IAES Journal of Electrical and Electronics Engineering
Vol. 3, No. 1, June 2016, pp. 21~24
ISSN: 2338-7432, DOI: 10.11591/jeee.v3i1.pp21-24

Microcontroller implementation in PMSM speed control systems: control strategies, embedded architectures, and practical challenges

Tole Sutikno[1], Mohd Hatta Jopri[2]
[1]Faculty of Industrial Technology, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[2]Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia

Article Info

Article history:

Received Sep 2, 2014
Revised Nov 5, 2015
Accepted Nov 26, 2015

Keywords:

Digital signal processor
Embedded system
Field-oriented control
Microcontroller
Permanent magnet synchronous motor
Sensorless control
Speed control

ABSTRACT

Permanent magnet synchronous motors (PMSMs) are increasingly used in industrial drives because of their high efficiency, power density, and favorable torque characteristics. However, achieving accurate speed regulation requires an effective control strategy and a digital platform capable of executing control algorithms in real time. Microcontrollers and digital signal processors (DSPs) provide the computational resources needed to implement current regulation, rotor-position estimation, pulse-width modulation, and speed feedback. This review examines the implementation of PMSM speed-control systems using embedded digital controllers, with particular attention to field-oriented control (FOC), sensor-based operation, and sensorless techniques. The reviewed studies demonstrate that embedded FOC can achieve satisfactory speed and torque control, while sensorless methods can reduce hardware requirements at the cost of additional computational and estimation complexity. The review concludes that successful implementation depends on the coordinated design of the control algorithm, processing platform, sensing system, inverter, and real-time software.

This is an open access article under the CC BY-SA license.

1. INTRODUCTION

Permanent magnet synchronous motors (PMSMs) are widely applied in industrial drive systems because they offer high efficiency, high torque density, and good dynamic performance. Their applications include robotics, machine tools, electric vehicles, compressors, and automated production equipment. Unlike conventional brushed DC motors, PMSMs require an electronic inverter and an appropriate control strategy to regulate their speed and torque. The increasing capability of microcontrollers and DSP-based controllers has made sophisticated PMSM control algorithms practical for embedded applications.

Despite these advantages, PMSM speed regulation presents several technical challenges. The motor's electrical and mechanical variables are coupled, and its dynamic behavior is influenced by rotor position, load torque, current, and operating speed. A controller must therefore coordinate the inverter switching signals with the rotor magnetic field to obtain the desired torque response. Inadequate synchronization or inaccurate rotor-position information can lead to torque ripple, reduced efficiency, unstable operation, or poor speed regulation.

Embedded digital control provides a practical approach to addressing these challenges. A microcontroller can acquire current and position signals, execute the speed and current control loops, and generate PWM signals for the inverter. More advanced platforms can also perform mathematical transformations, observer calculations, and fault-monitoring functions within a single control cycle. This review examines how these functions are implemented and evaluates the advantages, limitations, and practical considerations of the main control approaches.

2. PMSM CONTROL-SYSTEM ARCHITECTURE

A microcontroller-based PMSM drive generally consists of a reference-speed input, a digital controller, a voltage-source inverter, a PMSM, and a measurement system. The reference speed is compared with the measured or estimated motor speed to produce a speed-control error. The controller processes this error and generates a torque or current reference for the inner current-control loop. The inverter then converts the DC-link voltage into controlled three-phase voltages that drive the motor.

The digital controller is responsible for executing the control algorithm within a defined sampling period. Its hardware typically includes a timer, PWM modules, analog-to-digital converters, interrupt facilities, and communication interfaces. DSP-oriented microcontrollers are particularly useful because they provide arithmetic and peripheral capabilities suited to motor-control applications. The selected platform must have sufficient processing speed and memory to complete all calculations before the next control update.

Current and rotor-position measurements are essential for conventional FOC implementation. Current sensors provide information for regulating the motor's stator currents, while an encoder or resolver can provide rotor-position information for coordinate transformation. The measured signals must be conditioned and sampled accurately to avoid excessive noise and timing errors. These requirements show that reliable PMSM control depends not only on the control algorithm but also on the quality of the measurement and power-electronic hardware.

3. FIELD-ORIENTED CONTROL IMPLEMENTATION

Field-oriented control (FOC) is a widely used strategy for high-performance PMSM speed regulation. Its main purpose is to transform the three-phase stator current variables into a rotating reference frame aligned with the rotor magnetic field. This transformation allows torque-producing and flux-related current components to be regulated separately. The resulting control structure makes it possible to achieve dynamic performance comparable to that of separately controlled DC motor drives. A typical embedded FOC implementation includes current acquisition, coordinate transformation, current regulation, inverse transformation, and PWM generation. The microcontroller first samples the motor phase currents and obtains the rotor electrical position from a sensor or estimator. It then executes the control calculations and generates switching commands for the three-phase inverter. Because these operations must be completed repeatedly, the software must be carefully organized to satisfy the real-time requirements of the drive.

