academicJournals

Vol. 8(34), pp. 1649-1657, 11 September, 2013
DOI 10.5897/SRE12.396
ISSN 1992-2248 © 2013 Academic Journals
http://www.academicjournals.org/SRE

Scientific Research and Essays

Review

Salient features of vector control in AC motor drives: A review

Sarat Kumar Sahoo[1]* and A. Ramulu[2]

[1]School of Electrical Engineering, VIT University, Vellore-632014, Tamilnadu, India.
[2]Department of Electrical Engineering, GITAM University, Visakhapatnam-530045, Andhra Pradesh, India.

Accepted 13 August, 2013

This paper presents a review of vector control methods for AC drives for the last decade. A variety of techniques with different concepts are mentioned for the control of induction motors (IMs), permanent magnet synchronous motors (PMSMs), double fed induction generators (DFIGs) and switched reluctance motors (SRMs). Vector control has advanced its concept to AC drives for high performance applications with the help of digital signal processors (DSPs) and field programmable gate arrays (FPGAs). The development of vector control concept, sensorless vector control for AC drives using artificial intelligence (AI) techniques such as fuzzy logic controller (FLC), artificial neural network (ANN) and neuro-fuzzy controller along with DSPs and FPGAs implementation are stated in this paper.

Key words: Vector control, sensorless control, artificial intelligence, induction motors (IMs), permanent magnet synchronous motors (PMSMs), double fed induction generators (DFIGs), switched reluctance motors (SRMs), digital signal processors (DSPs), field programmable gate arrays (FPGAs).

INTRODUCTION

Alternating current (AC) drives have many advantages when compared to direct current (DC) drives. The well known advantages are simple construction, reliability, ruggedness, and low cost. Nevertheless' DC drives have dominated the field of adjustable speed drives, due to the high dynamic performances. AC drives were only possible after the development of powerful switching component and efficient control techniques. For instance, the first control theory was presented in 1971 and implemented ten years later with the advent of microprocessors. AC drives control methods can be divided into scalar and vector control.

In scalar control, to get the variable speed of induction motor, the variables frequency and voltage need to be applied to motor. The control algorithm does not need information about the angular speed or rotor position. The motor model is considered just for steady state. This method cannot achieve the best performance during transients. The efficiency of induction motor drive can be improved by using vector control method. Using vector control, decoupled control of flux and torque, full torque control, and improved dynamic performance are possible.

In vector control operation of permanent magnet synchronous motor, the inner current control loop generates sinusoidal stator currents to the motor. The outer speed loop provides speed differences, yielding torque command. Advanced control and estimation techniques such as direct/indirect vector control, artificial intelligence (AI) techniques and sensorless techniques are used to improve the dynamic performance of AC drives. Several sensorless methods have been proposed to estimate speed and position of the AC drive from the electrical quantities (stator voltages and currents) which are eliminating the need of sensors.

The stator resistance and dead-time effect have lessened the performance of drive systems at very low

*Corresponding author. E-mail: sarata1@rediffmail.com. Tel.: +91-9840263009. Fax: 0416-224 4023.

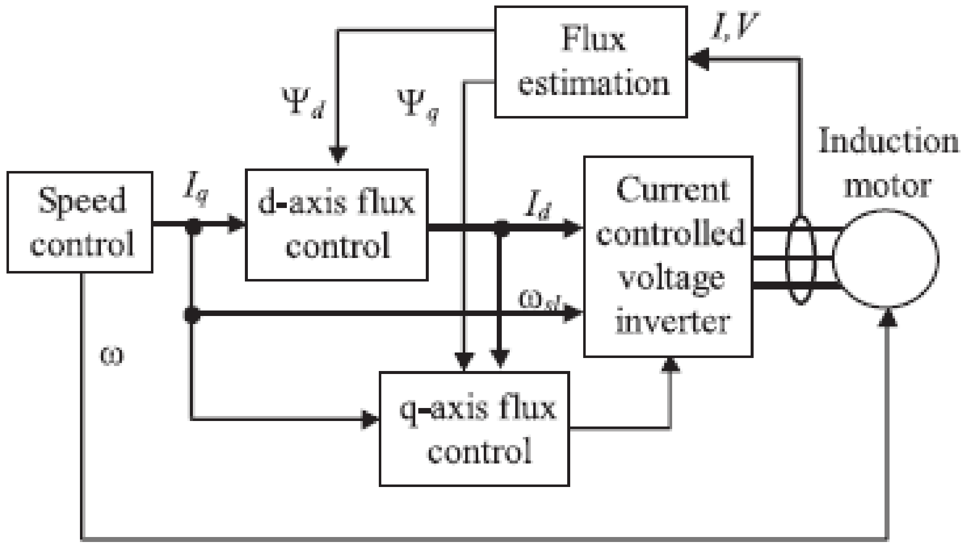

Figure 1. Adaptive field-oriented model reference control of current-fed induction motor.

speed. With the help of powerful controllers such as digital signal processors (DSPs) and field programmable gate arrays (FPGAs), the sensorless drives for a broader variety of applications with improved performance are a reality. Many advanced control and estimation techniques along with DSP and FPGA implementation for induction motors are applicable to synchronous motor drives as well. The stator of double fed induction generator (DFIG) is connected directly with the grid and the rotor is fed by a voltage or current source inverter to achieve variable speed operation. As an advanced control strategy and decoupled d-q vector control for DFIG using back-to-back converters give better performance.

This paper reviews the salient features of vector control in AC drives. The review then moves on to discuss how vector control concept is applied in different AC drives. The functionality concepts of advance control methods used are discussed and concentrating first on the basics of vector control.

