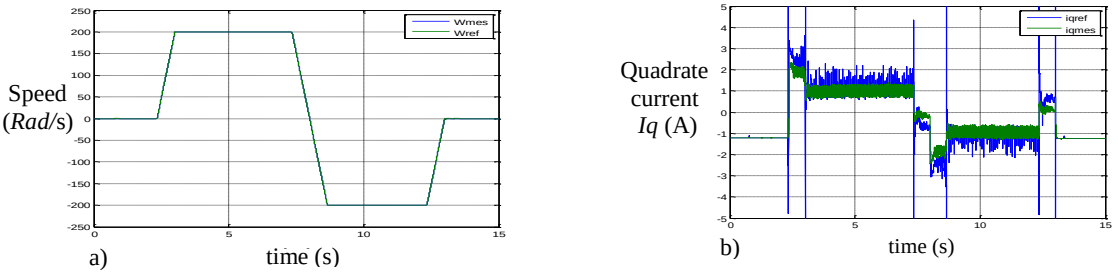

Figure 23. Experimental results under RST controller method: a) estimated speed, b) I_q current with variation of inductances L_{dq} of 50%

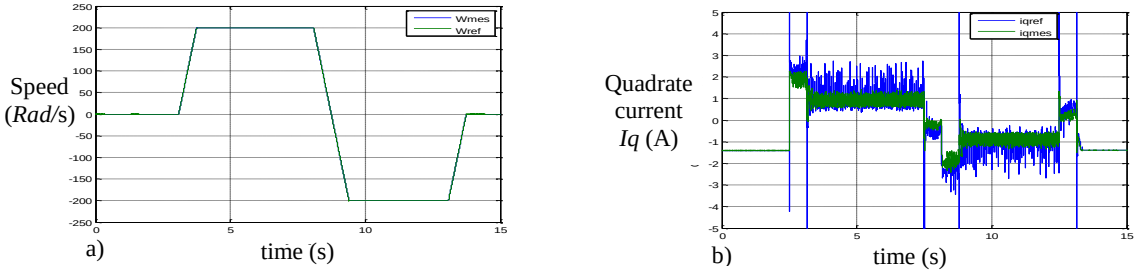

Figure 24. Experimental results under RST controller method: a) estimated speed, b) I_q current with variation of moment of inertia *J* of 50%

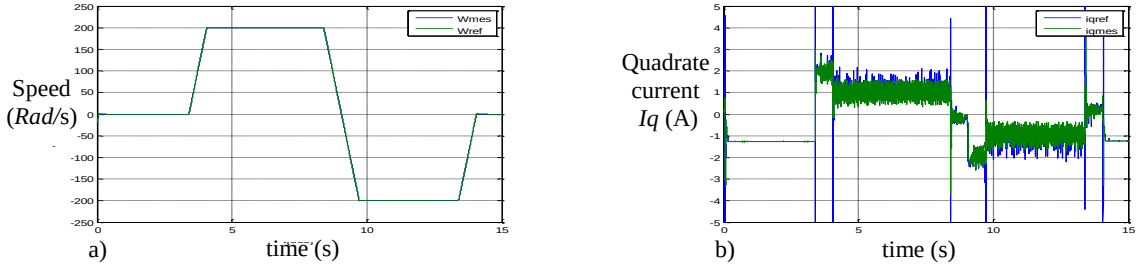

Figure 25. Experimental results under RST controller method: a) estimated speed, b) I_q current with variation of stator resistance *Rs* of 100%

Through these results, good robustness is observed in the response of the closed loop system with respect to parametric variations for the modified IMC method. The RST controller is more robust than the modified IMC one by the fact that there are no overshoot/undershoot in the shape of the speed response.

6. Conclusion

In this paper, we have developed two methods of control, namely the modified IMC and the RST controllers applied on a PMSM in order to regulate its speed and comparing the performance of each of them. Such controllers are adopted by the fact that they are largely used in industrial factories view to their simple implantation in microcontrollers. The study was done for the above PMSM in order to obtain high performances in terms of tracking and disturbances rejections. The two studied methods have present good results in both tracking and robustness towards parameters variations and load disturbance. Nevertheless, the IMC controller in spite of it's modified structure present some inflexibility. This is reflected in the presence of a little speed tracking error which is about of 0.2 and a little overshoot/undershoot.

This disadvantage is almost absent in the response of the closed loop system provided by the RST controller.

7. Acknowledgments

The autors wish to thank all the team of the resarch Unit of Industrial Processes Control " UIPC" in the National Engineering School of Sfax Tunisia which supported this work.

8. References

[1]. K. H. Kim and M.-J. Youn. "A nonlinear speed control for a PM synchronous motor using a simple disturbance estimation technique". *IEEE Trans. on Industrial Electronics*, 49: 524-535, 2002

[2]. T.H.Liu & C.P.Cheng, "Controller design for a sensorless permanent magnet synchronous drives system". *IEEE. Proceedings Electrical Power Applications Part B,* vol.140 (6), pp 368-378

[3]. T. L. Hsien, Y. Y. Sun, and M. C. Tsai, "H∞ control for a sensorless permanent-magnet synchronous drive". *IEE Proc.-Electr. Power Appl.*, 144: 173-181, 1997

[4]. P.M.Pelecezewski, W.Oberschelp, & U.K.Kunz, "Optimal model-following control of a positioning drive system with a permanent-magnet synchronous motor". *IEEE Proceeding Control Theory and Applications, Part-D,* vol 138 (3), pp 267-273, 1991

[5]. Y. A.-R. I. Mohamed, "Design and implementation of a robust current control scheme for a PMSM vector drive with a simple adaptive disturbance observer". *IEEE Trans. on Industrial Electronics*, 54: 1981-1988, 2007

[6]. N.Matsui., & H.Ohashi, "DSP-based adaptative control of a brushless motor". *IEEE Transactions on Industry Applications,* vol 28 (2), pp 448-454, 1992.

