an asymmetric half-bridge inverter

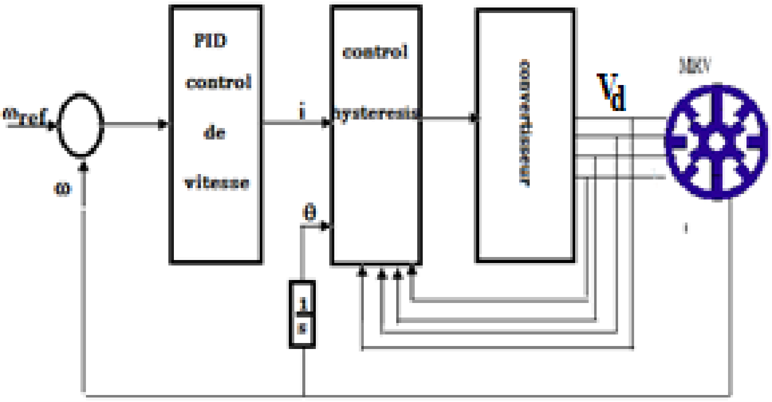

Figure 5. Controlling the MRV with a conventional PID controller

5. CONTROL OF VARIABLE RELUCTANCE MACHINE BY ARTIFICIAL INTELLIGENCE TECHNIQUES

Because of the way the torque is produced in the form of pulses, the VRM is particularly susceptible to producing large torque ripples. These undulations are generally undesirable, especially in the field of traction, where oscillations of the motor can cause dangerous situations. The conventional control algorithms, for example with derivative integral proportional control, may prove sufficient if the requirements on the accuracy and performance of the systems are not too strict. In the contrary case and especially when the controlled part is subjected to strong no-linearity and to temporal variations, intelligent control techniques must be devised which ensure the robustness of the process with respect to the uncertainties on the parameters and their variations [20]

5.1. Variable reluctance machine neural control

The principle of this control is based on an inverse model identification Figure 6. Shows the inverse control scheme by neural networks. The reference input ω_r is compared with the output y of the process to form the tracking error, $e=\omega-\omega_r$ which is used to modify the parameters of the network. After taking the inverse model, the neuro-controller delivers the output u of the RNC which is the command injected at the input of the process, then the error is zero and the output y is equal to the reference ω_r [21-23]. The simulation was performed with 10 hidden layers and an average final error of 0.00012 between the reference velocity and the output of the neuronal controller.

5.2. Variable reluctance machine fuzzy control the speed

The goal is to design a fuzzy PID controller Figure 7 in order to maintain the speed of the variable reluctance motor at the desired set points, then introduce a step where the motor is loaded and observed, at each instant adapt for different variations of velocity [24-27]. The conventional controller is replaced by a PID - fuzzy controller to ensure a 10% better operation by maintaining the set point speed even when charging the motor.

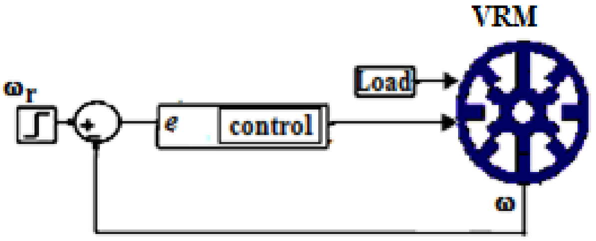

Figure 6. Neural network controller applied to VRM motor

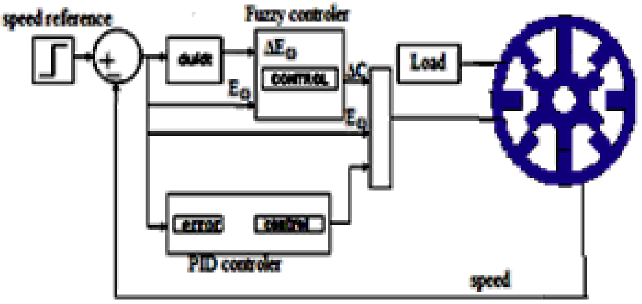

Figure 7. Block diagram of the Fuzzy-PID controller

The conventional regulator (PID) is replaced by a fuzzy regulator of the type Sugeno whose linguistic variables are [28]:

- The inputs are the error and the variation of the error denoted respectively E_ω and ΔE_ω .
- The output is '⊗Cem'.

