Real-time implementation of SVPWM-sensorless vector control of induction motor using an extended Kalman filter

Mustapha Bendjima[1], Abdeldjebar Hazzab[1,3,4], Mansour Bechar[1], Medjdoub Khessam[1,2], Miloud Rezkallah[3,4], Ambrish Chandra[3], Hussein Ibrahim[4]
[1]Laboratory of CAOSEE, Department of Technology, Faculty of Technology, Tahri Mohamed University, Bechar, Algeria
[2]Department of Technology, Institute of Science and Technology, University Center Salhi Ahmed Naama, Naâma, Algeria
[3]Department of Electrical Engineering, École de Technologie Supérieure, Montréal, Québec, Canada
[4]Centre de Recherche de Gestion Énergétique Intelligente des Systèmes Industriels et Dans les Bâtiments (CR2ie), Cégep de Sept-Îles, Sept-Îles, Québec, Canada

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ABSTRACT

In this research paper, space vector pulse width modulation (SVPWM)-sensorless vector control of an induction motor using an extended Kalman filter is presented. The aim of the proposed sensorless control method is to design, implement, and test a sensorless vector control scheme by simulation and experimental implementation. An extended Kalman filter (EKF) simultaneously estimates the rotor speed, the stator stationary axis components ($i_{\alpha s}$, $i_{\beta s}$), and the rotor fluxes ($\varphi_{\alpha s}$, $\varphi_{\beta s}$). The measured stator voltages and currents are employed as inputs for a recursive filter. Simulation results under various operating conditions validate the performances and effectiveness of the proposed observer. The experimental system consists of a host computer with two subsystems: console (SC) and master (SM). The SM subsystem converts to real-time C code, and this code is uploaded into OP5600 real time digital simulation (RTDS) for real-time execution. The obtained experimental results prove that the EKF speed observer can replace the speed or position sensor. This has the benefits of reducing the drive system's size and overall cost as well as high system reliability.

Corresponding Author:

Mustapha Bendjima
Laboratory of CAOSEE, Department of Technology, Faculty of Technology, Tahri Mohamed University Bechar, Algeria
Email: mustapha.bendjima08@gmail.com

1. INTRODUCTION

Modern industry frequently uses the squirrel cage induction machine because of its straightforward design, low cost, and robustness. Due to these advantages, this type of AC machine became a popular option for contemporary high-performance electric drives in areas where only DC motors were previously used [1]. However, the induction devices are difficult to control. This is owing to the fact that the stator current, which also contributes to the air-gap flux and is the source of the rotor current in an induction machine, which produces torque, resulting in a connection between the mechanisms that produce flux and torque [2].

Induction machine control for high performance drive applications now adheres to the field oriented control (FOC) or vector control developed by Blaschke [3] and Hasse [4]. Induction motor control based on the field orientation concept provides good performance in variable speed applications [5]–[7], as well as control properties resembling a separately excited dc machine. Although the stator current space vector can be oriented along the mutual flux, stator flux, or rotor flux, doing so alone results in a natural decoupling between the torque and flux-producing components of the stator current space vector. By using a speed estimator in place of the speed sensor in sensorless control approach, the costs associated with the speed sensor are eliminated. [8]–[11].

Kalman filter is a prtical choice when model has uncertainties and measurement signal is affected by Gaussian noise [12]–[21]. On the other hand, the fundamental problem with the extended Kalman filter (EKF) is that the estimate performance of the EKF is significantly impacted by the system parameters and the associated covariance matrices Q and R of the measurement noises [13]–[15].

In this paper, a recursive EKF based space vector pulse width modulation (SVPWM)-sensorless vector control of induction motor is presented. The rotor speed and flux of induction motor are estimated by EKF using the discrete time model of induction motor. Simulation and experimental implementation to validate the effectiveness of this method, simulation was carried out in MATLAB/Simulink, while the real-time implementation consist of OP5600 OPAL-RT simulator to generate the control signals (getting pulses) with sampling frequency 20 kH, the graphical programming interfaces (MATLAB/RT-LAB). This research paper is organized as follows: section 2 presents the design and implementation of EKF speed observer, the development of space vector PWM and the anti-windup PI controller, the section 3 shows real-time platform using RT-LAB packages. The section 4 presents the results of the real-time implementation of EKF observers. At the last, the conclusion is presented in section 5.

2. DESIGN OF KALMAN FILTER OBSERVER FOR SPACE VECTOR PWM

The induction motor's time-discrete state space model can be expressed as follows [13], [22]:

$$\frac{d\hat{X}_{k+1}}{dt} = A(\hat{X})\hat{X}_k + BU_k \tag{1}$$

$$\begin{bmatrix} i_{s\alpha}(k+1) \\ i_{s\beta}(k+1) \\ \phi_{r\alpha}(k+1) \\ \phi_{r\beta}(k+1) \end{bmatrix} = \begin{bmatrix} (1+a_1T_e) & 0 & a_2T_e & \omega(k)a_3T_e \\ 0 & (1+a_1T_e) & -\omega(k)a_3T_e & a_2T_e \\ a_4T_e & 0 & (1+a_5T_e) & -\omega(k)T_e \\ 0 & a_4T_e & \omega(k)T_e & (1+a_5T_e) \end{bmatrix} \cdot \begin{bmatrix} i_{s\alpha}(k) \\ i_{s\beta}(k) \\ \phi_{r\alpha}(k) \\ \phi_{r\beta}(k) \end{bmatrix} +3$$

