

Various Control Techniques for Induction Motor Drive: A Brief Insight

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Abstract

Automation and motion control are basically prime factors to run an industry. This paper presents a review on various control schemes available for control of Induction motor drives. This paper would be useful to both researchers as well as practicing engineers as they can find the various techniques available and compare them in a single paper at signpost to the current state of the art.

1. Introduction

The drive is a general term responsible for controlled motion with specific start/stop and matched torque properties as required by the process, keeping input energy level at most minimum level while keeping efficiency to be the best one; in other words minimizing the losses. The drive could be alone or a combination of mechanical, hydraulic, pneumatic, electrical motors combined with control elements like gearbox, belts and pulley drives, chain drives, throttle valve, pressure regulator, and electronic systems with analog/digital controls. Almost 80% industrial motions are achieved by asynchronous induction motor. Thereby there is increasing population of AC digital drives replacing DC drives and simplifying mechanical drives.

2. Various Control Techniques

Heung G. Kim, Seung K. Sul, and Min H. Park [1], developed a algorithm to improve the efficiency of a lightly loaded induction motor. The novel control loop realizing this algorithm is suggested, and its property is analyzed. This algorithm can be easily applied to any current source inverter induction motor drive system by a little modification of the conventional control. The CSI is commonly used to feed a single high-power induction motor driving a fan or blower or pump load. In this case, the information of load factor can be easily found, and the load torque is proportional to the square of the motor speed. If the proposed

optimal efficiency control algorithm is extensively adopted in such a field, the energy can be substantially saved.

Armando Bellini, Gennaro Figalli, and Michele La Cava [2], presented a approach which simplifies the application of optimal control techniques to frequency controlled induction motor drives. Some simplifying hypotheses related to the difference between the dynamics of the electromagnetic variables and that of the mechanical ones have made it possible to obtain a suboptimal control system by applying the results of the optimization theory for steady-state linear servo-systems. To take into account both the discretization introduced by the inverter and the computation delay, a discrete-time model of the motor electromagnetic circuits has been employed, and a suitable increase of the dimensions of the state vector has been affected. The results obtained by simulation have made it possible to verify the efficiency of the proposed approach and the validity of the simplifying hypotheses. The control strategy has been chosen without considering the particular modulation law of the inverter. Several tests have shown that, at least in correspondence with the sampling instants, the modulation law does not make appreciable changes in the state variables. A preliminary analysis of the structure of the controller and the computation times necessary to implement the control law has shown the practical possibility of carrying out the proposed control mode by utilizing a modern 16-b microcomputer. The present studies intending both to realize the control circuit and to determine the sensitivity of the obtained results with respect to the variation of the machine parameters and the measurement errors.

Armando Bellini, Gennaro Figalli, and Giovanni Ulivi [3], discussed the application of an optimal bilinear control technique to induction machines. Presented technique performs a tight and fast control of the values of the torque and of the stator flux and current, even if the machine parameters are not perfectly known or they change during the motor operation. Moreover, it does not require a high precision tachometer, as also the

speed measurement errors are compensated by the slip control loop. The control circuit necessary to implement the proposed control technique is practically the same used for an optimal linear controller; only the software is a little more complex. It can be implemented on two loosely coupled microcomputers. The first microcomputer controls the mechanical variables and computes the desired value of the torque; moreover, it performs the acquisition of the measured variables and a first elaboration to provide the second one with all the necessary data. The second microcomputer determines the proper motor voltages to control the electromagnetic variables and to obtain the desired torque; eventually, it can also determine the sequence of the commutating instants of the inverter. Many tests have been carried out using two simulation most suitable values of the performance index parameters and to single out the drive performances. The other program has been used to analyze the effects of the errors introduced by the control circuit. The entire test has shown the good performances offered by the proposed technique and its robustness as regards the parametric variations, the variables' quantization, and the noises added to the measurements.