In the case of speed control, the error is usually used

$$E_\omega(k) = G_{E_\omega}\big(\omega_{ref}(k) - \omega(k)\big) \tag{13}$$

and the variation of the error ΔE_ω:

$$\Delta E_\omega(k) = G_{\Delta E_\omega}\big(E_\omega(k) - E_\omega(k-1)\big) \tag{14}$$

$G_{\Delta E_\omega}$ and $G_{\Delta E_\omega}$ represent the adaptation gains, they are chosen to be low for the stability of the system. They play an extremely important role. Indeed, these are the ones that will fix the performance of the command. This law is a function of error and its variation:

$$\Delta C_{em} = f(E_\omega, \Delta E_\omega) \tag{15}$$

5.2.1. Structure of the fuzzy control

We retained for the controller [29]:

- Input variables whose member ship functions of the fuzzy sets are triangular and trapezoidal.
- The quantities E_ω and $\Delta E_\omega$are standardized in a discourse universe [-5, + 5], [-2.5, + 2.5], refer Figure 8.
- The output variable ⊗C_{em} is normalized in a speech universe [- 40, + 40], refer Figure 9.

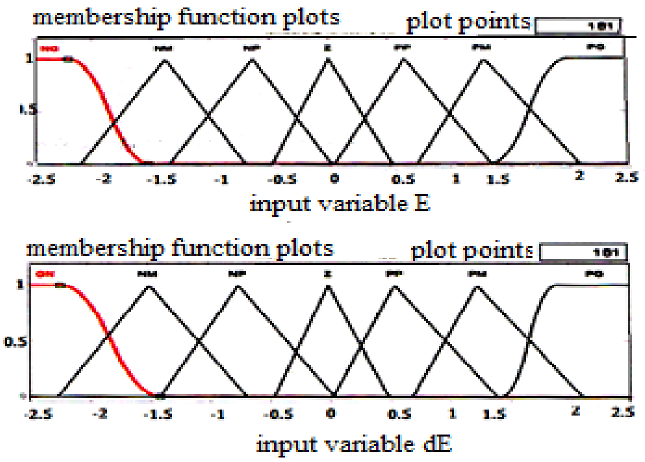

Figure 8. The membership functions for the input variables

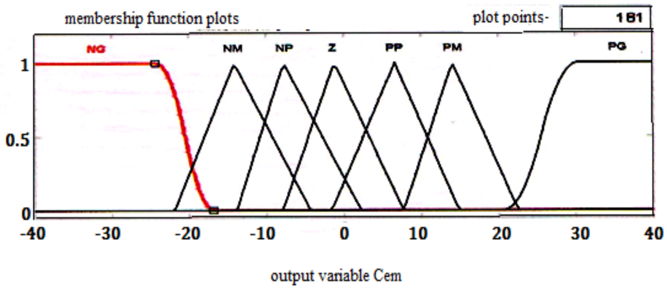

Figure 9. The membership functions for the output variable

- An incremental PID structure (two-dimensional inference matrix). Based on the operation of the controller and the behavior of the machine, we deduce the rules of fuzzy inferences
- Fuzzy rules, allowing determining the variable of output of the regulator according to the variables of inputs are deduced from the table of Mac-Vicar called inference. In this case, it contains 49 rules as shown in the inference table below in Table 1. The interval of each linguistic variable is subdivided into seven classes. To each of the classes we associate a membership function. Based on the operation of the controller and the behavior of the machine, the following fuzzy inference rules are deduced:

Table 1. Inference table with seven fuzzy sets

ΔE_ω / E_ω	BN	MN	SN	Z	SP	MP	BP
N	BN	BN	BN	BN	MN	SN	Z
MN	BN	MN	SN	Z	SP	BN	BN
SN	MN	SN	Z	SP	MP	BN	MN
Z	SN	Z	SP	MP	BP	BN	SN
SP	Z	SP	MP	BP	BP	SN	Z
MP	BP	MP	BP	BP	BP	Z	SP
BP	BP	MP	BP	BP	BP	BN	BN

- What we try to reproduce intuitively is to react, when we are far from the objective, the fuzzy sets "big negative" and "big positive", knowing that often in this case the actual output of the regulator will have reaches its saturation limit value. When close to the reference speed, the "small negative" and "small positive" fuzzy sets will be solicited and their membership functions will be closer to that of the "zero" set, the answer will be sweeter. When one is far from the objective, variable gains at the input and output of the regulator to adjust its operation and vary its range of sensitivity.