$$\begin{bmatrix} bT_e & 0 \\ 0 & bT_e \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} V_{s\alpha}(k) \\ V_{s\beta}(k) \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} i_{s\alpha}(k+1) \\ i_{s\beta}(k+1) \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} i_{s\alpha}(k) & i_{s\beta}(k) & \phi_{r\alpha}(k) & \phi_{r\beta}(k) \end{bmatrix}^T \tag{3}$$

where:

$$a_1 = \frac{1}{\sigma L_s}R \; ; a_2 = \frac{M}{\sigma L_s L_r T_r} \; ; a_3 = \frac{M}{\sigma L_s L_r} \; ; a_4 = \frac{M}{T_r} \; ; a_5 = \frac{1}{T_r} \; ; a_6 = \frac{C_{cst}}{J} \; ; a_7 = \frac{f}{J} \; ; a_8 = \frac{PM}{JL_r} \; ; b = \frac{1}{\sigma L_s}$$

The EKF algorithm primarily consists of two main stages: a filtering stage and a prediction stage. During the prediction stage, the subsequent predicted values of the states are derived by applying a mathematical model as well as the past values of estimated states. Prior to the new measurement, the predicted-sate covariance matrix is also obtained [14]. The system covariance matrix Q and the time-discrete state space model of the induction motor are both employed. The subsequent estimated states $\hat{X}(k+1)$ are generated from the predicted estimates $X(k+1)$ by adding a correction term $K_f(y_{k+1} - \hat{y}_{k+1})$ to the expected value during the filtering step, where $e = (y_{k+1} - \hat{y}_{k+1})$, the error term uses the measured stator currents.

$$\frac{d\dot{\hat{X}}_{k+1}}{dt} = A(\hat{X}_k)\hat{X}_k + B_kU_k + K_f(y_{k+1} - \hat{y}_{k+1}) \tag{4}$$

Figure 1 depicts the EKF's structural layout.

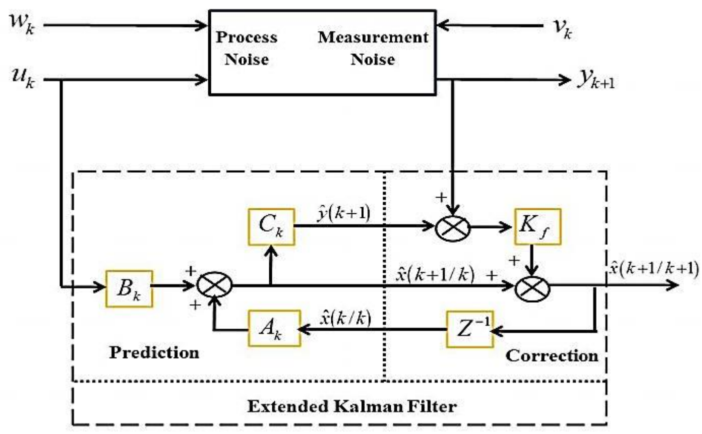


Figure 1. Structure of the EKF

Figure 2 shows the principle of SVPWM, in which a half-bridge three-phase inverter's $\vec{V}_1, \vec{V}_2, \vec{V}_3, \vec{V}_4, \vec{V}_5$ and $\vec{V}_6$ consists of six sectors with a length of $60°$each and six basic voltage space vectors that are nonzero [17]. Space vector PWM is used to create the reference vector V_s, which represents three-phase sinusoidal voltage, by switching between the two nearest active vectors and zero vectors [15], [23]. Consider Figure 3, which shows the positions of several accessible space vectors and the reference vector in the first sector, to determine the duration of application for different vectors.

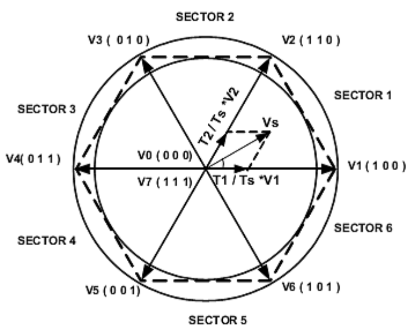


Figure 2. Voltage space vectors and sector distribution

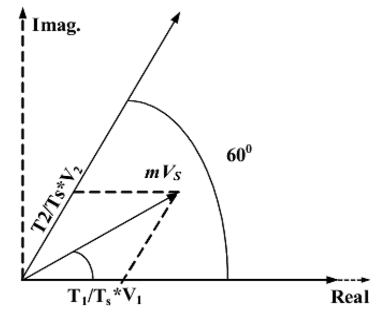


Figure 3. Principle of time calculation for SVPWM in sector1

The active space vector application's times are as:

$$T_1 = \frac{\sqrt{3}}{2} m T_s \sin(60 - \alpha) \tag{5}$$

$$T_2 = \frac{\sqrt{3}}{2} m T_s \sin(\alpha) \tag{6}$$

$$T_0 + T_7 = T_s - (T_1 + T_2) \tag{7}$$

where m is the modulation index,$\alpha$is position of the reference vector or the angle and T_0, T_1, T_2 are time of application of zero vectors, vector V_1, vector V_2 respectively. The main objective of induction motor vector control is the separate the control of flux and torque, which is accomplished by employing a d-q rotating reference frame synchronised with the rotor flux space vector. the (q) component of rotor flux will be zero when the field orientation law is applied [12], [24].