PRINCIPLE OF VECTOR CONTROL

In spite of complexity, vector control plays a key role for AC drives, replacing scalar control. The d-q model of machine and parameter variation effect is important in vector control. The vector control has become a powerful and frequently adopted technique that permits the use of induction and synchronous machine drives for high performance. High performance motor control is characterized by smooth rotating over the entire speed range of the motor, full torque control at nearly zero speed, fast accelerations and decelerations.

Vector control in AC motor model, consider the rotor flux as a reference coordinates, stator current is decomposed into two orthogonal components: same direction with magnetic excitation component (d-axis), and torque component (q-axis) orthogonal with magnetic excitation direction. Vector control is a method of independently varying the magnitude and phase of the stator current vectors to adapt to the instantaneous speed and torque demands on the motor. It enables parameters over which no direct control is possible to be changed by changing instead, parameters which can be measured and controlled.

The currents i_d and i_q of the stator current in synchronously rotating reference frame are analogous to the field current I_f and to the armature current I_a of the DC machine, and the torque can be expressed as $T_e = k_t \Psi i_q = k_t^{'} I_f I_a = k_t^{''} i_d i_q$. The adaptive field oriented model reference control of current-fed induction motor is shown in Figure 1 (Noureddine and Amar, 2006).

The principle of vector control is to regulate the components of the PMSM stator currents, in a rotating reference frame d, q aligned with the rotor flux. The vector controlled PMSM drive provides better dynamic response, lesser torque ripples and necessitates only a constant switching frequency. The inner loop is current control loop, which generates sinusoidal stator currents to the motor. The outer speed loop provides speed differences, yielding torque command for vector control operation. The block diagram of conventional Proportional-Integral (PI) based PMSM vector control system is given in Figure 2 (Naouar et al., 2007).

The DFIG uses two back-to-back converters: Rotor Side Converter (RSC) and Supply Side Converter (SSC). Using a stator flux oriented reference frame, for the RSC, the rotor d-component controls the stator reactive power, while the rotor q-component controls the stator active

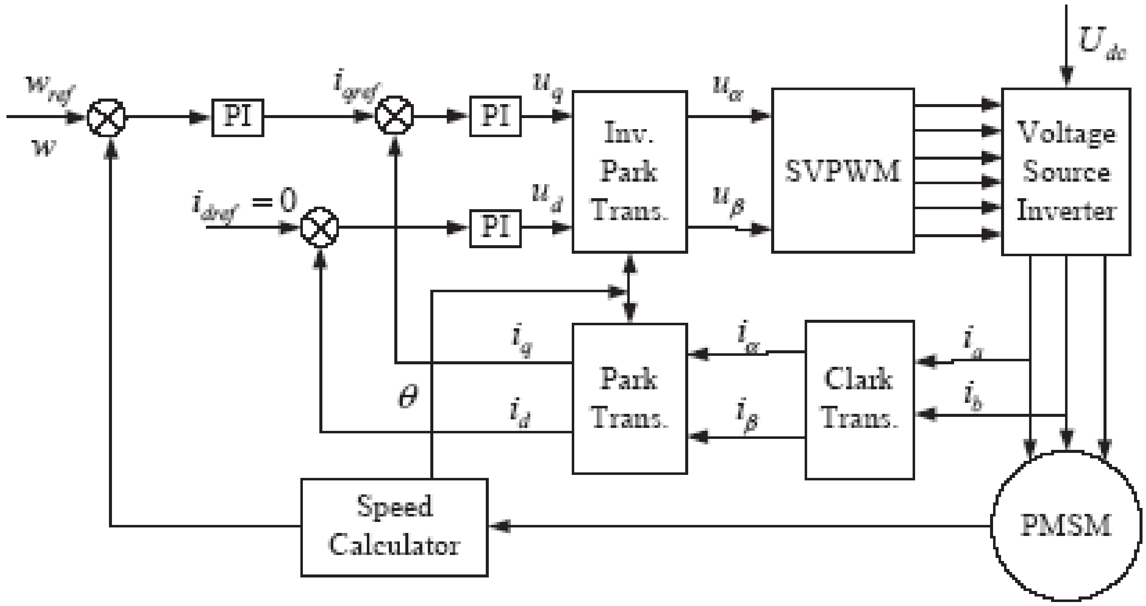

Figure 2. Block diagram of conventional PI PMSM vector control system.