6. ORDER SIMULATION RESULTS

The simulation tool used is Mathwork MATLAB version 7.5. It is a mathematical calculation tool based on matrix calculation. It offers a library of specific functions for the development of control algorithm under Simulink graphical environment [30]. The block diagram of the simulation studies the dynamic behavior of the closed loop VRM fed by the half bridge inverter. It is a linear model representative of the three phases of our machine. The global converter-machine model and its control is obtained by associating the operation of the three offset angles of $\pi/6$. The different phase currents of the stator winding, the torque developed in the motor, the speed of the latter are illustrated.

- The best results of the currents Figures 10, 11, 12 are obtained with the fuzzy controller, it is noted that the total current is stable and the response time is fast and the overruns have completely disappeared, compared to the currents obtained with the neuronal controller or the conventional PID controller.
- The total torque Figures 13, 14, 15 of the machine obtained by the PID controller is pulsating. It is less satisfactory when compared with the neuronal controller because the ripple band of the torque obtained by this controller is uniform and constant, but the best result of Torque is obtained by the fuzzy controller because this ripple band is minimal, it reaches 0.98 N.m
- The speed response Figures 16, 17, 18 obtained with the fuzzy controller is the best compared to the other neuronal or classical correctors because the undulations have faded and the overrun is almost zero, the reference is well followed since it reaches 200 rd /s,
- It is noted that the error Figures 19, 20 is more important for a neuronal controller; it has decreased until cancelled with the fuzzy controller.

The results obtained concerning the application of the fuzzy control show a marked improvement in the performance of the phase currents and the torque, but the best improvement is manifested in the quality of the velocity signal because the ripple bandwidth has been reduced to the maximum.