$$\begin{cases} \phi_{dr} = \phi_r \\ \phi_{qr} = 0 \end{cases} \tag{8}$$

The expression of the electromagnetic torque becomes (9).

$$Te = \frac{3}{2} P \frac{L_m \phi_r}{L_r} i_{qs} \tag{9}$$

The current components become (10).

$$\begin{cases} i_{ds}^* = \frac{\phi_r^*}{L_m} \\ i_{qs}^* = \frac{L_r T_e}{P L_m \phi_r^*} \end{cases} \tag{10}$$

The angular speed of the rotor flux ω_s becomes (11).

$$\omega_s = \frac{R_r i_{qs}^*}{L_r i_{ds}^*} + P\Omega = \omega_{sl} + P\Omega \tag{11}$$

The scheme of the field-oriented control and the proposed EKF observer are shown in Figure 4.

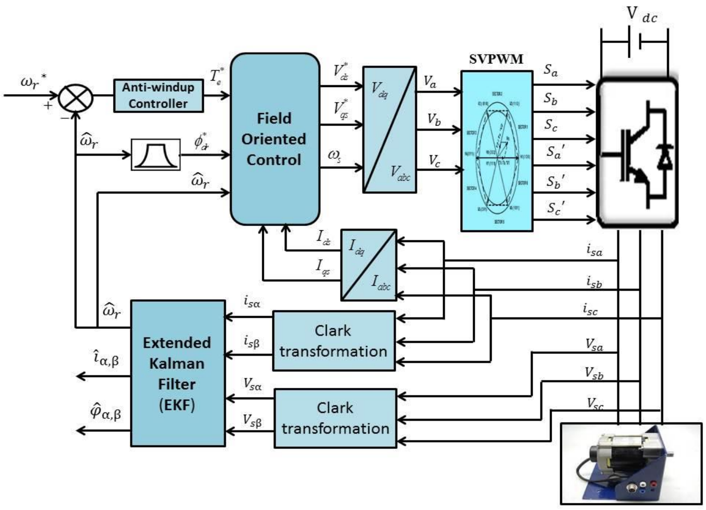


Figure 4. Global diagram of sensorless vector control of IM with SVPWM

When there is a significant step change in the speed reference, the PI controller typically ignores the system's physical constraints, which causes the phenomena known as windup to provide subpar results. The saturation of the pure integrator causes the wind-up phenomenon is thus cancelled using an anti-windup approach in this case [18], [25]. The figure 5 shows synoptic scheme of the anti-windup PI controller of the motor speed.

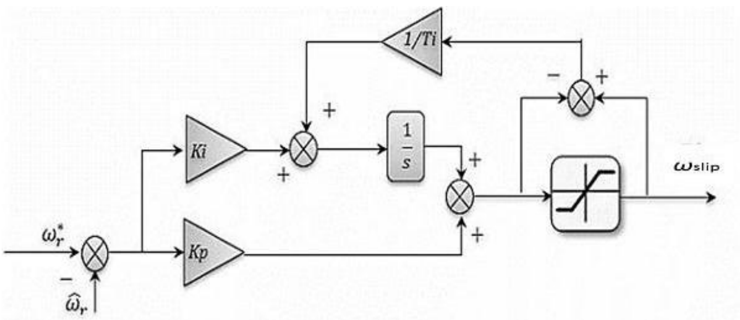
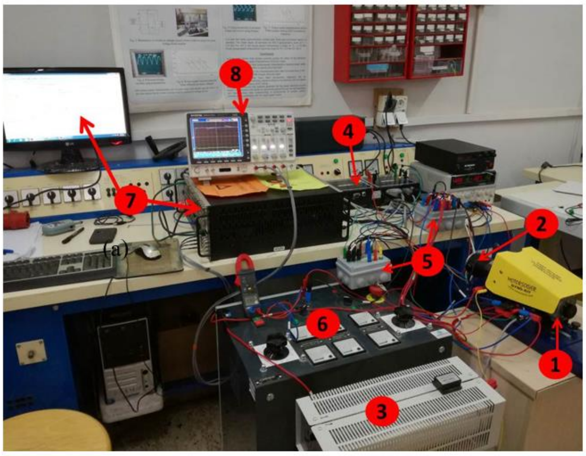


Figure 5. Diagram block of the anti-windup PI controller

3. REAL-TIME PLATFORM USING RT-LAB

Figures 6 shows the photo of the test bench and its synoptic sheme is shown in figure 7. This platform uses OPAL-RT real-time simulator. One Drivelab OPAL-RT Board and one OP5600 OPAL-RT Simulator are now installed at the CAOSEE Laboratory at Bechar University [21], [26], [27]. RT-LAB is employed to build the SM subsystem wich is converted into C code by using the Real-Time-Works hop (RTW). The algorithm of the control and observer are validated in Matlab/Simulink of the host computer. And the code is upload by the OP5600 via target network connections and the TCP/IP Protocol [19], [25].