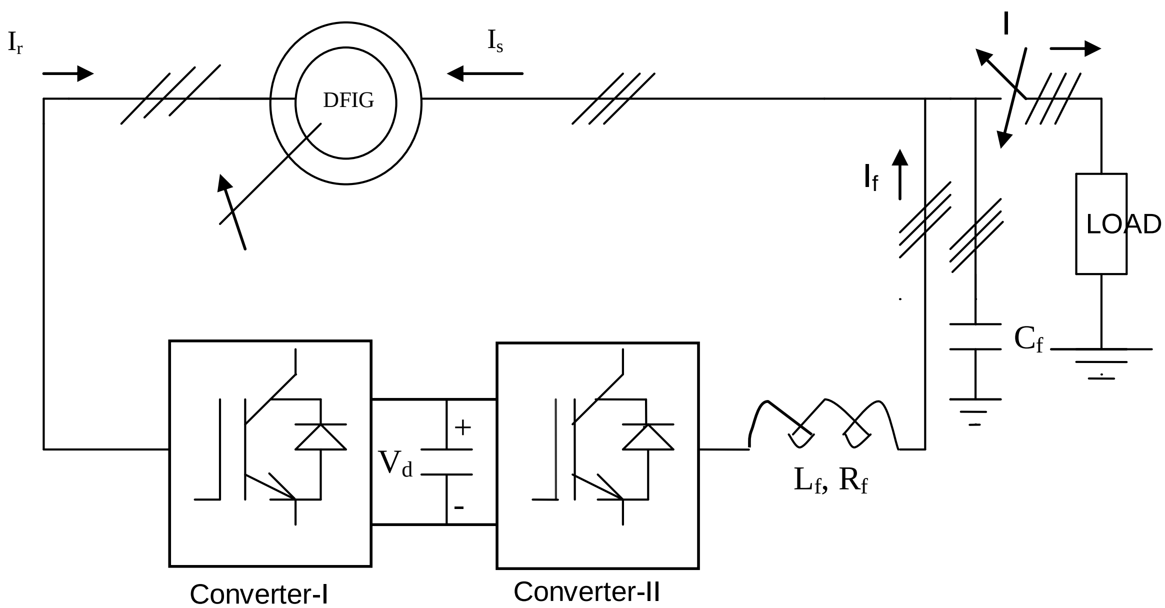

Figure 3. Schematic diagram of a DFIG based VSCF system.

power. For the SSC, the d-component controls the DC-link voltage, while the q-component controls the reactive power. The schematic diagram of a DFIG based variable speed constant frequency (VSCF) system is shown in Figure 3 (Pattnaik and Kastha, 2011).

The switched reluctance motor (SRM) is a type of synchronous machine. It has wound field coils of a DC motor for its stator windings and has no coils or magnets on its rotor. A typical SRM drive is made up of four basic components: power converter, control logic circuit, position sensor and the SRM. Based on the vector control with a d-q synchronous frame, the d-axis current is fixed at a constant value to produce flux. The q-axis current, which is called torque current, is determined by the speed loop controller and the speed error. Thus a fast torque response can be achieved. The vector controlled SRM with second order sliding mode controller (SOSMC) is given in Figure 4 (Mohamadian et al., 2004).

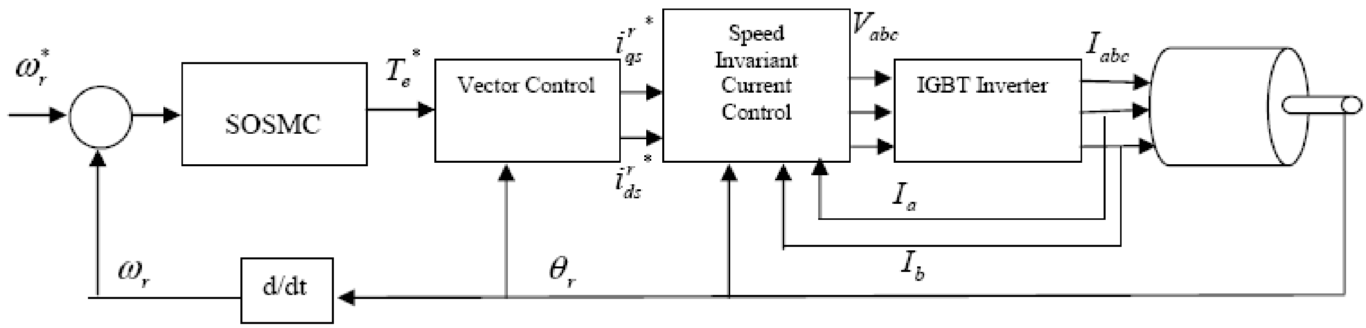

Figure 4. Vector controlled SRM with SOSMC.

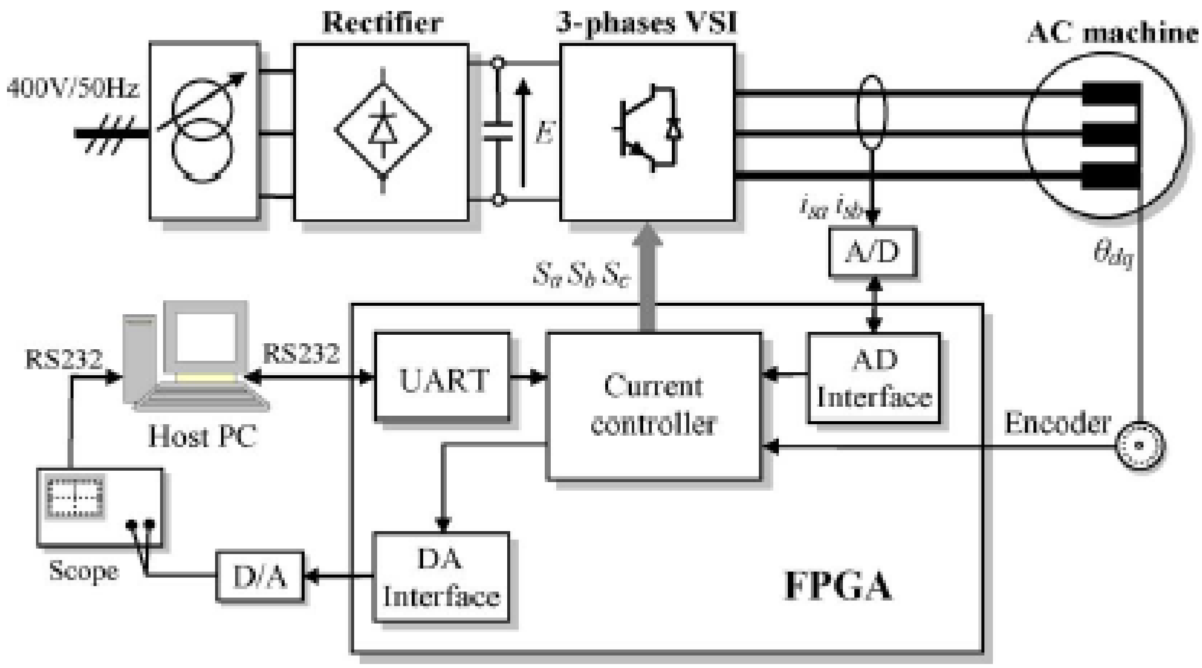

Figure 5. FPGA based current controllers for AC machine drives.