Bin Wu, Gordon R. Slemon and Shashi B. Dewan [4] presented a new phase angle control scheme which provides a simple, rugged means of controlling the speed or torque of an induction motor without the use of a speed sensor. It incorporates a capacitor loaded current source inverter system which has great advantages of simplicity, low switching frequency, four quadrant operation, over-current protection and low harmonic content in the motor current and voltage. Maximum value for the capacitor depends on the degree of nonlinearity which can be tolerated in the torque-stator current relation while its minimum value depends on the need for a low impedance path for inverter current harmonics. In this case while the speed of response will be lower than with vector control, it is likely to be adequate for many drives, particularly at high power levels.

Jun K. Kang et. al. [5], discussed a speed controller of a field-oriented induction motor controller, in which a PDF controller with load torque observer is used. The main advantage of using PDF controller is that it is easy to design the control response and provides the robustness against the load disturbance without a poor performance in the speed step response. By applying a disturbance observer, the overall speed system becomes robust against mechanical

parameter variations as well as sudden load circumstance changes.

Gilberto C. D. Sousa, Bimal K. Bose [6], proposed a new method for efficiency optimization of vector control drives. Proposed scheme uses a fuzzy controller to adaptively adjust the magnetizing current based on the drive measured input power, thus yielding true optimum efficiency operation with fast convergence. Problem of pulsating torque has been successfully addressed by implementing a feed-forward torque compensator. The overall resulted system was initially validated through simulation studies, followed by an extensive experimental study. The proposed method can be incorporated into an existing vector drive system with a minimum of extra hardware. In most cases, the extra software can be easily implemented by the existing processor, resulting in a cost effective improved efficiency drive.

P. Vas, A. F. Stronach, M Neuroth [8], described briefly the application of conventional and AI-based techniques in sensorless high-performance torque-controlled drives. Experimentally obtained results have also been shown for vector and DTC drives where all the controllers and estimators have been implemented in real-time. Presented results prove the viability of the techniques considered. It is believed that artificial-intelligence-based techniques will have an increased role in future industrial drives. Performance of torque-controlled drives at extremely low speeds is currently being investigated by the authors.

Lino Rosell Valdenebro, Edson Bim [9], presented a new approach for the problem of rotor time constant identification of the induction motors using genetic algorithms. The proposed GA optimization has been performed on-line based on the steady state model of the indirect field oriented control. From the simulation results, it was proved that substantial improvement in the drive performance can be obtained with the GA approach. Thus it was concluded that in steady state conditions, when the GA updating scheme is connected, the motor and commanded currents are approximately equal even in strong detuning conditions.

Cristian Lascu, Ion Boldea, Frede Blaabjerg [10], has introduced a new direct torque and flux control strategy based on two PI controllers and a voltage space-vector modulator. The complete sensorless solution was presented. The main conclusions drawn from [10] are as: DTC-SVM

strategy realizes almost ripple-free operation for the entire speed range. Consequently, the flux, torque, and speed estimation is improved; the fast response and robustness merits of the classical DTC are entirely preserved; the switching frequency is constant and controllable. In fact, the better results are due to the increasing of the switching frequency. While for DTC a single voltage vector is applied during one sampling time, for DTC-SVM a sequence of six vectors is applied during the same time. This is the merit of SVM strategy; an improved MRAC speed estimator based on a full-order rotor flux estimator as reference model was proposed and tested at high and low speeds. It can be stated that, using the DTC-SVM topology, the overall system performance is increased.

Pawel Z. Grabowski et. al. [11], discussed the application of an NF approach for direct torque control of a PWM-inverter-fed induction motor through DSP-based experimental implementation. The design and tuning procedure have been described along with the improved stator flux estimation algorithm, which guarantees eccentric estimated flux.