(1) Squirrel cage induction motor
(2) DC generatrice
(3) Load
(4) Inverter Drivelab Board
(5) Current and volatge sensors
(6) Auto transformer
(7) OP5600 simulator
(8) Numerical oscilloscope

Figure 6. Photo of the realized test bench

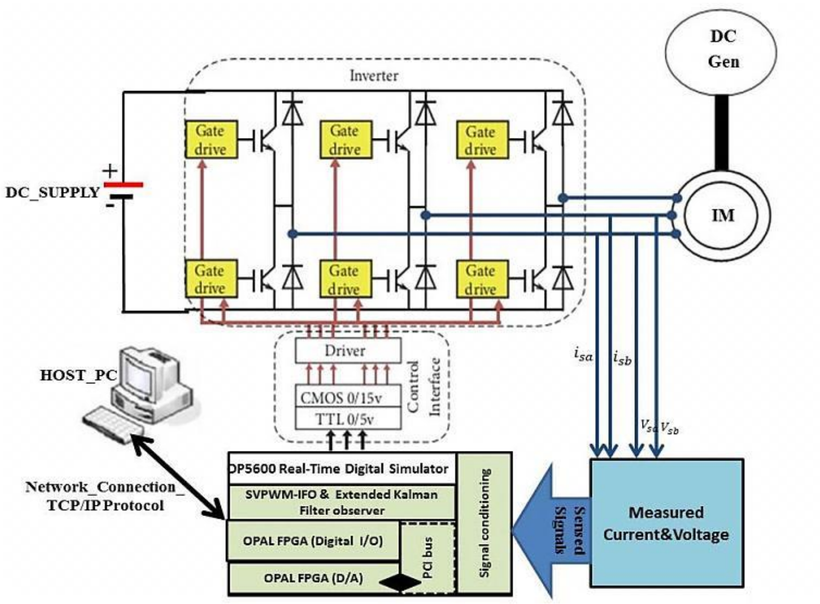


Figure 7. Synoptic scheme of the test bench

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

The sampling time has been set at 400 μs. The different given responses are obtained from digital oscilloscope with 4 channels. Figures 8 and 9 show actual speed and estimated speed run up to 350 rad/sec in the startup (1div=87 rad/sec), the performance of EKF is very high (the real and estimated speed are in superposition) as seen in thesefigures even with load charge application at 2 sec, the anti-windup PI speed controller react very fast in term of load charge rejection, it’s seen also that the estimation error converge to zero in steady state.

For the diffrentes situations, transient speed tracking at starting and at steady state, the EKF speed observer performancesare quite acceptable. In addition, the direct current (1div=A) is stabilized at its reference value, while the quadratic current (1div=A) is an image of the electromagnetic torque evolution. These results in Figure 10, Figure 11, afforded a good decoupled vector control between torque and rotor flux.

The zoom of measured and the observed currents of the motor in the reference frame (α, β) are presented in Figure 12, it can be seen that the observed current is superposed on the measured one with sinusoidal waveforms. Figure 13 shows the flux axes (real and estimated) components (1div=Wb), the waveforms are identical to each other with reduced ripple due to space vector pulse width modulation (SVPWM). Figure 14 illustrated the rotor flux angle of the estimated one.

It is shown in Figure 15 for various step changes in the reference, EKF speed observer sensorless control under high (400 rad/sec)/medium (250 rad/sec) speed applications respectively. The reference speed gradually increased and decreased (350,250,400,250,350 rad/sec) during 19 sec. In these tests the estimated speed is used as feedback signal for closed-loop sensorless control while reference variation, the estimation error between the estimated and measured speeds shown in Figure 16, this error equals to zero in steady state.

In this final test, the induction motor is run at no load, it's accelerated from 0 to 350 rad/sec at 0.8 sec, then the load is applied at 2sec and unloaded at 4sec, after that the speed is reversed at 6 sec, then also reversed again at 9 sec as shown in Figure 17, it's obvious that the proposed EKF observer presents good performances in the term of sense reversing and zero speed crossing, The use of anti-windup PI controller improve the system performances, it's clear that the speed follows rapidly the set reference without significant overshoot and static error. Figure 18, presents the estimation error between the two speeds approximately neglected. On the whole the experimental results were very positive, the proposed SVPWM-sensorless vector control of IM can achieve good performances for (direct, variable, and reverse) sense operations.