For AC drives, the high performance control and estimation for complex drive system can be carried out using powerful DSPs and FPGAs. A review paper on contributions of FPGAs to industrial drives was carried out (Sahoo et al., 2007). The block diagram of FPGA based current controllers for AC machine drives is shown in Figure 5 (Naouar et al., 2007).

ADVANCED CONTROL TECHNIQUES

The vector control of 3-Φ AC motor involves imitating the DC motor's operation. All controlled variables are transformed to DC instead of AC via mathematical transformation. The main goal is to control torque and flux independently.

Direct/Indirect vector control

Based on the method of flux acquisition, the vector control can be direct or indirect. In direct field oriented control (DFOC), the rotor flux angle is directly computed from flux estimation or measurement. The rotor flux angle is indirectly computed from available speed and slip computation in case of indirect field oriented control (IFOC). The proportional and integral (PI) controller was used for the optimal response of the control system (Khalaf et al., 2009). An unbalanced induction motor was modeled with a few modifications in the conventional vector control (Jannati and Fallah, 2010). A closed loop speed control strategy using the space vector modulated method was presented (Anurag et al., 2008). A neutral-point clamped inverter was presented to achieve static

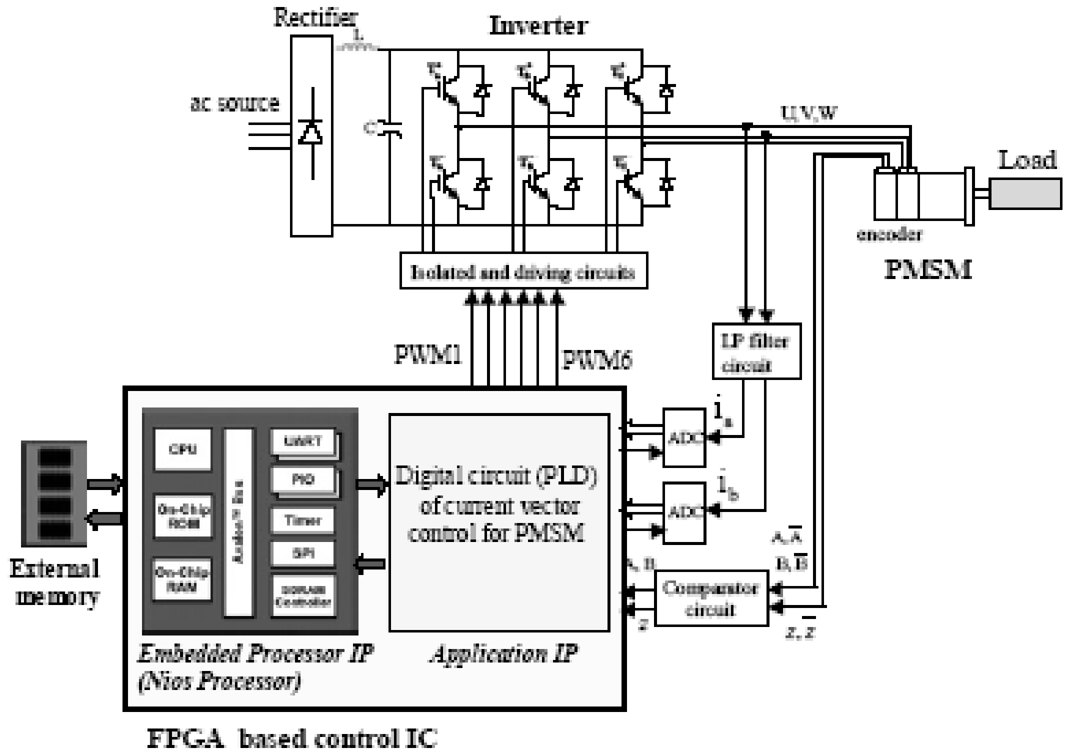

Figure 6. FPGA- based Control IC for PMSM drive.

and dynamic performances (Shuxi et al., 2010]. But the FOC is very sensitive to the rotor resistance which affects the robustness of the control.

A grid side converter is proposed by the authors (Meihua et al., 2011; Srirattanawichaikul et al., 2010) that can give better steady state performance and good transient response. The authors (Xueqin et al., 2010) have implemented the vector control in stator flux orientation of rotor side converter and vector control of grid side PWM converter. As a result, active and reactive power controls were decoupled dynamically. An indirect vector control was used for squirrel cage induction generator (Domínguez-García et al ., 2010). Shiyi et al. (2009) have adapted stator flux oriented power winding to control both the speed and reactive power. A high performance direct torque control of induction motor drive based on VLSI design approach was implemented (Sarat et al., 2008).

For PMSM, the flux position of the rotor is the same as the mechanical position, so the flux position can be obtained through inspecting the mechanical position, so as to simplify the control process. A hybrid controller that integrates the traditional PID with variable structure control (VSC) to reduce vibration and to improve the static precision of the system has been implemented by (Xu Dan et al., 2011). It has the advantage of overcoming the problem of slow response speed and poor anti-interference with the traditional PID controller.