Yusivar *et al.* [1] reported an implementation of FOC for PMSM in a real-time embedded system. Their experimental results showed satisfactory torque and speed control, demonstrating the practical feasibility of embedded FOC rather than relying solely on computer simulation. This study is particularly relevant because it was conducted by researchers from an Indonesian university and presented at the 2014 International Conference on Electrical Engineering and Computer Science. It provides direct evidence that embedded digital control can be applied to PMSM drives using a structured FOC architecture.

Zhang *et al.* [2] presented an FOC strategy for PMSM using a DSP experimental platform. Their approach used PI current controllers designed in MATLAB/Simulink and evaluated the control strategy through offline simulation and semi-physical experiments on the DSP platform. The study illustrates the importance of combining algorithm design with embedded-platform evaluation. However, semi-physical testing should be distinguished from a complete full-power motor-drive experiment because the two approaches do not necessarily expose the controller to identical hardware conditions.

4. SENSOR-BASED AND SENSORLESS SPEED CONTROL

Rotor-position measurement is a major consideration in PMSM control because the accuracy of coordinate transformation depends on the estimated electrical angle. Encoder-based or resolver-based systems provide direct rotor-position information and are generally suitable for applications requiring reliable low-speed operation. However, these sensors increase system cost, wiring complexity, mechanical installation requirements, and potential maintenance needs. The additional hardware can be undesirable in compact or cost-sensitive drive systems.

Sensorless control attempts to estimate rotor position and speed using electrical measurements and mathematical observers. Depending on the operating range, the estimation process may use back electromotive force, machine-model observers, high-frequency signal injection, or state-estimation algorithms. These techniques can reduce dependence on mechanical position sensors, but their performance depends on motor parameters, measurement quality, and operating conditions. Low-speed operation is particularly challenging because the available electrical information may be insufficient for accurate position estimation.

Wang *et al.* [3] investigated DSP-based sensorless control of interior PMSM drives over a wide speed range. Their strategy combined high-frequency signal injection at low speed with an extended-electromotive-force-based sliding-mode observer at medium and high speeds. The researchers also incorporated a software

phase-locked loop and dead-time compensation to improve position estimation accuracy. Their experimental results demonstrated the feasibility of sensorless operation using a DSP-based drive platform.

Kung *et al.* [4] proposed a sensorless PMSM drive using a microprocessor-based PI speed controller and a dedicated hardware extended kalman filter (EKF) estimator. Their architecture used estimated rotor flux angle and speed information for vector control and closed-loop speed regulation. This approach demonstrates how estimation and control functions can be distributed between digital processing and dedicated hardware. The study is important for embedded-system design because it highlights the computational demands associated with sensorless estimation, although the reported work should be interpreted according to its particular hardware and simulation configuration.

5. ADVANCED SPEED-CONTROL STRATEGIES

Conventional PI control is commonly used in the speed and current loops of PMSM drives because of its relatively simple structure and manageable computational requirements. However, periodic torque disturbances, current measurement errors, inverter dead time, and motor harmonics can affect the quality of speed regulation. These disturbances may become particularly noticeable in low-speed and high-torque applications. Advanced control strategies have therefore been investigated to improve speed smoothness and reduce periodic speed variations.

Xia *et al.*[5] proposed a proportional-integral-resonant (PIR) control strategy for a low-speed, high-torque PMSM drive. Their approach addressed periodic torque ripple by incorporating resonant control into the speed and current regulation structure. Experimental results from a 10-kW setup demonstrated the effectiveness of the method in reducing periodic speed ripple. Although the study is not exclusively a microcontroller implementation paper, its control structure is relevant to embedded PMSM drives because it introduces additional control calculations that must be scheduled within the digital controller.

Model predictive control (MPC) is another approach that can be implemented using digital processing platforms. It evaluates possible switching states or control actions and selects an action based on predicted system behavior and a defined cost function. Formentini *et al.* [6] investigated finite-control-set MPC for a PMSM supplied by a matrix converter. Their work demonstrates the relevance of predictive control to advanced digital motor-drive systems, although implementation complexity and computational timing must be considered when transferring such algorithms to embedded hardware.

The choice between PI, PIR, and predictive control depends on the application requirements and available processing resources. PI control remains attractive for conventional industrial drives because it is comparatively straightforward to tune and implement. PIR control may be beneficial when periodic speed disturbances are a major concern, while MPC offers a systematic way to handle switching decisions and multiple control objectives. Nevertheless, the performance of advanced algorithms must be validated on the intended embedded platform rather than inferred from simulation results alone.

6. COMPARATIVE EVALUATION AND IMPLEMENTATION CHALLENGES

The principal control approaches discussed in this review are compared in Table 1. The comparison considers their basic implementation requirements, strengths, and practical limitations rather than assigning numerical performance rankings. This distinction is necessary because the reviewed publications use different motor ratings, inverter configurations, sampling periods, and experimental procedures. Consequently, their reported results cannot be treated as measurements obtained under identical test conditions.