Cao-Minh Ta, Yoichi Hori[12], discussed that in order to improve the efficiency of the IM drive under light-load conditions, the air-gap flux is generally reduced to minimize the total losses. Many publications have reported on the techniques of flux reduction to find the optimum-efficiency condition. The power-measure-based approach is known as a simple and robust method, but relatively slow due to the searching process. In [12] a novel algorithm was proposed to improve the convergence of that approach. The golden section technique is employed in the proposed algorithm to reduce the flux-producing current component until the measured input power reaches its minimum for a given torque and speed. The eventual torque pulsation caused by the stepwise decrease in the flux current has been eliminated by incorporating a simple LPF in the EOA. Excellent performance has been found during the transient and steady-state operation by properly applying the EOA in the indirect vector control environment. The simulation and experimental results of the no-load and light-load tests show the fast convergence of the proposed algorithm, as the reference flux current is settled down to its optimum within 1.5% of the current tolerance after only nine iterations. Under this condition, the input power is minimum. In addition to its quickness and simplicity, the proposed technique preserves the good dynamic performance and it is completely insensitive to the parameter variation. Other important advantage of

the technique is that we do not need to know *a priori* the number of functional evaluations and, moreover, the knowledge of speed or torque is not required in the search process. A speed error is used only for detecting transient operations of the system. Even though the technique has been developed for an IM in this paper, it can be universally applicable to other ac machines.

In the proposed scheme, if the detecting signal is another variable than the speed error, a complete sensor less efficiency-optimization control of an IM can be designed, which is a good solution for EV applications, one of the fastest developing technologies in recent years. Investigation in this direction is in progress in our laboratory.

Sheng-Ming Yang, Feng-Chieh Lin [13], proposed a new minimum-loss control scheme for vectpr-controlled induction motor drives. The control scheme utilizes the motor power factor as the main control variable and manipulates the magnetizing current in order for the motor to operate at its minimum-loss point. In conjunction with the power factor control, a scheme for the measurement of the optimal power factor command was proposed. The main advantage of this scheme is that it is simple for implementation and does not require an a priori knowledge of the motor parametem. The experimental results have confirmed the effectiveness of the control scheme in controlling the motor to its minimum-loss condition regardless of load variations.

Lixin Tang , M.F. Rahman [14], presented a modified DTC algorithm. Proposed algorithm is based on the induction model and Space Vector Modulation theory. The only difference is the modified DTC uses SVh4 to replace switching table. As a result, both torque and flux linkage ripples are greatly reduced, and the switching frequency is kept fixed. Further simulation on the flux and torque estimation and experiment verification is being currently investigated.

Chady El Moucary, Eduardo Mendes, and Adel Razek [15], firstly recalled the well known Flux Oriented Control (FOC) and Stator Flux Vector Control (SFVC) methods. Then, introduced a new direct torque and stator flux control method, the Decoupled Direct Control (DDC) method. From this, two DDC-based strategies have been developed. The first, Predictive-DDC (P-DDC), lies on decoupling flux and torque control by real-time estimating some coupling terms. This method is very dependant of the model parameters values. Experimentally, this method exhibits almost the same performances as the SFVC method. In order

to enhance the performances, we have proposed a second control method, the PI-DDC. This method uses PI regulators in order to estimate the coupling terms, thus avoiding the parameters dependency of the first control law. In addition, it allows selecting separately the torque and the flux dynamics by tuning the PI gains. Finally, PI-DDC does not need any induction machine parameter value. Several experimental tests have been carried out in order to compare the performances of the SFVC, FOC, P-DDC and PI-DDC methods. The two controlled quantities, i.e. the stator flux and the motor torque, were estimated using a simple rotor flux estimator expressed in the rotating rotor flux reference frame. The experimental results have shown the effectiveness of the proposed method, i.e. PI-DDC, in terms of parameters robustness, torque and flux ripples and dynamic performances compared to the others. Moreover, this method requires a third less calculations than FOC or SFVC.

