# Simple direct torque control of induction machine using space vector modulation

J. Rodríguez, J. Pontt, C. Silva, R. Huerta and H. Miranda

A new method for direct torque control (DTC) based on load angle control is developed. The use of simple equations to obtain the control algorithm makes it easier to understand and implement. Fixed switching frequency and low torque ripple are obtained using space vector modulation, overcoming the most important drawbacks of classic DTC.

*Introduction:* Direct torque control (DTC) introduced in [1] shows a very high quality torque control without the need of tuning current controllers or using co-ordinate transformations. Today, the following are considered the most important drawbacks of DTC: operation with variable switching frequency and large torque ripple, due to the hysteresis comparators.

The use of DTC in conjunction with space vector modulation (SVM) has been proposed as a solution to overcome the problems mentioned above [2–5]. To obtain the reference for the SVM these methods use either deadbeat controllers [2] or co-ordinate rotation [5].

The main contribution of the work reported in this Letter is the use of a new and very simple one-step flux control algorithm for an induction motor avoiding co-ordinate rotations and complicated predictive controllers. In addition, SVM is used here to improve the performance of DTC.

*Principle of torque control:* A very well-known relation to calculate machine torque is [6]:

$$T_e = \frac{3}{2} p \frac{k_r}{l_s \sigma} |\Psi_r| \cdot |\Psi_s| \sin(\delta) \qquad (1)$$

where $\delta$, known as load angle, is the angle between rotor and stator fluxes, as shown in Fig. 1, $k_r$, $l_s$ and $\sigma$ are constants given by machine parameters, $p$ is the number of pole pairs, and $\Psi_r$ and $\Psi_s$ are the rotor and stator flux vector, respectively.

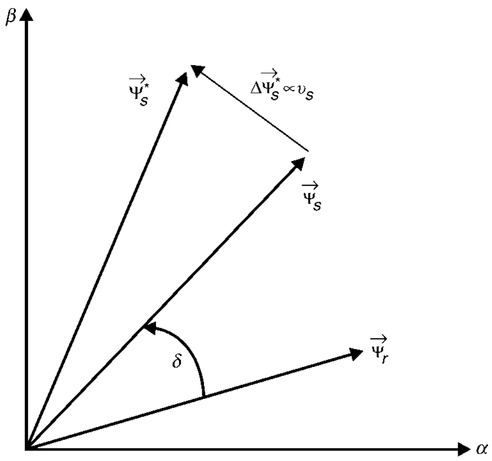


**Fig. 1** *Reference and estimated flux relations*

From (1) it becomes clear that a direct relation exists between load angle and machine torque. This means that it is possible to control machine torque by controlling the angle between rotor and stator fluxes.

Owing to the slow rotor flux dynamics, the fastest way to vary the load angle is to change stator flux appropriately by actuating on the stator voltage. Neglecting the stator resistance voltage drop and for small sampling time $\Delta t$, the equation that relates stator voltage and stator flux can be approximated by

$$\Delta\Psi_s = \Delta t \cdot v_s \qquad (2)$$

*Control scheme:* Based only on (1) and (2) a complete control scheme that allows fast torque control is designed. This scheme is shown in Fig. 2.

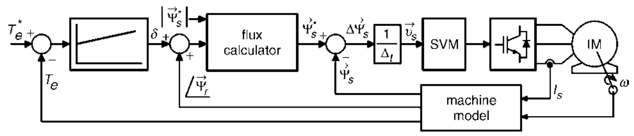


**Fig. 2** *Main control scheme*

The objective of the control method is to rotate the stator flux to reach the load angle reference while keeping stator flux constant by an appropriate stator voltage vector selection. The strategy uses one PI controller to obtain the load angle needed to meet the torque reference. The output of the flux calculation block is given by

$$\Psi_s^* = |\Psi_s^*| \cos(\delta + \angle\Psi_r) + j|\Psi_s^*| \sin(\delta + \angle\Psi_r) \qquad (3)$$

The flux reference obtained by (3) is compared with the stator flux estimated by the machine model obtaining $\Delta\Psi_s$ needed to follow the torque reference. Then, (2) is applied to calculate the required stator voltage vector. The SVM block performs the usual space vector modulation to obtain the gate drive firing pulses for the inverter IGBTs.

*Results:* Closed-loop performance of the proposed method was tested and compared with classic DTC. A 5.5 kW, 380 $V_{l-l}$, two pole pairs induction machine driven by a 500 V inverter was considered. Control system sampling frequency was 10 kHz.

Results for the proposed method are shown in Fig. 3*a*. Here, speed reference tracking is shown at the top, torque response in the middle and stator flux magnitude at the bottom. The results for the same test using classic DTC are shown in Fig. 3*b*.