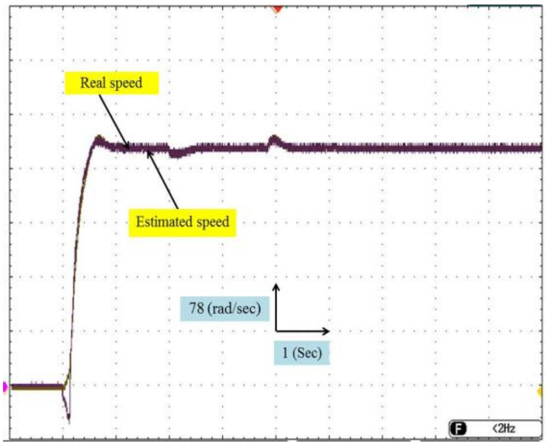


Figure 8. Real speed and estimated speed using EKF

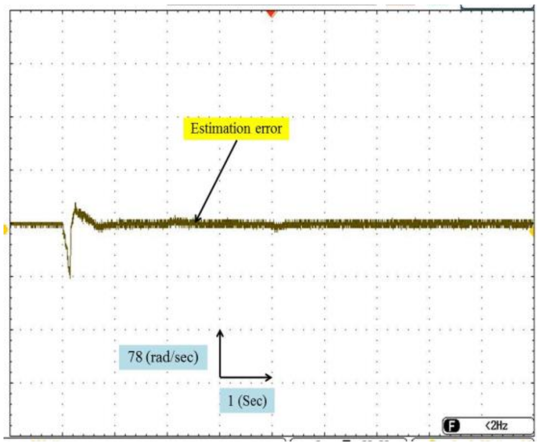


Figure 9. Speed estimation error

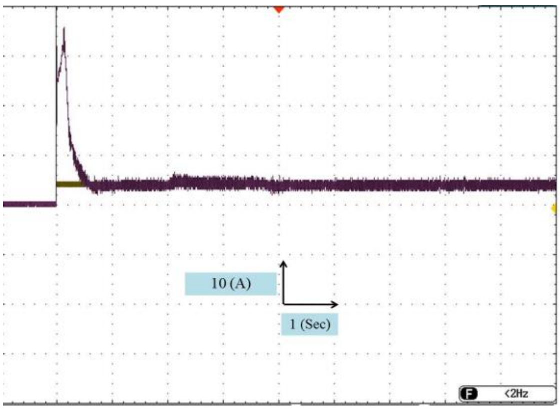


Figure 10. Direct current component

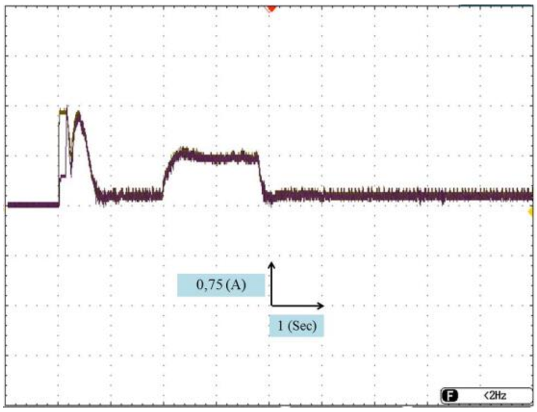


Figure 11. Quadratic current component

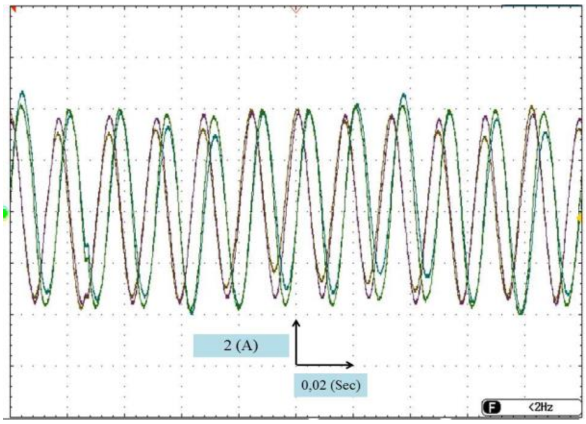


Figure 12. Zoom of observed and the measured currents

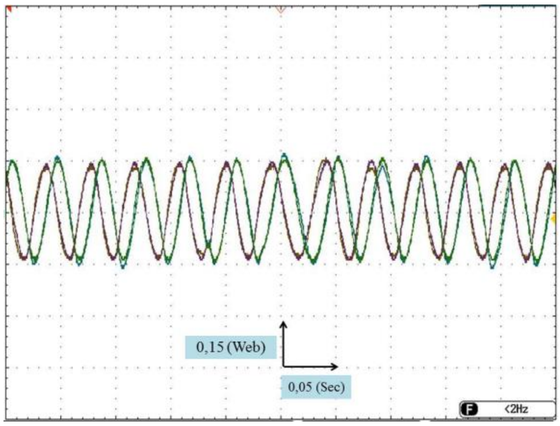


Figure 13. Zoom of estimated and real rotor fluxes

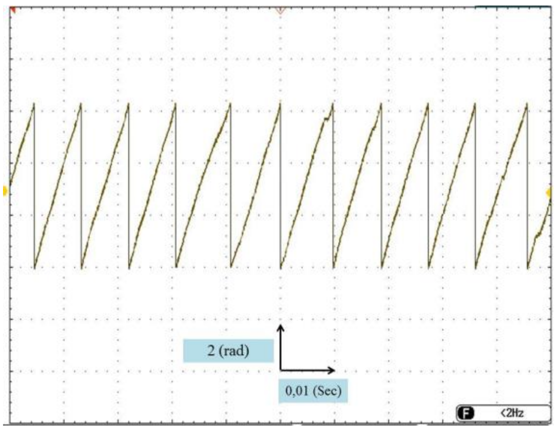


Figure 14. Position of estimated rotor flux

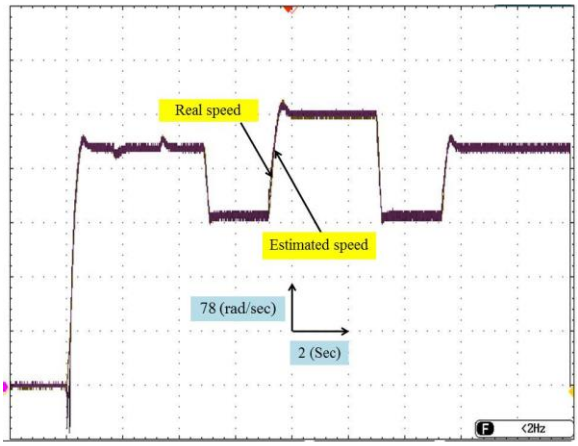


Figure 15. Speed variation test

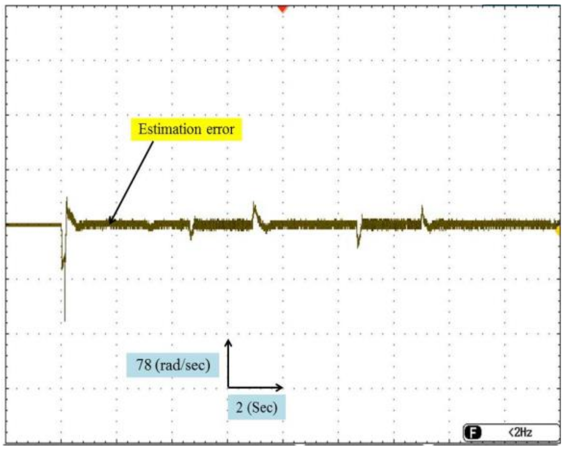


Figure 16. Estimation error for speed variation test

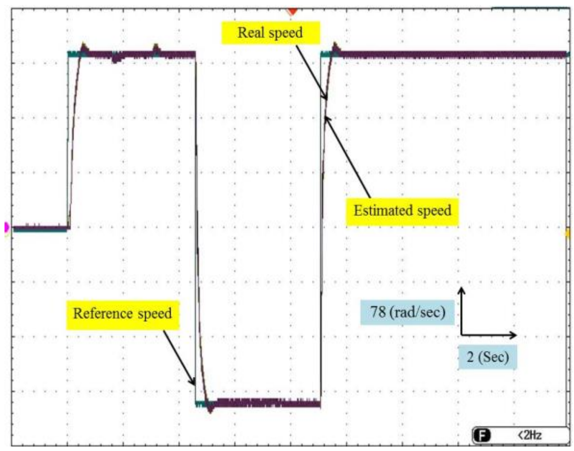


Figure 17. Estimated rotor speed with double speed sense reversing test

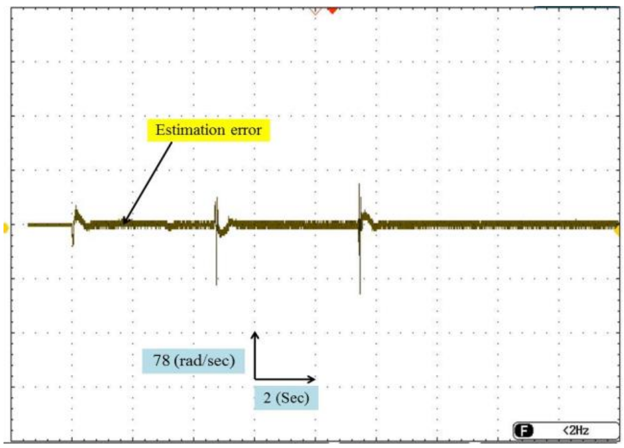


Figure 18. Estimation error for double sense reversing test

5. CONCLUSION

Simulation and experimental validation of the SVPWM-Sensorless vector control of induction motor using an extended Kalman has been presented in this paper. Generally it is known that the mechanical sensors are costly, fragile and degrade the system reliability particularly in hostile environments, therefore sensorless control operating without speed sensor has the advantages of reduced hardware complexity, lower cost and high system reliability. In the design of the EKF speed observer we use the discrete model of induction motor and the covariance matrix of prediction error has been calculated for the deterministic