Cristian Lascu, Ion Boldea, Frede Blaabjerg [16], A family of variable-structure direct torque controllers for sensorless induction machine drives has been proposed and tested. It integrates the DTC with VSC in a high-performance drive and employs the SVM for ripple reduction and constant frequency operation. Three new control strategies have been studied and the most relevant results were presented. Experimental results prove that all proposed strategies have superior behavior and offer more flexibility in control than the classic DTC. The comparative analysis allows establishing the following hierarchies. In terms of dynamic response, the LFSG and the LVSC are as fast as the DTC (1 ms), while the RCG is slower. LFSG, followed by LVSC, have the best behavior in terms of steady-state torque ripple, far better than DTC, while RCG control shows larger ripple, but still much smaller than DTC. Flux ripple is practically nonexistent for all strategies. Robustness with respect to torque and speed transients and to lack of decoupling between the torque and flux controllers appear better for the LVSC and RCG, while the LFSG shows minor sensitivity to torque transients. All strategies operate at constant and controllable switching frequency and have excellent behavior at low rotor speeds. Acoustical noise is very low for the LVSC and LFSG, and moderate to low for the RCG control. Overall, the best strategies are LVSC and LFSG, with LVSC being more versatile. There are the requirements of each application that will eventually determine which strategy is more advantageous.

Kyo-Beum Lee, Frede Blaabjerg [17], In order to realize high performance control of induction

motor drives fed by matrix converter, a new matrix converter modeling for low speed operation and robust speed controller using a disturbance observer have been proposed in this paper. The nonlinear voltage distortion that is caused by commutation delay and on state voltage drop in the power device is corrected by a simple feed-forward compensation method using the direction of current. In addition, to achieve a robust control characteristic against un-modeled disturbances such as parameter variations and load disturbances, the un-modeled disturbances are approximated by the radial basis function network. Experimental results show that the proposed control scheme can provide good performance at the low speed region and robust and stable characteristics against parameter variations and load disturbance.

Javier Pereda, Juan Dixon, Mauricio Rotella [18], presented a Sensorless DTC using a simplified multilevel inverter by means of special topologies and control strategies. Experimental results showed a satisfactory control of the ultra-capacitor voltages and regeneration avoid in the Aux-2. However, when INC is enabled, the THD has some increment in comparison with a conventional 27-Level inverter, but the proposed inverter was simpler and its voltages remain almost sinusoidal, improving the high-performance of the DTC. The simulations showed a high-accuracy control of the speed and torque, with very low torque ripple. The estimation of speed by MRAS was simple and precise at normal speeds.

Martin Jones, Slobodan N. Vukosavic, Drazen Dujic, Emil Levi [19], examined the feasibility of using a single pair of synchronous d-q current controllers for multiphase drives with sinusoidal MMF distribution. It is shown that such a solution, while theoretically viable, does not suffice in reality due to the winding imbalance and/or inverter parasitic effects. A modified current control scheme is therefore proposed, in which two pairs of current controllers, both operated in the synchronous reference frame, are utilized. The ability of such a current control scheme to fully compensate for any imbalance of the machine and the inverter dead time effects is verified experimentally using two different experimental setups with two different inverters and a different connection of the machine's phase half-windings.

3. References

- [1] Heung G. Kim, Seung K. Sul, and Min H. Park, "Optimal Efficiency Drive of a Current Source Inverter Fed Induction Motor by Flux Control",