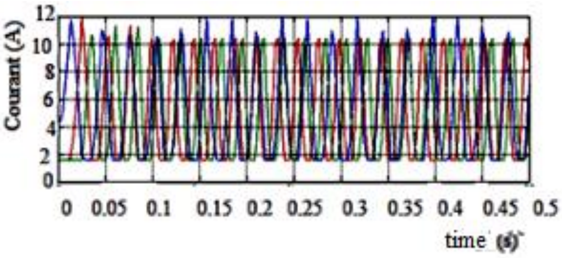

Figure 10. Total currents with PID controller

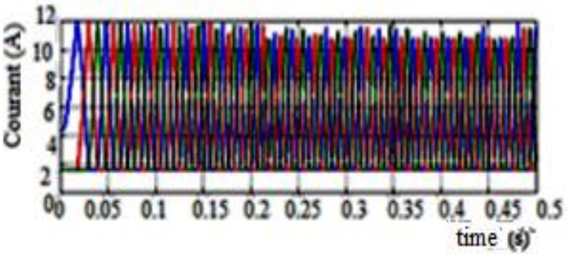

Figure 11. Total current with neuronal controller

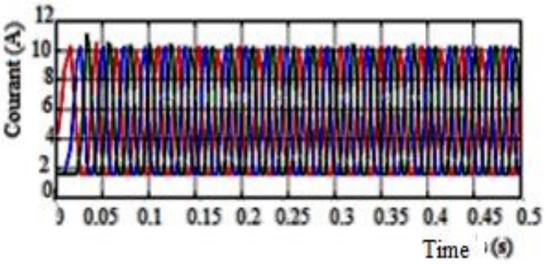

Figure 12. Total current with a fuzzy controller

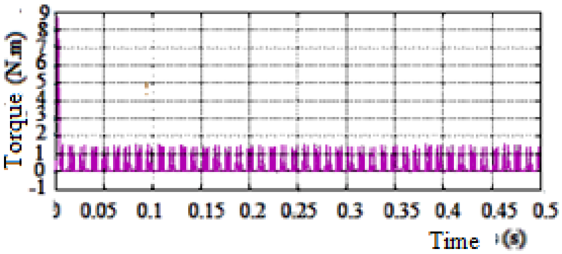

Figure 13. Total torque with PID controller

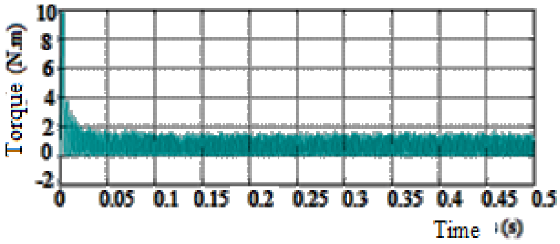

Figure 14. Total Torque with neuronal controller

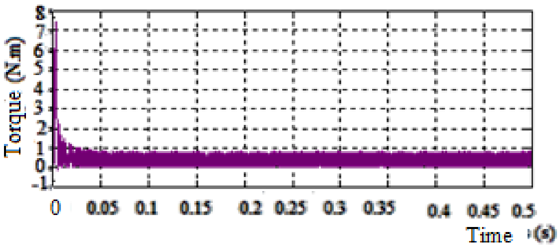

Figure 15. Total torque with a fuzzy controller

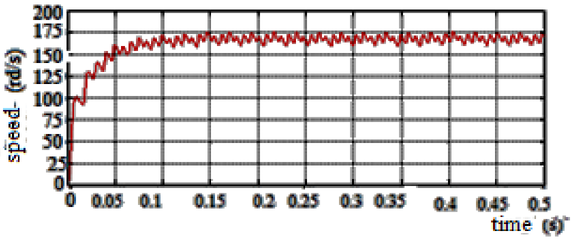

Figure 16. Speed with PID controller

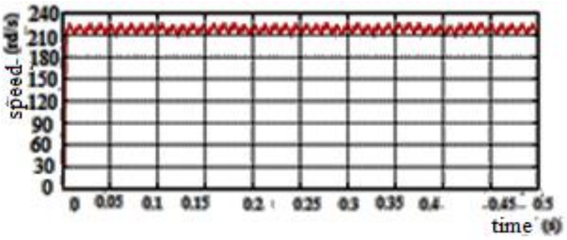

Figure 17. Speed with neuronal controller

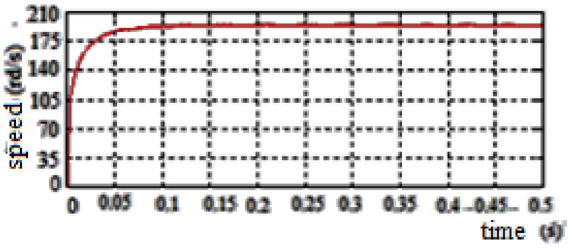

Figure 18. Speed with fuzzy controller

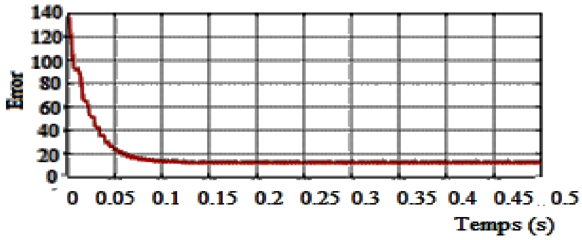

Figure 19. Speed error with neuronal controller

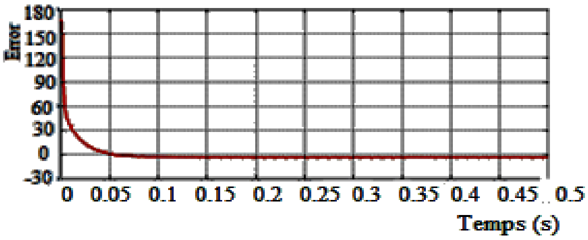

Figure 20. Error with the fuzzy controller

7. ROBUSTNESS STUDY OF CONTROLLERS USING ARTIFICIAL INTELLIGENCE

To test the robustness of the neuronal control algorithm, see the Figures 21 and 23 or the fuzzy control see the figures (22 and 24), parametric variations are imposed [31]. The variation in the inductance due to the derivative of this quantity or to a misidentification of this parameter directly affects the energy and the co-energy, which directly influence the speed of rotation as well as the torque of the variable reluctance machine VRM. By varying the maximum and minimum inductance values by+10% (L_{max}=120 mH and L_{min}=90 mH). It is observed that, despite the parametric variations, the behavioral changes of the adaptive fuzzy controller are not important, and the behavior in regulation and tracking remains very reliable. Indeed disturbances are rejected very quickly. It can therefore be said that the adaptive blur controller is robust.