equation, the rotor speed and rotor fluxes have been estimated. The simulation studies carried out in MATLAB/Simulink, have confirmed the efficacy of this approach, the real-time implementation was done on the OP5600 real time digital simulation (RTDS), using rapid control prototyping system, and the experimental waveforms show that the estimated speed matches the real speed closely in all mode of operation. In the addition anti-windup PI speed controller is introduced in our technique to have fast response and overshoot suppression. It's concluded from the results presented in this research paper that the proposed algorithm based EKF speed observer performs well for operating regimes.

REFERENCES

[1] J. W. Finch and D. Giaouris, "Controlled AC Electrical Drives," *IEEE Transactions on Industrial Electronics*, vol. 55, no. 2, pp. 481–491, 2008, doi: 10.1109/TIE.2007.911209.

[2] A. K. Chattopadhyay, "Advances in vector control ofac motor drives — A review," *Sadhana*, vol. 22, no. 6, pp. 797–820, Dec. 1997, doi: 10.1007/BF02745846.

[3] F. Blaschke, "The principle of field orientation as applied to the new transvector closed-loop control system for rotating field machines," *Siemens Review*, vol. 34, no. 3, pp. 217–220, 1972.

[4] K. Hasse, "On the dynamics of speed control of a static ac drive with a squirrel-cage induction machine," Ph.D. dissertation, Tech. Hochsch. Darmstadt, 1969.

[5] S. Rafa, A. Larabi, L. Barazane, M. Manceur, N. Essounbouli, and A. Hamzaoui, "Implementation of a new fuzzy vector control of induction motor," *ISA Transactions*, vol. 53, no. 3, pp. 744–754, May 2014, doi: 10.1016/j.isatra.2014.02.005.