- IEEE Transactions On Industry Applications, Vol. IA-20, No. 6, pp. 1453-1459, November/December 1984.
- [2] Armando Bellini, Gennaro Figalli, and Michele La Cava, "A Discrete Feedback Suboptimal Control for Induction Motor Drives" IEEE Transactions On Industry Applications, Vol. IA-1, No. 2, pp. 422-428, March/April 1985.
- [3] Armando Bellini, Gennaro Figalli, and Giovanni Ulivi, "A Microcomputer-Based Optimal Control System to Reduce the Effects of the Parametric Variations and Speed Measurement Errors in Induction Motor Drives" IEEE Transactions on Industry Applications, Vol. IA-22, No. 1, pp. 42-50, January/February 1986
- [4] Bin Wu, Gordon R. Slemon, Shashi B. Dewan, , "PWM-CSI Induction Motor Drive with Phase Angle Control", Ieee 1989, Pp 674-679.
- [5] Jun K. Kang, Jae T. Lee, Young L.M. Kim, Bong H. Kwon and Kyung S. Choi, "Speed Controller Desigx For Induction Motor Drives Using s PDF Control and Load Disturbance Observer" I ECON '91, pp 799-803.
- [6] Gilberto C. D. Sousa, Bimal K. Bose, "Fuzzy Logic Based On-Line Efficipncy Optimization Control Of An Indirect Vector Controlled Induction Motor Drive", IEEE 1993.
- [7] Gilberto C. D. Sousa, Bimal K. Bose, and John G. Cleland, "Fuzzy Logic Based On-Line Efficiency Optimization Control of an Indirect Vector-Controlled Induction Motor Drive", IEEE Transactions On Industrial Electronics, Vol. 42, No. 2, pp 192-198, April 1995.
- [8] P Vas , A F Stronach, M Neuroth, "DSP-Based Speed-Sensorless Vector Controlled Induction Motor Drives Using AI-based Speed Estimator And Two Current Sensors", Power Electronics and Variable Speed Drives, September 1998, Conference Publication No. 456, pp. 442-446, IEE 1998.
- [9] Lino Rosell Valdenebro, Edson Bim, "A Genetic Algorithms Approach for Adaptive Field Oriented Control of Induction Motor Drives", IEEE 1999, pp. 643-645.
- [10] Cristian Lascu, Ion Boldea, Frede Blaabjerg, "A Modified Direct Torque Control for Induction Motor Sensorless Drive", IEEE Transactions On Industry Applications, Vol. 36, No. 1, pp. 122-130, January/February 2000.
- [11] Pawel Z. Grabowski, Marian P. Kazmierkowski, Bimal K. Bose, Frede Blaabjerg, "A Simple Direct-Torque Neuro-Fuzzy Control of PWM-Inverter-Fed Induction Motor Drive", IEEE Transactions On Industrial Electronics, Vol. 47, No. 4, pp. 863-870, August 2000.
- [12] Cao-Minh Ta, Yoichi Hori, "Convergence Improvement of Efficiency-Optimization Control of Induction Motor Drives IEEE Transactions On Industry Applications, Vol. 37, No. 6, pp. 1746-1753, November/December 2001.
- [13] Sheng-Ming Yang, Feng-Chieh Lin, "Loss-Minimization Control of Vector-Controlled Induction Motor Drives", IEEE, pp. 182-187, 2001.
- [14] Lixin Tang , M.F. Rahman, "A New Direct Torque Control Strategy for Flux and Torque Ripple Reduction for Induction Motors Drive-A Matlab/Simulink Model", IEEE, pp. 884-890, 2001.
- [15] Chady El Moucary, Eduardo Mendes, and Adel Razek, "Decoupled Direct Control for PWM Inverter-Fed Induction Motor Drives", IEEE, pp. 37-43, 2001.
- [16] Cristian Lascu, Ion Boldea, Frede Blaabjerg, "Variable-Structure Direct Torque Control—A Class of Fast and Robust Controllers for Induction Machine Drives", IEEE Transactions On Industrial Electronics, Vol. 51, No. 4, pp.785-792, August 2004.
- [17] Kyo-Beum Lee, Frede Blaabjerg, "Improved Sensorless Vector Control for Induction Motor Drives Fed by a Matrix Converter Using Nonlinear Modeling and Disturbance Observer", IEEE Transactions On Energy Conversion, Vol. 21, No. 1, pp. 52-59, March 2006.
- [18] Javier Pereda, Juan Dixon, Mauricio Rotella, "Direct Torque Control for Sensorless Induction Motor Drives Using an Improved H-Bridge Multilevel Inverter", IEEE, pp. 1110- 1115, 2009.
- [19] Martin Jones, Slobodan N. Vukosavic, Drazen Dujic, Emil Levi, "A Synchronous Current Control Scheme for Multiphase Induction Motor Drives" IEEE Transactions On Energy Conversion, Vol. 24, No. 4, pp. 860-868, December 2009.