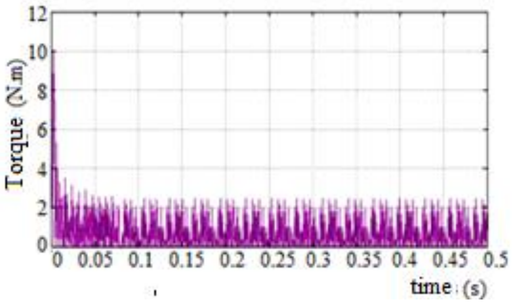

Figure 21.Total torque with neural controller with a 10% increase in inductance values L_{max} and L_{min}

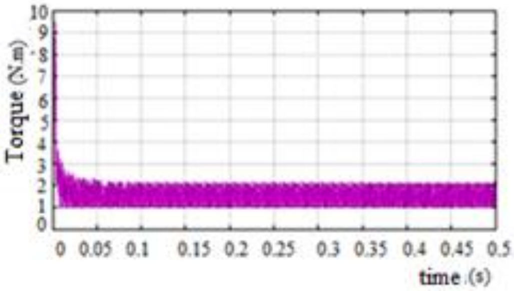

Figure 22. Total torque with fuzzy controller with a 10% increase in inductance values L_{max} and L_{min}

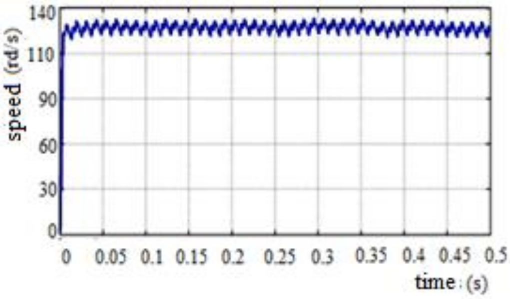

Figure 23. Speed with neuronal controller with a 10% increase in inductance values L_{max} and L_{min}

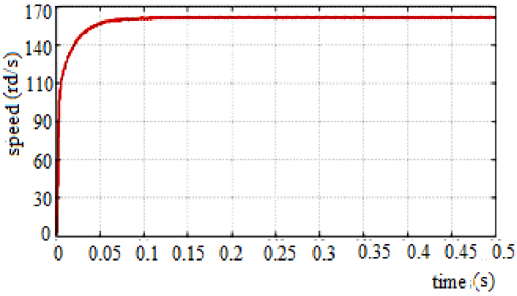

Figure 24. Speed with fuzzy controller with a 10% increase in inductance values L_{max} and L_{min}

8. CONCLUSION

The variable reluctance motor has a simple construction, but its mathematical model is relatively difficult, due to its nonlinear behaviour because its flux is a function of two variables: the current i and the position of the rotor angle θ. The PID regulator achieves good performance near an operating point, but this regulator fails in the case of the 8/6 variable reluctance machine which is highly non linear. The torque of this machine is highly pulsating, so it is impossible to obtain good dynamic performances using simple linear control laws like the PID regulator. We presented two studies of nonlinear control by artificial intelligence (neural and fuzzy logic) that make it possible to compensate the nonlinearities of the motor and to reduce the torque ripples even in the presence of parametric uncertainties in the model. The fuzzy logic controller is better than the neural controller. The fuzzy controller improves the accuracy of the system's steady state, and when the error is large, this controller is used to accelerate the dynamic response rate. The controller - fuzzy logic is also the most flexible and its response is relatively fast compared to the response of the neural regulator. We can conclude that the fuzzy logic controller, stabilizes the speed fairly quickly, with a smooth response and improves the dynamic behaviour of the motor, this response is without overshoot, thus leading to better performance and greater robustness.