[6] J. Holtz, "Sensorless control of induction motor drives," *Proceedings of the IEEE*, vol. 90, no. 8, pp. 1359–1394, Aug. 2002, doi: 10.1109/JPROC.2002.800726.

[7] J. S. Thongam, "Commande de haute performance sans capteur d'une machine asynchrone," PhD, Thesis, UQAC, 2006.

[8] K. Yazid, R. Ibtiouen, O. Touhami, and M. Fadel, "Robust vector control without speed sensor of an induction motor using neural network and extended Kalman filter," *WSEAS Transactions on Systems*, vol. 5, no. 12, pp. 2744–2750, 2006.

[9] G. S. Buja and M. P. Kazmierkowski, "Direct torque control of PWM inverter-Fed AC motors—a survey," *IEEE Transactions on Industrial Electronics*, vol. 51, no. 4, pp. 744–757, Aug. 2004, doi: 10.1109/TIE.2004.831717.

[10] J. S. Thongam and V. P. S. Thoudam, "Stator flux based speed estimation of induction motor drive using EKF," *IETE Journal of Research*, vol. 50, no. 3, pp. 191–197, May 2004, doi: 10.1080/03772063.2004.11665505.

[11] Y. Zhang, Z. Zhao, T. Lu, L. Yuan, W. Xu, and J. Zhu, "A comparative study of Luenberger observer, sliding mode observer and extended Kalman filter for sensorless vector control of induction motor drives," in *2009 IEEE Energy Conversion Congress and Exposition*, Sep. 2009, pp. 2466–2473, doi: 10.1109/ECCE.2009.5316508.

[12] T. Ameid, A. Menacer, H. Talhaoui, and I. Harzelli, "Rotor resistance estimation using extended Kalman filter and spectral analysis for rotor bar fault diagnosis of sensorless vector control induction motor," *Measurement*, vol. 111, pp. 243–259, Dec. 2017, doi: 10.1016/j.measurement.2017.07.039.

[13] M. Yazdanian, A. Mehrizi-Sani, and M. Mojiri, "Estimation of electromechanical oscillation parameters using an extended Kalman filter," *IEEE Transactions on Power Systems*, vol. 30, no. 6, pp. 2994–3002, Nov. 2015, doi: 10.1109/TPWRS.2015.2388694.

[14] M. N. Marwali, A. Keyhani, and W. Tjanaka, "Implementation of indirect vector control on an integrated digital signal processor-based system," *IEEE Transactions on Energy Conversion*, vol. 14, no. 2, pp. 139–146, Jun. 1999, doi: 10.1109/60.766961.

[15] K. L. Shi, T. F. Chan, Y. K. Wong, and S. L. Ho, "Speed estimation of an induction motor drive using an optimized extended Kalman filter," *IEEE Transactions on Industrial Electronics*, vol. 49, no. 1, pp. 124–133, 2002, doi: 10.1109/41.982256.

[16] D. G. Holmes and T. A. Lipo, *Pulse width modulation for power converters: principles and practice*. Hoboken, NJ: John Wiley, 2003.
[17] B. Zhang and D. Qiu, *m-Mode SVPWM Technique for Power Converters*. Singapore: Springer Singapore, 2019. doi: 10.1007/978-981-13-1382-0.
[18] D. Zhang, H. Li, and E. G. Collins, "Digital Anti-Windup PI Controllers for Variable-Speed Motor Drives Using FPGA and Stochastic Theory," *IEEE Trans. Power Electron.*, vol. 21, no 5, pp. 1496-1501, Sep. 2006, doi: 10.1109/TPEL.2006.882342.
[19] M. Habbab, A. Hazzab, and P. Sicard, "Real Time Implementation of Fuzzy Adaptive PI-sliding Mode Controller for Induction Machine Control," *Int. J. Electr. Comput. Eng. IJECE*, vol. 8, no 5, p. 2883, Oct. 2018, doi: 10.11591/ijece.v8i5.pp2883-2893.
[20] S. T. Cha, Q. Wu, A. H. Nielsen, J. Østergaard, and I. K. Park, "Real-Time Hardware-In-The-Loop (HIL) Testing for Power Electronics Controllers," in *2012 Asia-Pacific Power and Energy Engineering Conference*, Shanghai, China, 2012, pp. 1-6. doi: 10.1109/APPEEC.2012.6307219.
[21] D. Ali, M. Asim, F. Wallam, Z.-H. Qazi, A. Abbas, and Y. Naudhani, "Experimental Testing of Observers Comprising Discrete Kalman Filter and High-Gain Observers," in *2019 2nd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET)*, Sukkur, Pakistan, Jan. 2019, p. 1-5, doi: 10.1109/ICOMET.2019.8673453.
[22] R. Demir and M. Barut, "Novel hybrid estimator based on model reference adaptive system and extended Kalman filter for speed-sensorless induction motor control," *Trans. Inst. Meas. Control*, vol. 40, no 13, pp. 3884-3898, sept. 2018, doi: 10.1177/0142331217734631.
[23] M. Bechar, A. Hazzab, M. Habbab, and P. Sicard, "Reduced-order observer for real-time implementation speed sensorless control of induction using RT-LAB software," *Int. J. Power Electron. Drive Syst. IJPEDS*, vol. 10, no 3, pp. 1148, Sep. 2019, doi: 10.11591/ijpeds.v10.i3.pp1148-1156.
[24] J. Holtz, "Sensorless control of induction motor drives," *Proc. IEEE*, vol. 90, no 8, pp. 1359-1394, 2002, doi: 10.1109/JPROC.2002.800726.
[25] M. Touhami, P. Sicard, A. Hazzab, and F. Mokhtari, "Comparative study between the NLPI controller and the CPI controller," *Int. J. Power Electron. Drive Syst. IJPEDS*, vol. 10, no 3, p. 1178, Sep. 2019, doi: 10.11591/ijpeds.v10.i3.pp1178-1186.
[26] M. Bechar, A. Hazzab, and M. Habbab, "Real-Time scalar control of induction motor using rt-lab software," in *2017 5th International Conference on Electrical Engineering - Boumerdes (ICEE-B)*, Boumerdes, Oct. 2017, pp. 1-5. doi: 10.1109/ICEE-B.2017.8192002.
[27] S. Allaoui, K. Chafaa, Y. Laamari, and B. Athamena, "Induction motor state estimation using tuned Extended Kalman Filter," in *2015 4th International Conference on Electrical Engineering (ICEE)*, Boumerdes, 2015, pp. 1-5. doi: 10.1109/INTEE.2015.7416676.