The development of high performance speed control has been developed using DSP (Ying-Shieh Kung et al., 2004) and FPGA based control IC (Ying-Shieh et al., 2005). The first IP (Intellectual Property) in FPGA is for an adaptive fuzzy control is implemented by using software tools and the second IP is for current vector control is implemented by hardware. A controller is developed to test vector control algorithm by the pure hardware circuit using FPGA to satisfy the requirements of motors real-time control. The FPGA based control IC for PMSM drive is given in Figure 6.

A second order sliding mode control has been designed for SRM for the advantage of good robustness to the variations of mechanical load parameters is obtained (Mohamadian et al., 2004).

Artificial intelligence (AI) techniques

The AI techniques, such as fuzzy logic and Artificial Neural Network (ANN) have brought a new area of expertise in motor drives. The goal of AI is to plant human intelligence in a computer. The fuzzy controller concept is used for improvement of dynamic operating conditions for induction motor (Anggun et al., 2011). The fuzzy PI offers effectiveness in dealing with non linear or unknown parameter variation of system. Improvement in speed response and low torque ripple has been reported.

The robustness of system was improved in a voltage source inverter based Space Vector Pulse Width Modulation (SVPWM) (Satean et al., 2007). The high dynamic performance was observed (Arulmozhiyal et al., 2010; Chitra and Prabhakar, 2006; Rajesh et al., 2007). The TSK (Takagi-Sugeno Kans)-Fuzzy rotor resistance observer (Shun-Yuan et al., 2011), has been designed accurately for rotor resistance estimation. The fuzzy controllers have difficulties in tuning the parameters of the membership functions for system changes.

The ANN's can adapt themselves for changes in system input and output. (Bimal, 2007) presents the stator flux oriented induction motor vector drive with neural network based space vector modulation for flux estimation. A better performance of the drive is obtained when compared to PI controllers (Baruch and Cruz, 2010). An ANN based rotor resistance estimator has been reported (Huerta-González et al., 2006). The hybrid AI controllers (Neuro-fuzzy) are considered for powerful intelligent control (Mouloud et al., 2002).

The fuzzy based gain scheduling of PI controller for Permanent Magnet Synchronous Motor (PMSM) has been proposed for speed response during stat-up under no load, load disturbance and changes in command settings (Adhavan et al., 2011). A software is written in assembly language of DSP to realize the speed, current and position loop control (Yanping et al., 2009). The control algorithm of the fuzzy precompensated PI speed controller (Singh et al., 2006), and sliding mode speed controller (Brandstetter et al., 2010) is implemented in the assembly language of DSP to improve dynamic behavior and reliability of PMSM drive. A neuro-fuzzy PI controller was proposed in (Jabr et al., 2011) to control the rotor side voltage source converter of DFIG. The advantage was faster system response, shorter settling time and no steady state error.

The Fuzzy Logic Controller (FLC) can be used for solving nonlinearity of SRM. A TSK-fuzzy controller and a compensated controller have been used to regulate the speed of a SRM (Chwan-Lu et al., 2012). The robustness to the parameter variations and external load disturbance has been verified to be good. The FLC presents fast response with little overshoot and a short settling time (Sung-Jae et al., 2002; Xiu and Xia, 2007). It has been reported that there is little error in steady state of the system. An adaptive FLC is tuned by adjusting the scaling gains according to the speed error (Xiu and Xia, 2007). The improvement in the transient response and steady state performance of the system is reported. The fuzzy adaptive control scheme for automatic control of excitation angles is presented (Cheshmehbeigi et al., 2009). The modified fuzzy PI-like controllers with gain self tuning mechanism have been designed for the SRM drive system (Shun-Chung et al., 2010, 2009). A good stability and robustness against speed and load variations over a wide range of operating conditions was reported. A fuzzy logic basic adaptive PID control strategy was developed to improve the high system performance (Aijuan et al., 2010). A high performance torque control scheme with minimum torque ripple has been used, using an adaptive neural fuzzy system and adaptive sliding mode current control (Xuelian et al., 2010).

Sensorless control techniques (SCT)

The vector controlled induction motors without encoders are used in many industrial applications due to high performance, reliability and low cost. The sensorless induction motor drives estimate the speed from the measured stator voltages and currents. The goal of sensorless control is to improve high accuracy machine parameter tuning method and to develop a robust speed and torque estimation method.

SCT for IM

A speed sensorless control of induction motor at low speed using a low frequency signal which is injected to stator currents has been presented (Li and Wu, 2009). The resultant angle error is detected to estimate the rotor position and speed. The rotor slot harmonic technique for high speed accuracy in the steady state was implemented (Phipps and Al-Bahadly, 2002). A slip detection method is used at lower speeds. The sensorless control methods have been reported to overcome the high order non-linearity of induction motor's dynamics using extended complex Kalman filter (Menaa et al., 2007), ANN's observer and extended Kalman filter (Gherram et al., 2010; Mishra et al., 2010; Fatma, 2011), sliding mode approach and Luenberger observer (Aydeniz et al., 2009; Aamir et al., 2010), TS-Fuzzy observer (Kuang-Yow and Cheng-Yao, 2006; Zhang et al., 2008), adaptive observer (Zerikat et al., 2011) and integral sliding mode flux observer (Hung-Chih et al., 2010; Yeong-Hwa et al., 2011).

SCT for PMSM

The evaluation of some position and speed estimation methods for PMSM sensorless drives have been reported (Yousfi et al., 2009; Chunxia and Lei, 2010). The rotor magnetic flux estimation method for the estimation of mechanical speed was carried out in (Brandstetter et al., 2010).The good dynamic responses were reported. An adaptive fuzzy controller (which includes a fuzzy controller, a reference model and an adjusting mechanism) has been used in speed loop to increase the performance of the speed controller for sensorless control of PMSM (Ying-Shieh et al., 2009). The EKF-based sensorless operation for synchronous motor using software DSP controllers and hardware FPGA's solution has been implemented (Idkhajine et al., 2010) for the on-line estimation of the rotor position and speed from the measurement of electrical quantities.