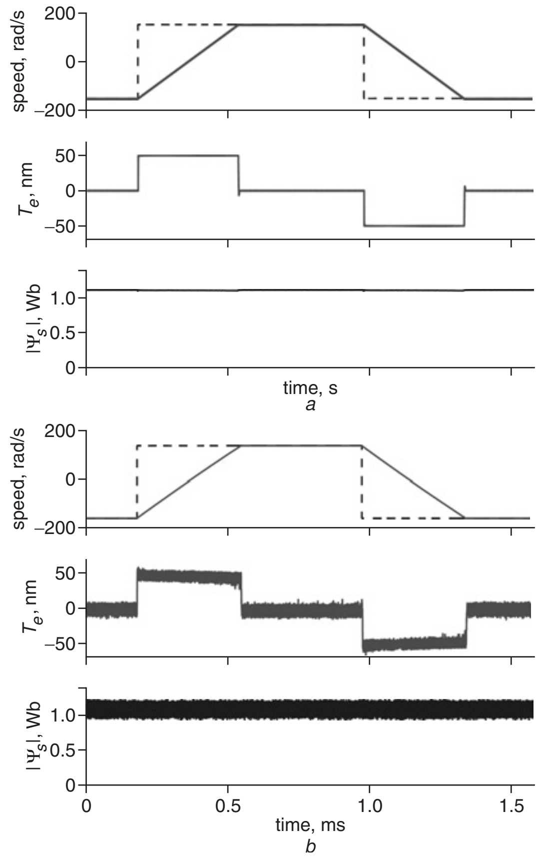


**Fig. 3** *Speed tracking results*

*a* Proposed method
*b* Classic DTC

Fig. 3 demonstrates that the proposed method has similar speed dynamic response to classic DTC while having significantly less torque ripple. This is better observed in Fig. 4. Here, torque response to a step reference change is shown. Test results for the proposed method and classic DTC are shown in Figs. 4*a* and *b*, respectively. It is clearly demonstrated that the use of DTC in conjunction with SVM greatly improves torque performance.

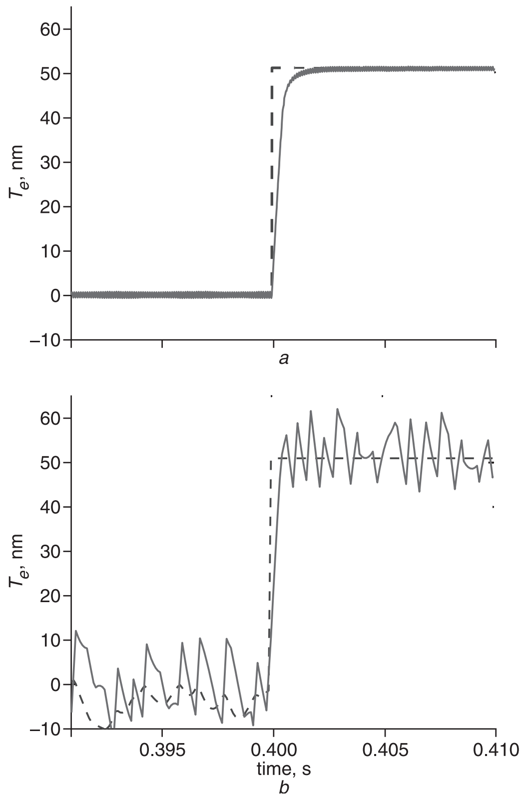


**Fig. 4** *Torque response to step reference change*

*a* Proposed method
*b* Classic DTC

*Conclusion:* A simple strategy to obtain stator voltage reference for induction motors is presented. Space vector modulation is applied obtaining improved torque performance with reduced torque ripple and fast dynamic response, while operating with fixed switching frequency as in known SVM methods.

*Acknowledgments:* The authors acknowledge the support of the Chilean Research Found CONICYT (grant 1030368) and the Universidad Técnica Federico Santa María.

 *22 January 2004*

*Electronics Letters* online no: 20040299
doi: 10.1049/el:20040299

J. Rodríguez, J. Pontt, C. Silva, R. Huerta and H. Miranda (*Electronics Engineering Department, Universidad Técnica Federico Santa María, Avenida España 1680, Casilla 110-V, Valparaíso, Chile*)

E-mail: flako@elo.utfsm.cl

## References

1 Takahashi, I., and Ohmori, Y.: 'High-performance direct torque control of an induction motor', *IEEE Trans. Ind. Appl.*, 1989, **25**, (2), pp. 257–264
2 Habetler, T., Profumo, F., Pastorelli, M., and Tolbert, L.: 'Direct torque control of induction machines using space vector modulation', *IEEE Trans. Ind. Appl.*, 1992, **28**, (5), pp. 1045–1053
3 Tang, L., Zhong, L., and Rahman, F.: 'Modeling and experimental approach of a novel direct torque control scheme for interior permanent magnet synchronous machine drive'. IECON 02, Industrial Applications Society, November 2002, Vol. 1, pp. 235–240
4 Swierczynski, D., and Kazmierkowski, M.: 'Direct torque control of permanent magnet synchronous motor (PMSM) using space vector modulation (DTC-SVM)—simulation and experimental results'. IECON 02, Industrial Applications Society, November 2002, Vol. 1, pp. 751–755
5 Lai, Y.S., and Chen, J.H.: 'A new approach to direct torque control of induction motor drives for constant inverter switching frequency and torque ripple reduction', *IEEE Trans. Energy Convers.*, 2001, **16**, (3), pp. 220–227
6 Mohan, N.: 'Advanced electric drives, analysis, control and modelling using simulink' (MNPERE, 2001)