Table 1. Comparison of PMSM speed-control approaches for embedded implementation

Control approach	Main implementation requirement	Main advantage	Main limitation	Potential application
Sensor-based FOC with PI	Current sensors and encoder/resolver	Established structure and good dynamic response	Sensor cost and installation requirements	Industrial servo drives and machine tools
Sensorless FOC	Current/voltage measurement and rotor-position observer	Reduces mechanical sensor dependence	Estimation accuracy can deteriorate at low speed	Compact industrial drives and electric traction
FOC with EKF estimation	Digital controller and observer computation or dedicated estimator hardware	Provides estimated position and speed for closed-loop control	Computational and model-parameter requirements	Advanced sensorless PMSM drives
FOC with PIR control	Current and speed feedback with resonant control calculation	Can reduce periodic speed ripple	Additional tuning and stability considerations	Low-speed, high-torque drives
Finite-control-set MPC	Fast digital processing and predictive switching evaluation	Supports predictive control of switching actions	Higher computational demand and implementation complexity	Advanced high-performance drives

As shown in Table 1, sensor-based FOC with PI regulation provides a practical starting point for many embedded PMSM applications. Sensorless FOC and EKF-based estimation can reduce mechanical sensor dependence, but they require more sophisticated estimation algorithms. PIR control is relevant when periodic speed ripple is a significant performance concern. Predictive control offers further flexibility, although its computational requirements may restrict implementation on lower-performance microcontrollers.

One of the main implementation challenges is ensuring that all control calculations are completed within the sampling period. Current acquisition, filtering, coordinate transformation, controller execution, and PWM updates must be carefully scheduled to avoid timing overruns. Excessive computational delay can reduce control bandwidth and negatively affect system stability. Hardware timer synchronization, interrupt prioritization, and efficient fixed-point or floating-point programming are therefore important considerations.

Another challenge is the interaction between the digital controller and the inverter. Dead time, switching losses, voltage saturation, current-sensor offsets, and DC-link voltage variations can influence actual motor behavior. The controller should therefore incorporate appropriate compensation and protection mechanisms where necessary. Overcurrent protection, overvoltage protection, thermal monitoring, and safe shutdown procedures are essential for practical industrial deployment.

7. CONCLUSION

This review has examined the implementation of microcontroller-based PMSM speed-control systems, emphasizing embedded FOC, sensor-based operation, sensorless estimation, and advanced control strategies. The reviewed studies show that embedded FOC can provide satisfactory speed and torque regulation when the controller, sensing system, and inverter are appropriately designed. Sensorless techniques can reduce mechanical sensor requirements, although they introduce additional estimation complexity and operating-range limitations. Advanced approaches such as PIR and MPC offer potential improvements for specialized applications but require more careful computational and stability analysis.

The comparison indicates that sensor-based FOC with PI control is a suitable general-purpose solution for many industrial PMSM drives. Sensorless FOC and EKF-based methods are attractive when reducing sensor hardware is important and sufficient processing capability is available. PIR and predictive control should be selected when their specific performance benefits justify their additional implementation effort. Ultimately, successful PMSM speed regulation requires an integrated design that considers control performance, processing capability, sensor quality, inverter behavior, and real-time reliability.

REFERENCES

[1] F. Yusivar, N. Hidayat, R. Gunawan, and A. Halim, "Implementation of field oriented control for permanent magnet synchronous motor," in *Proceedings of 2014 International Conference on Electrical Engineering and Computer Science, ICEECS 2014*, IEEE, Nov. 2014, pp. 359–362. doi: 10.1109/ICEECS.2014.7045278.

[2] X. Zhang, X. Xie, and R. Yao, "Field oriented control for permanent magnet synchronous motor based on DSP experimental platform," in *Proceedings of the 2015 27th Chinese Control and Decision Conference, CCDC 2015*, IEEE, May 2015, pp. 1870–1875. doi: 10.1109/CCDC.2015.7162224.

[3] G. Wang, R. Yang, and D. Xu, "DSP-based control of sensorless IPMSM drives for wide-speed-range operation," *IEEE Transactions on Industrial Electronics*, vol. 60, no. 2, pp. 720–727, Feb. 2013, doi: 10.1109/TIE.2012.2205360.

[4] Y. S. Kung, N. P. Thanh, and M. S. Wang, "Design and simulation of a sensorless permanent magnet synchronous motor drive with microprocessor-based PI controller and dedicated hardware EKF estimator," *Applied Mathematical Modelling*, vol. 39, no. 19, pp. 5816–5827, Oct. 2015, doi: 10.1016/j.apm.2015.02.034.

[5] C. Xia, B. Ji, and Y. Yan, "Smooth speed control for low-speed high-torque permanent-magnet synchronous motor using proportional-integral-resonant controller," *IEEE Transactions on Industrial Electronics*, vol. 62, no. 4, pp. 2123–2134, Apr. 2015, doi: 10.1109/TIE.2014.2354593.

[6] A. Formentini, A. Trentin, M. Marchesoni, P. Zanchetta, and P. Wheeler, "Speed finite control set model predictive control of a PMSM fed by matrix converter," *IEEE Transactions on Industrial Electronics*, vol. 62, no. 11, pp. 6786–6796, Nov. 2015, doi: 10.1109/TIE.2015.2442526.