SCT for DFIG

A sensorless control of doubly fed generators was presented using sliding mode observer to improve the dynamic and static performance of the speed estimation (Jian et al., 2011). The Model Reference Adaptive System (MRAS) has been used to estimate the rotor position and speed from the machine rotor currents (Pea et al., 2008). Comparisons of three sensorless control strategies (open loop, closed loop and MARS control strategy) are made (Pattnaik and Kastha, 2011; Cardenas et al., 2008). It has been reported that in MARS strategy, though complex, the rotor/position estimation is independent of the parameter uncertainties and the operation state of the DFIG. The excitation component of winding currents to perform speed/position has been proposed (Mohammed et al., 2005). It provides good speed control performance at around the synchronous speed.

SCT for SRM

With the help of the measured values of terminal phase voltage, current and di/dt as inputs of the model which includes the voltage equation, the determination of the improved rotor position of SRM at medium speed have been reported (Bekiesch and Schroder, 2006). A speed control system using back EMF and position estimator to reduce wide range of inaccuracy motor resistance/inductance estimation is proposed (Urbanski and Zawirski, 2007). The variation of an active phase inductance without additional hardware is used for sensorless control SRM in steady state (Miki et al., 2005). The neural network is used to construct the current flux-rotor position look up table based on sensorless operation of a SRM and is trained by sufficient available data. Actual and estimated rotor position/speed is reported (Won-Sik et al., 2004; Min-Huei et al., 2007). An improved back propagate neural network has been used for the rotor position estimator to reduce the computational burden and to achieve better accuracy (Zhong et al., 2012).

CONCLUSION

The developments of vector control of AC drives for the last 10 years are reviewed. The features of advanced control techniques with the availability of more powerful controller such as DSPs and FPGAs, high performance AC drives can be obtained as surveyed. The focus of this paper is to create much interest in recent advances in the filed of high performance AC drives.

ACKNOWLEDGEMENTS

We are grateful to all members of the Power Electronics and Drives Laboratory, School of Electrical Engineering, VIT University, Vellore, India for their excellent assistance and encouragement.

REFERENCES

Aamir HOA, Martino OA, Shamboul AM, Matthew WD (2010). peed Control of Induction Motor Using New Sliding Mode Control Technique. Iraq J. Electr. Electron. Eng. 6(2):111-115.

Adhavan B, Kuppuswamy A, Jayabaskaran G, Jagannathan V (2011). Field oriented control of Permanent Magnet Synchronous Motor (PMSM) using fuzzy logic controller. Recent Advances in Intelligent Computational Systems (RAICS), IEEE, pp. 587-592.

Aijuan S, Yali C, Deying G (2010). Study of based Fuzzy-PID control for switched reluctance motor. Comput. Des. Appl. (ICCDA) 3:V3-558-V3-561.

Anggun A, Rosli O, Marizan S, Azhar A (2011). Fuzzy optimization for speed controller of an indirect vector controlled induction motor drive using Matlab Simulink JATIT 28(2):108-113.

Anurag T, Arunima D, Bharti D, Bhim S, Dinesh C (2008). A new closed loop speed control strategy for a Vector Controlled Three- Phase Induction Motor Drive. Electr. Power Qual. Util. 14(1):67-72.

Arulmozhiyal R, Baskaran K, Manikandan R (2010). An intelligent speed controller for indirect vector controlled induction motor drive. Computational Intelligence and Computing Research (ICCIC), IEEE International Conference, pp. 1-5.

Aydeniz MG, Senol I (2009). A novel approach to sensorless control of induction motors. Electrical and Electronics Engineering, ELECO, pp. I-179-I-183.

Baruch IS, De la Cruz IP (2010). An indirect adaptive neural control of a three phase induction motor velocity. Elect. Eng. Comput. Sci. Aut. Cont. (CCE), pp. 105-110.

Bekiesch J, Schroder G (2006). A new Sensorless Control for the Switched Reluctance Machine. Power Electronics and Motion Control Conference, pp. 425-430.

Bimal KB (2007). Neural Network Applications in Power Electronics and Motor Drives-an Introduction and Perspective. Ind. Electron. IEEE Trans. 54(1):14-33.

Brandstetter P, Francik O, Simonik P (2010). AC drives with permanent magnet synchronous motor and sensorless control. Power Electronics and Motion Control Conference (EPE/PEMC), T2-66 - T2-71.

Cardenas R, Pena R, Clare J, Asher G, Proboste J (2008). MRAS Observers for Sensorless Control of Doubly-Fed Induction Generators. Power Electron. IEEE 23(3):1075-1084.

Cheshmehbeigi HM, Yari S, Yari AR, Afjei E (2009). Self-tuning approach to optimization of excitation angles for Switched-Reluctance Motor Drives using fuzzy adaptive controller. Power Electron. Appl. EPE, pp. 1-10.

Chitra V, Prabhakar RS (2006). Induction Motor Speed Control using Fuzzy Logic Controller. World Acad. Sci. Eng. Technol. 23:17-22.

Chunxia G, Lei Z (2010). An Improved Position Sensor-Less Estimator for Vector Control of IPMSM. Elect. Cont. Eng. (ICECE), pp. 3288 – 3291.

Chwan-Lu T, Shun-Yuan W, Shao-Chuan C, Chaur-Yang C (2012). Development of a Self-Tuning TSK-Fuzzy Speed Control Strategy for Switched Reluctance Motor. Power Electron. IEEE 27(4):2141-2152.