[7]. E.Cerruto, A.Consoli, A.Racitti, & A.Testa, "A robust adaptative controller of PM motor drives in robotic applications". *IEEE Transactions on Power Electronics,* vol 10 (1), pp 62-71, 1992

[8]. N.Hemati, J.S.Thorp & M.C.Leu, "Robust nonlinear control of brushless DC motors for direct-drive robotic applications", *IEEE Transactions on Industrial Electronics,* vol 37 (6), pp 460-468, 1990

[9]. I. C. Baik, K.-H. Kim, and M. J. Youn, "Robust nonlinear speed control of PM synchronous motor using boundary layer integral sliding mode control technique", *IEEE Trans. on Control Systems Technology,* 8: 47-54, 2000

[10]. F. J. Lin, C. H. Lin, "A permanent magnet synchronous motor servo drives using self-constructing fuzzy neural network controller", *IEEE Trans. on Energy Conversion,* 19: 66-72, 2003.

[11]. C. E. Garcia, M. Morari, "Intenal model control-1:a unifying review and some new results", *Industrial Engineering Chemistry Process Design and Development,* 21: 308-323, 1982

[12]. M. Morari, E. Zafirious, "Robust Process Control", *New Jeresy: Prentice-Hall,* 1989.

[13]. L. Harnefors, H. P. Nee, "Model-based current control of AC machines using the internal model control method", *IEEE Trans on Industry Applications,* 34: 133-141, 1998.

[14]. I. G. Horn, J. R. Arulandu, R. D. Braatz, "Improved filter design in internal model control", *Industrial Engineering Chemistry Research,* 35: 3437-3441, 1996

[15]. A. Zheng, M. V. Kothare, M. Morari, "Anti-windup design for internal model control", *International J of Control,* 60: 1015-1024, 1994

[16]. H. Gharsallaoui, M.Ayadi, M.Benrejeb, P.Borne, "Flatness-based control and conventional RST polynomial controlof a thermal process", *Int. J of Computers, Communications & Controls,* ISSN 1841-9836, E-ISSN 1841-9844 Vol. IV (2009), No. 1, pp. 41-56

[17]. Bendjedia, K. Tehrani, and Y. Azzouz, "Design of RST and fractional order PID controllers for an induction motor drive for electric vehicle application," 2014

[18]. M. Khanchoul and M. Hilairet, " Design and comparison of different rst controllers for pmsm control," *IECON 2011-37th Annual Conference on IEEE Industrial Electronics Society. IEEE,*2011, pp.1795–1800
[19]. J. Khedri, M.Chaabane, M.Souissi, "Speed control of a permanent magnet synchronous machine powred by voltage inverter : Moment approach", *Int. J of Computers, Communications & Controls*, ISSN 1841-9836, E-ISSN 1841-9844 Vol. VI (2011), No. 1 (March), pp. 90-100
[20]. J. Khedri, M.Chaabane, M.Souissi, D.Mehdi, "Speed control of a permanent magnet synchronous machine (PMSM) fed by volatge inverter fuzzy control approach", *Int. J of Electrical and Information Engineering* 4.4 2010
[21]. J. Khedri, M.Chaabane, M.Souissi, "Robust control of a permanent magnet synchronous machine (PMSM) using internal model control", *Proceedings of the International Technology Management Conference Antalya, Turkey* 2015
[22]. Shihua Li, Senior Member, IEEE, Hao Gu,"Fuzzy Adaptive Internal Model Control Schemes for PMSM Speed-Regulation System", *IEEE Transactions On Industrial Informatics*, Vol. 8, No. 4, November 2012
[23]. C. Eric, "Internal model predictive control," *Automatica,* vol. 31, no.10, pp. 1471–1482, 1995.
[24]. F. J. Lin and C. H. Lin, "A permanent magnet synchronous motor servo drives using self-constructing fuzzy neural network controller," *IEEE Trans. Energy Convers*, vol. 19, no. 1, pp. 66–72, Jan. 2003.
[25]. D. Landau, G. Zito, "*Digital Control Systems: Design, Identification and Implementation*". *Springer*,2006
[26]. Ostertag, E, E. Godoy, "RST-controller design for sinewave references by means of an auxiliary Diophantine equation", *Proc. 44th IEEE Conference on Decision and Control and European Control Conference,* CDC-ECC'05, pp. 6905-6910, Seville

Jamel Khedri received the Ph. D degree from National School of Engineers of Sfax (ENIS), University of Sfax, Tunisia, in 2010. His currents research interests robust control, fuzzy logic control, D-stability analysis and applications of these techniques to induction motors

Mansour SOUISSI received his Ph. D in Physical Sciences from the University of Tunis in 2002. He is Professor in Automatic Control at Preparatory Institute of Engineers of Sfax, Tunisia. Since 2003, he is holding a research position at Automatic Control Unit, National School of Engineers of Sfax, Tunisia. His current research interests robust control, optimal control, fuzzy logic, linear matrix inequalities and applications of these techniques to agriculture systems. Dr Souissi is a member of the organization committees of several national and international conferences (STA, CASA)