

High Performance Control of Permanent Magnet Synchronous Motors

By: **S. Vaez-Zadeh**

vaezs@ut.ac.ir

<http://eng.ut.ac.ir/ece/vaez-zadeh>

Tutorial length: 2.5 hours

Abstract: Industry automation is mainly developed around motion control systems in which controlled electric motors play a crucial role as heart of the system. Therefore, the high performance motor control systems contribute, to a great extent, to the desirable performance of automated manufacturing sector by enhancing the production rate and the quality of products. In fact the performance of modern automated systems, defined in terms of swiftness, accuracy, smoothness and efficiency, mainly depends to the motor control strategies. The advancement of control theories, power electronics and microelectronics in connection with new motor designs and materials have contributed largely to the field of electric motor control for high performance systems. Newly developed permanent magnet synchronous (PMS) motors with high energy permanent magnet materials particularly provide fast dynamics, efficient operation and very good compatibility with the applications if they are controlled properly. However, the AC motor control including control of PMS motors is a challenging task due to very fast motor dynamics and highly nonlinear models of the machines. Therefore, a major part of motor control development consists of deriving motor mathematical models in suitable forms. The dynamic models of the motors are presented in this tutorial in different reference frames to lay down a basis for the motor control design. The mathematical formulations and the equivalent circuit models are provided.

There are two competing control strategies for AC motors i.e. vector control (VC) and direct torque control (DTC). These two control strategies when applied to PMS motors are presented in this tutorial based on the developed models. Vector control, as the most used control strategy, is presented first. The decoupling of torque control and flux linkage control under VC is described and the benefits gained are highlighted. The motor phasor diagrams are used to make the presentation easily understandable. The design of linear controllers is presented and the opportunity for nonlinear and intelligent controls is mentioned. The motor control system block diagram is also described, followed by the analysis of motor performance. The motor performance under the control strategy is presented by detailed simulation using Matlab Simulink. Finally DSP implementation of PMS motor control is briefly offered.

Next, the principles of DTC and its main features and requirements are elaborated. The fast response of motors under this control strategy, resulted from the direct selection of inverter voltage vectors, is especially highlighted. The system block diagram and the simulation results are also presented and the performance gains and drawbacks of the strategy are listed. The opportunity for enhancing DTC by using nonlinear and intelligent control methods is mentioned.

The tutorial is aimed to be self contained. The math is used where it is appropriate. However, the most straightforward approaches to motor modeling and control are used to reduce the analytical burden. The tutorial is presented by about 120 power point slides. The participants will receive a copy of the power point file.

Potential Audience:

The tutorial provides an opportunity for control professionals to grasp an overview of high performance electric motor control strategies. Participants should be familiar with the basics of three-phase electric motors and power electronic converters.

Sadegh Vaez-Zadeh, received the B.Sc. degree from Iran University of Science and Technology, in 1985 and the M.Sc. and Ph.D. degrees from Queen's University, Canada, in 1993 and 1997 respectively, all in Electrical Engineering.

He is now a full professor at the school of Electrical and Computer Engineering, University of Tehran and the Director of Advanced Motion Systems Research Laboratory which he founded in 1998. His research interests include DSP based high performance control of rotary and linear electric motors, magnetic levitation and electric vehicles. He has published over 130 research papers.

Dr. Vaez-Zadeh is an Editor of IEEE Transactions on Energy Conversion, a Co-Editor of Journal of Asian Electric Vehicles and a member of editorial boards of two domestic research journals. He has served many international conferences as a member of technical and steering committees, session chair, etc. Prof. Vaez-Zadeh is a senior member of IEEE and a member of IEEE PES Motor Sub-Committee.

Selected Publications:

- S. Vaez-Zadeh, A. Hassanpour Isfahani, "Enhanced Modeling of Linear Permanent Magnet Synchronous Motors," IEEE Trans. on Magnetics, Vol. 43, No. 1, Jan. 2007, pp. 33-39.
- Hassanpour Isfahani, S. Vaez-Zadeh, "Design Optimization of a Linear Permanent Magnet Synchronous Motor for Extra Low Force Pulsations," Energy Conversion and Management, Vol. 48, Jan. 2007, pp. 443-449.
- S. Vaez-Zadeh, A. Payman, "Design and Analysis of Sensorless Torque Optimization for Single Phase Induction Motors," Energy Conversion and Management, Elsevier, Vol. 47, No. 11-12, July 2006, pp. 1464-1477.
- S. Vaez-Zadeh, A. Hassanpour Isfahani, Multi-Objective Design Optimization of Air-Core Linear Permanent Magnet Synchronous Motors for Improved Thrust and Low Magnet Consumption, IEEE Trans. on Magnetics, Vol. 42, No. 3, March 2006, pp. 446-452.
- S. Vaez-Zadeh, A. R. Ghasemi, "Design Optimization of Permanent Magnet Synchronous Motors for High Torque Capability and Low Magnet Volume," Electric Power Systems Research, Elsevier, Vol. 74, 2005, pp. 307-313.
- H. Ghasemi, S. Vaez-Zadeh, "A Very Fast Direct Torque Control for Permanent Magnet Synchronous Motors Start up," Journal of Energy Conversion and Management, Elsevier, Vol. 46/5, 2005 pp. 715-726.
- S. Vaez-Zadeh, F. Hendi, "A Continuous Efficiency Optimization Controller for Induction Motor Drives," Energy Conversion and Management, Elsevier, Vol. 46/5, 2005, pp 701-713.
- J. Habibi, S. Vaez-Zadeh, "Efficiency Optimizing Direct Torque Control of Permanent Magnet Synchronous Machines," Proc. IEEE Power Electronics Specialists Conference, PESC 2005, Recife, Brazil, June 2005, pp. 759-764.
- S. Vaez-Zadeh, M. Zamanian, "Permanent Magnet DC Motor Sliding Mode Control System," International Journal of Engineering, Vol. 16, No. 4, Nov. 2003, Transactions A: Basics, pp. 367-376.
- S. Vaez-Zadeh, G. H. Mazareie, "On-Line Determination of Hysteresis Band Amplitudes in Direct Torque Control of Induction Motor Drives," International Journal of Engineering, Vol. 15, No. 4, Trans. A, Nov. 2002, pp. 329-338.
- S. Vaez-Zadeh, "Variable Flux Control of Permanent Magnet Synchronous Motor Drives for Constant Torque Operation," IEEE Trans. on Power Electronics, Vol. 16, No. 4, July 2001, pp. 527-534.
- S. Vaez-Zadeh, V. I. John, M. A. Rahman, "An On-Line Loss Minimization Controller for Interior Permanent Magnet Motor Drives," IEEE Trans. on Energy Conversion, Dec. 1999, pp. 1435-1440.