Domínguez-García JL , Gomis-Bellmunt O , Trilla-Romero L , Junyent-Ferré A (2010). Vector control of squirrel cage induction generator for wind power . Electric. Mach. (ICEM), pp. 1-6.

Fatma HF (2011). Sensorless Vector Control of Three Phase Induction Motor Based on Full Neural Estimator and Controller. Eng. Tech. J. 29(9):1737-1750.

Gherram K, Yazid K, Menaa M (2010). Sensorless indirect vector control of an induction motor by ANNs observer and EKF. Control Autom. (MED), pp. 521-526.

Huerta –González P, Rodríguez-Rivas J, Torres-Rodríguez I (2006). Indirect Vector-Controlled Induction Motor Drive. System with Rotor Resistance Estimation using an Artificial Neural Network. Científica. 10(4):191-197.
Hung-Chih C, Chun-I W, Chia-Wen C, Yeong-Hwa C, Hung-Wei L (2010). Integral sliding-mode flux observer for sensorless vector-controlled induction motors. System Science and Engineering (ICSSE), pp. 298-303.
Idkhajine L, Monmasson E, Maalouf A (2010). Extended Kalman Filter for AC drive Sensorless Speed Controller - FPGA-based solution or DSP-based solution. Ind. Elect. (ISIE), IEEE, pp. 2759-2764.
Jabr HM, Dongyun L, Kar NC (2011). Design and Implementation of Neuro-Fuzzy Vector Control for Wind-Driven Doubly-Fed Induction Generator. Sustain. Energy IEEE 2(4):404-413.
Jannati M, Fallah E (2010). Modeling and vector control of unbalanced induction motors (faulty three phase or single phase induction motors). Power Electronic and Drive Systems and Technologies Conference (PEDSTC), pp. 208-211.
Jian Q, Jian-ping W, Chong-wei Z (2011). Adaptive sliding mode speed identification for vector control system of doubly fed wind turbine. Elect. Cont. Eng. (ICECE), pp. 54-58.
Xiu J, Changliang X (2007). An Application of Adaptive Fuzzy Logic Controller for Switched Reluctance Motor Drive. Fuzzy Syst. Knowl. Discov. FSKD 4:154-158.
Khalaf SG, Hew Wooi P, Haider Mohamed AF (2009). Indirect Vector Control of a Variable Frequency. Induction Motor Drive (VCIMD), pp. 36-40.
Kuang-Yow L, Cheng-Yao H (2006). Sensorless Control for Induction Motors via Fuzzy Observer Design. Ind. Electron. IEEE 3:2140-2145.
Li Y, Wu S (2009). A new method of speed-sensorless control of induction motor at very low speed. Advanced Electromechanical Motion Systems & Electric Drives Joint Symposium, Electromotion, pp. 1-5.
Meihua Z, Yi R, Yang S, Bingying Y, Qinhong Z, Zhao M (2011). Comparative study of vector control with direct power control for grid side converter of DFIG wind power generation system. Electrical and Control Engineering (ICECE), pp. 3398-3402.
Menaa M, Touhami O, Ibtiouen R, Fadel M (2007). Sensorless direct vector control of an induction motor. Sci. Direct pp. 67-77.
Miki I, Komatsuzaki A, Yoshida K (2005). A new sensorless control for switched reluctance motor. Power Electron. Appl. p. 10.
Min-Huei K, Won-Sik B, Dong-Hee K, Nam-Hun K, Kyeong-Ho C (2007). A position sensorless control system of SRM over wide speed range. Power Elect. ICPE, pp. 640-643.
Mishra JP, Gupta SP, Padhy NP (2010). Sensorless vector control of induction motor using direct adaptive RNN speed estimator. National Power Electronics Conference (NPEC), pp. 1-9.
Mohamadian M, Pedram MM, Ashrafzadeh F (2004). Digital second order sliding mode control for a synchronous reluctance motor. Industry Applications Conference, 39th IAS Annual Meeting, IEEE 3:1899-1902.
Mohammed OA, Liu Z, Liu S (2005). A novel sensorless control strategy of doubly fed induction motor and its examination with the physical modeling of machines. Magnetics IEEE 41(5):1852-1855.
Mouloud AD, Sid Ahmed A (2002). Fuzzy and neural control of an induction motor. Int. J. Appl. Math. Comput. Sci. 12(2):221–233.
Naouar M-W, Monmasson E, Naassani A A, Slama-Belkhodja I, Patin N (2007). FPGA-Based Current Controllers for AC Machine Drives-A Review. Ind. Elect. IEEE. 54(4):1907-1925.
Noureddine G, Amar G (2006). High performance adaptive field–oriented model reference control of current–fed induction motor. J. Elect. Eng. 57(2):78-86.
Pattnaik M, Kastha D (2011). Comparison of MRAS based speed estimation methods for a stand alone Doubly Fed Induction Generator. Energy, Automation and Signal (ICEAS), pp. 1-6.
Pea R, Cerdenas R, Proboste J, Asher G, Clare J (2008). Sensorless control of doubly-fed induction generators using a rotor-current-based MRAS observer. Ind. Elect. IEEE 55(1):330-339.
Phipps W, Al-Bahadly I (2002). Sensorless speed control in induction motor drives. Electronic Design, Test and Applications, IEEE, pp. 480-482.