REFERENCES

[1] Chun Gan., Yihua Hu, Xigang, Chen. X. Wang. “Renewable energy-fed switched reluctance motor for PV pumps applications,” *Conference: IEEE Transportation Electrification Conference and Expo (ITEC) Asia-Pacific. August* 2014.
[2] K. T. Chau, W. L. Li, and C. H. T. Lee. “Challenges and opportunities of electric machines for renewable energy,” *Progress In Electromagnetics Research B*, Vol. 42, 45–74, 2012.
[3] Masic, S., Corda, J., Smaka, S. “Computation of Static, Steady State and Dynamic Characteristics of the Switched Reluctance Motor,” *Korema Journal Automatics Zagreb, Croatia*. 34: pp. 109-11. 2002.
[4] Nutan.Saha, A.K. Panda, Sidhartha Panda, “Speed control with torque ripple reduction of switched reluctance motor by many optimizing liaison technique,” *Journal des systèmes électriques et des technologies de l'information.* Volume 5, numéro 3, pages 829-842, Décembre 2018.
[5] Nutan Saha, Sidhartha Panda, “Speed control with torque ripple reduction of switched reluctance motor by Hybrid Many Optimizing Liaison Gravitational Search technique,” *Engineering Science and Technology, an International Journal*, Volume 20, Issue 3, Pages 909-921, June 2017.
[6] Moussa Boukhnifer, Ahmed Chaibet, Nadir Ouddah, Eric Monmasson. “Speed robust design of switched reluctance motor for electric vehicle system,” *Advances in Mechanical Engineering. vol. 9*, 11, First Published November 6, 2017.
[7] Mininger, X., Rain, X., Hilairet, M., Krebs, G. & Marchand, C. “Modelling of SRM vibrations for two current controls,” *Proceedings of Electrimacs, Cergy-Pontoise, France*, 09. pp. 1- 6. 2011.
[8] Guojun,Yu.,Cheng, He,The “Design of switched reluctance motor variable-speed system based on digital signal controller,” *IPEC Conference on Power & Energy*. 11, 2012.
[9] Chouitek, M., Bekouche, B., Benouza, N. “Comparison of Methodologies for the Design of Variable Reluctance Machine,” *International Review on Modelling and Simulations*, 10. In: I.RE.MO.S.7, (5): pp.1974 -9821, 2014.
[10] Hui Cai, Hui Wang, Mengqiu Li, Shiqi Shen, Yaojing Feng and Jian Zheng, “Torque Ripple Reduction for Switched Reluctance Motor with Optimized PWM Control Strategy,” *Energies*, Volume 11 numero 11, 3215, 2018.
[11] Haoding Li, Berker Bilgin, Ali Emadi, “An improved torque sharing function for torque ripple reduction in switched reluctance machines,” *IEEE Transactions on Power Electronics*. Volume: 34,Numéro: 2 ,février 2019 .
[12] P. Srinivas, “Implementation of PWM Control of DC Split Converter Fed Switched Reluctance Motor Drive,” *International Journal of Electrical and Computer Engineering (IJECE)*, Vol.7, No2, April, pp. 604~609, 2017.

[13] Aguemon, Dourodjaye Pierre, Agbokpanzo, Richard Gilles, Houngan, Kokou Theophile and Vianou Antoine, "Torque Ripple Minimization in Switch Reluctance Motor Using Model Predictive Control for Water Pumping Application," *current journal of applied science and technology* 32(4): 1-9, 2019;

[14] Derradji Ilhem, Hachelfi Walid,| Rahem Djamel. "Sizing and Control of a Typical 6/4 Switching Reluctance Motor," *European Journal of Electrical Engineering*, Vol. 21, No. 1, February, pp. 19-25, 2019.

[15] Rain, X., Krebs, G. "Caractérisation d'une machine à réluctance variable à double saillance avec bobinage d'excitation," *Symposium de genie electrique*, Cachan, 07. Pp.8-9, 2014.

[16] Chouitek, M., Bekouche, B., Benouza, N. "Startegies d'Alimentation d'un Moteur a Reluctance variable (Switched reluctance varaible motor Reluctance Engine Power Startegies," *International Conference On Electronics* & Oil from theory to appication ICEO'11 in Kasdi Merbah University, Ouargla Algeria, 03, 2011.