BIOGRAPHIES OF AUTHORS

Mustapha Bendjima was born in Bechar, Algeria. He received the state engineer degree in electrical engineering from Tahri Mohammed University in 2006, the M.Sc. degree from Tahri Mohammed University in 2009. Where he is currently working toward the Ph.D. degree in electrical engineering. His research interests include power electronics, process control. Observer and estimator design for induction motor drive systems, Electrical vehicles. He can be contacted at email: mustapha.bendjima08@gmail.com.

Abdeldjebar Hazzab received the state engineer degree in electrical engineering in 1995 from the University of Sciences and Technology of Oran (USTO), Algeria the M.Sc. degree from the Electrical Engineering Institute of the USTO in 1999, and the Ph.D. degree from the Electrical Engineering Institute of the USTO in 2006. He is currently professor of electrical engineering at University of Bechar, Bechar, Algeria, where he is Director of the Research Laboratory of Control Analysis and Optimization of the Electro-Energetic Systems. His research interests include power electronics, electric drives control, and artificial intelligence and their applications. He can be contacted at email: hazzab.abdeldjebar@etsmtl.ca, abdeldjebar.hazzab@gmail.com.

Mansour Bechar was born in Bechar, Algeria. He received the M.S. degree in electrical engineering from Tahri Mohammed University in 2015. Where he is currently working toward the Ph.D. degree in electrical engineering. His research interests include power electronics, process control. Observer and estimator design for induction motor drive systems, renewable energy. He can be contacted at email: mansourbechar@gmail.com.

Medjdoub Khessam was born in 1984 at Naama-Algeria he's received the electrical engineering diploma from Bechar University, Algeria in 2009, and the Master degree from the University Sidi bel abbes Algeria in 2011.and the Ph.D. degree from the Electrical Engineering University of Bechar, Bechar, Algeria in 2017. He is currently professor of electrical engineering at Institute of science and technology, University center Salhi Ahmed Naama, Algeria. His research interests include power electronics, electric drives control, and artificial intelligence and their applications. He can be contacted at email: khessam@cuniv-naama.dz, khessam.medjdoub@hotmail.fr.

Miloud Rezkallah (M'14- SM'20) received the B. Tech. degree in electrical machines and drive from the University of Science and Technology USTO, Oran, Algeria, and the M. Tech. and Ph.D. degrees in power electronics and system control from École de Technologie Supérieure (ETS), Université, Montréal, Canada., in 2010 and 2016, respectively. He is working as a senior researcher with CR2ie at Sept-Îles in Quebec and as an adjunct professor with Electrical Engineering Department at ETS. His research interests include the control and design of microgrids, renewable energy generations and applications, and energy storage systems. He can be contacted at email: miloud.rezkallah@etsmtl.ca.

Ambrish Chandra B.E. degree from the University of Roorkee, India, in 1977, the M.Tech. degree from IIT Delhi, in 1980, and the Ph.D. degree from the University of Calgary, in 1987. Before joining as an Associate Professor at the ÉTS, Montreal, in 1994, he worked as an Associate Professor at IITR. Since 1999, he has been a Full Professor of electrical engineering with ÉTS. From 2012 to 2015, he was the Director of the Multidisciplinary Graduate Program on Renewable Energy and Energy Efficiency with ÉTS. He is currently the Director of the master program in electrical engineering. The primary focus of his work is related to the advancement of new theory and control algorithms for power electronic converters for power quality improvement in distribution systems and integration of renewable energy sources. He can be contacted at email: ambrish.chandra@etsmtl.ca.

Hussein Ibrahim received a Ph.D. degree in engineering from Québec University at Chicoutimi, Canada. Since July 2009, he has research director at Cégep of Sept-Iles northern Quebec. His research interests include renewable energy sources integration, hybrid energy power system, storage energy, heat and mass transfer, fluid dynamics, and energy efficiency. He can be contacted at email: hussein.Ibrahim@itmi.ca.