Rajesh K, Gupta RA, Bhangale SV (2007). Indirect vector controlled induction motor drive with fuzzy logic based intelligent controller. IET-UK International Conference on Information and Communication Technology in Electrical Sciences (ICTES), pp. 368-373.
Sahoo SK, Das GTR, Subrahmanyam V (2007). Contributions of FPGAs to industrial drives: A review. IET Semin. Digest. 2:343-348.
Sarat KS, Tulasi RGD, Subrahmanyam V (2008). VLSI design approach to high-performance direct torque control of induction motor drives. World J. Model. Simul. 4(4):269-276
Satean T, Tianchai S, Sompong S (2007). Fuzzy Logic Control for a Speed Control of Induction Motor using Space Vector Pulse Width Modulation. World Acad. Sci. Eng. Technol. 25:71-77.
Shiyi S, Abdi E, Barati F, McMahon R (2009). Stator-Flux-Oriented Vector Control for Brushless Doubly Fed Induction Generator. Ind. Electron. IEEE Trans. 56(10):4220-4228.
Shun-Chung W, Chia-Cheng L, Yi-Hua L, Yuan-Lin C (2010). A correction PI-like fuzzy logic controller for SRM drives system. Ind. Electron. Appl. (ICIEA) IEEE pp. 1346-1351.
Shun-Chung W, Yi-Hua L, Chia-Cheng L (2009). A modified PI-like fuzzy logic controller for switched reluctance motor drive. Power Electron. Drive Syst. PEDS pp. 1366-1371.
Shun-Yuan W, Chwan-Lu T, Chun-Jung C (2011) Design of adaptive TSK-fuzzy observer for vector control induction motor drives. Elect. Cont. Eng. (ICECE), pp. 5220-5223.
Shuxi L, Shan L, Huihui X (2010). Vector Control System of Induction Machine Supplied by Three-Level Inverter Based on a Fast SVPWM Algorithm. Intell. Syst. Des. Eng. Appl. (ISDEA) 2:810-813.
Singh B, Singh BP, Dwivedi S (2006). DSP Based Implementation of Fuzzy Precompensated PI Speed Controller for Vector Controlled PMSM Drive. Ind. Electron. Appl. 1ST IEEE, pp. 1-6.
Srirattanawichaikul W, Kumsuwan Y, Premrudeepreechacharn S, Wu B (2010). A vector control of a grid-connected 3L-NPC-VSC with DFIG drives. Electrical Engineering/Electronics Comput. Telecommun. Inf. Technol. (ECTI-CON), pp. 828-832.
Sung-Jae H, Kyu-Dong K, Huh Uk-Youl H, Joon-Hyun J, Byung-Suk L, Woo-Yong C (2002). Fuzzy logic based control of high current SRM. SICE 2:1216-1219.
Urbanski K, Zawirski K (2007). Sensorless control of SRM using position observer. Power Electron. Appl. Eur. Conf. pp. 1-6.
Won-Sik B, Min-Huei K, Nam-Hun K, Dong-Hee K (2004). Position sensorless control system of SRM using neural network. Power Electron. Specialists Conf. PESC. 5:3471-3475.
Xiu J, Xia C (2007). An Application of Fuzzy Logic Controller for Switched Reluctance Motor Drive. Control Conf. CCC, pp. 50-53.
Xu D, Huanqiang L, Wang F, Xiaomei Y, Nianxing F (2011). Research on the sliding-mode variable structure control based on the vector control of PMSM. Elect. Cont. Eng. (ICECE), pp. 2529-2532.
Xuelian Y, Ruiyun Q, Zhiquan D, Jun C (2010). High-Performance Torque Control for Switched Reluctance Motor Based on Online Fuzzy Neural Network Modeling. Intell. Syst. Des. Eng. Appl. (ISDEA) 1:817-822.
Xueqin Z, Donghui G (2010). Study on the Connection of DFIG to Grid Based on Double-vector PWM. Elect. Cont. Eng. (ICECE) pp. 2139-2143.
Yanping L, Shuhong L, Huajun W (2009). DSP control implement of Permanent Magnet Synchronous AC servo motor based on vector control. Mechatron. Autom. ICMA pp. 866-870.
Yeong-Hwa C, Chun-I W, Hung-Chih C, Chia-Wen C, Hung-Wei L (2011). Fractional-Order Integral Sliding-Mode Flux Observer for Sensorless Vector-Controlled Induction Motors. Am. Control Conf. pp. 190-195.
Ying-Shieh K, Chia-Sheng C, Kiing-Ing W, Ming-Hung T (2005). Development of a FPGA-based control IC for PMSM drive with adaptive fuzzy control . Ind. Electron. Soc. IECON, IEEE pp. 1544-1549.
Ying-Shieh K, Ming-Shyan W, Chung-Chun H (2009). DSP-based adaptive fuzzy control for a sensorless PMSM drive. Control Decis. Conf. CCDC pp. 2379-2384.
Ying-Shieh K, Pin-Ging H (2004). High performance position controller for PMSM drives based on TMS320F2812 DSP. Control Appl. IEEE 1:290-295.
Yousfi D, Halelfadl A, El Kard M (2009). Review and evaluation of some position and speed estimation methods for PMSM sensorless drives.

Multimedia Comput. Syst. ICMCS pp. 409-414.
Zerikat M, Mechernene A, Chekroun S (2011). High-performance sensorless vector control of induction motor drives using artificial intelligent technique. Eur. Trans. Electr. Power pp. 787-800.
Zhang J, Wen XH, Hua Y (2008). Practical speed estimation method for induction motor vector control system using digital signal processor (DSP). Electric. Mach. Syst. ICEMS pp. 74-78.
Zhong R, Wang YB, Xu YZ (2012). Position sensorless control of switched reluctance motors based on improved neural network. Electric Power Appl. IET 6(2):111-121.