[17] Betz, R.E., Lagerquist, R., "Control of synchronous reluctance machines," *IEEE Transactions on Industry Applications*, 12. 29(6): pp .1110 – 1122, 1993.

[18] Irimia, N-D., Simion, A., Dabija, O. & Vlăsceanu, S, "Sinusoidal control of a 6/4 variable reluctance machine without rotor position sensor," *Optimization of Electrical and Electronic Equipment OPTIM*, 13th *International Conference IEEE Explore*, 07 2012.

[19] Tahour, A. "Neural Controller for a Switched Reluctance Machine," *Revue Roumaine des Sciences Technique's - Série Électrotechnique et Énergétique*, 53 (4): pp.473-482, 10. 2008.

[20] Mese, E., Torrey, DA., "Sensorless position estimation for variable-reluctance machines using artificial neural networks," *Industry Applications Conference, Thirty-Second IAS Annual Meeting, IAS '97. Conference Record of the 1997 IEEE*, 1997.

[21] Mohamed Habbab, Abdeldjebar Hazzab, Pierre Sicard, "Real Time Implementation of Fuzzy Adaptive PI-sliding Mode Controller for Induction," *International Journal of Electrical and Computer Engineering (IJECE),* Vol.8, No. 5, pp. 2883~2893, October 2018.

[22] Abid, H. "Adaptive Neuro-Fuzzy Controller of Switched Reluctance Motor," *Serbian Journal of Electrical Engineering*, 4(1): pp.23–34. 06, 2007.

[23] Gamal, M., Hashem, H. "Speed Control of Switched Reluctance Motor Based on Fuzzy Logic Controller," *Proceedings of the 14th International Middle East Power Systems Conference (MEPCON'10)*, Cairo University, Egypt. Paper ID 166. pp 19-21. 12, 2010.

[24] Yifan, T., longya, Xu, "Adaptive fuzzy control of a variable speed power generating system with doubly excited reluctance machine," *Spécialistes électronique de puissance Conférence*, CSEP '94 Record, 25 IEEE annual. 08, 06, 2002.

[25] Chouitek, M. "Commande d'un Moteur à Reluctance Variable par l'Emploi de l'Intelligence Artificielle (Control of a Variable Reluctance Motor by the Use of Artificial Intelligence)," Doctorat thesis, University of Science and Technology of Oran Mohamed Boudiaf. 11, 2016.

[26] Babazadeh, A., Karimi, HR. "Robust Adaptive Control of Transverse Flux Permanent Magnet Machines Using Neural Networks," *Electronic Equipment*, Brasov, Romania. 2: pp. 53-58. 2005.

[27] Daryabeigi, E., Abootorabi, H.Z., Markadeh, G. R. A., Soltani, J. & Blaabjerg, F. "Control Approach for Synchronous Reluctance Motor Drives Based on Emotional Controller," *IEEE Transactions on Power Electronics*. vol. 30, no. 4, pp. 2157-2166, April 2015.

[28] Ferrari, M., Bianchi, N. and Fornasiero, E. "Analysis of Rotor Saturation in Synchronous Reluctance and PM-Assisted Reluctance Motors," *IEEE Transactions on Industry Applications*. vol. 51, no. 1, pp. 169-177, Jan.-Feb. 2015.

[29] Cunhe Li, Guofeng Wang, Yan Li et Aide Xu, "Robust adaptive neural network control for switched reluctance motor drives," *Automatika,* Volume 59, 2018 - Numéro 1. Publié En Ligne: 06 Juil. 2018.

[30] Flieller, D., Nguyen, N.K., Wira, P, Sturtzer, G, Abdeslam D. O. and Merckle, J. "Self-Learning Solution for Torque Ripple Reduction for Non sinusoidal Permanent Magnet Motor Drives Based on Artificial Neural Networks," *IEEE Transactions on Industrial Electronics*. 61: pp. 655-666. 2014.

[31] Hao, Z., Xiao, X. and Yongdong, L."Torque Ripple Reduction of the Torque Predictive Control Scheme for Permanent-Magnet Synchronous Motors," *IEEE Transactions on Industrial Electronics*. vol. 59, no. 2, pp. 871-877, Feb. 2012.

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