Tutorial Title : ELECTRICAL MACHINE PWM LOSS EVALUATION BASICS

by Dr. Alex Ruderman

Tutorial length: 3 hours

Abstract: Modern servo amplifiers and inverters induce additional losses in electrical machines due to Pulse Width Modulation (PWM) voltage control [L1]. Electrical machines / drives community is generally accounting for PWM loss by simply de-rating a machine by ~10-15% or even up to 25% for inverter (vector) duty AC motor operation [L2].

Since understanding Pulse Width Modulation (PWM) loss mechanisms is increasingly important for improving efficiency and for reliable modeling of electrical machines, research is being undertaken on theoretical and experimental approaches to PWM loss characterization. Though a problem of electrical machine PWM loss is known for years, at present there is no accepted PWM loss theory suitable for every day use and recognized by engineers and technicians - no PWM loss mechanism satisfactory engineering explanation, just a lot of myths and misunderstandings instead.

Suggested PWM loss engineering approach assumes that PWM eddy current core loss dominates over additional PWM copper and hysteresis iron losses and comprises theoretical (normalized) PWM loss evaluation and experimental characterization.

Once PWM loss is measured for some operating point [L3], it could be then easily scaled for an arbitrary operating conditions using simple formula.

Impact of switching frequency on machine PWM loss is studied. Theoretical results are shown to be in a good agreement with a published experimental data [L3].

Considered are different types of electrical machines (DC brush, 2- and 3-phase AC machines, switched reluctance motor), converters (two- and multi-level, Vienna unity power factor PWM rectifier) and different DC / AC modulation techniques and switching patterns – constant frequency, classic 3-phase sinusoidal, hysteretic, space vector, random, multi-level etc.

Finally, possible ways for machine PWM loss reduction are examined.

Literature:

L1. A. Boglietti, P. Ferraris, M. Lazzari, and F. Profumo, “Iron losses in magnetic materials with six-step and PWM inverter supply”, IEEE Trans. On Magnetics, v. 27, No. 6, 1991.

L2. T. Haring, “Design of motors for inverter operation”, Energy Efficiency Improvements in Electronic Motors and Drives, P. Bertoldi, A.T. de Almeida, and H. Falkner, Eds., Springer, Berlin, 2000.

L3. M. Sokola, V. Vuckovic, and E. Levi, "Measurement of Iron Losses in PWM Inverter Fed Induction Machines", Proc. of UPEC'95, London, UK, September 1995.

Description of potential audience and any prerequisite knowledge expected from audience:
Motor, drive and system researchers and engineers interested in losses and thermal aspects.
Basic knowledge of electrical machines, power electronics and Pulse Width Modulation.

About the lecturer : Dr. Alex Ruderman is a senior lecturer at the School of Engineering, University Bar Ilan, Israel.

Alex obtained his Honors MS EE from Leningrad Electrical Engineering University (USSR, 1980) and PhD EE from Leningrad Polytechnic (USSR, 1987). His PhD thesis was on multi-circuit rotor synchronous machine analytical transients calculation with an application to a superconducting turbine generator. Alex was an apprentice of the world-renowned electrical machine experts Prof. E. Kazovsky and Prof. V. Dombrovsky.

Having immigrated to Israel (1990), Alex became focused on PWM technologies and electrical machine / power electronics interaction effects. Areas of interest include electrical machinery / drives, sensorless control, high performance digital current loop control; power electronics, power factor correction; electric vehicle; autonomous induction generator with a non-linear (rectifier) load and more.

In 1995-2003 Dr. Ruderman worked for Intel Microprocessor Design Center (Haifa) in the areas of VLSI static timing CAD development, circuit design and testing. Alex put forward some original corporate and VLSI industry wise research ideas and solutions in the field of modeling of signal delay / slew propagation via non-linear CMOS gate and RC-interconnect, power grid resonance passive damping, short-circuit power calculation, and isothermal-on-die shmoo testing methodology. The last project Dr. Ruderman contributed to whilst at Intel was Centrino. He still has deep submicron VLSI design research interests.

Dr. Ruderman's research and teaching style is to make theory transparent and understandable by engineers and technicians and to show basic things understanding developing into practical useful results. His recipes are always ready for immediate efficient application.

In 2005 Dr. Ruderman was on academic PWM loss visits to UK reporting at the University of Sheffield (Prof. David Howe - d.howe@sheffield.ac.uk), UMIST (Prof. Andrew Forsyth - andrew.forsyth@manchester.ac.uk), Liverpool John Moore University (Prof. Emil Levi - e.levi@ljmu.ac.uk), Cranfield University (Dr. Patrick Luk - p.c.k.luk@cranfield.ac.uk, Dr. John Economou - j.t.economou@@cranfield.ac.uk) and to US reporting at University of Wisconsin - Madison (Prof. Bob Lorenz - lorenz@engr.wisc.edu, Prof. Tom Lipo - lipo@engr.wisc.edu) and University of Illinois - Urbana-Champaign (Dr. Patrick Chapman - chapman@ece.uiuc.edu).

General References:

1. Dr. Ali Emadi, Director of Power Electronics and Motor Drives Laboratory, Electrical and Computer Engineering Department, Illinois Institute of Technology - emadi@iit.edu
2. Prof. Dr.-Ing. Ralph Kennel, Chair Electrical Machines and Drives, Wuppertal University, Germany - kennel@ieee.org
3. Prof. Francesco Profumo, Politecnico di Torino, IEEE IAS Industrial Dives Committee Chairman - francesco.profumo@polito.it

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Audio-visual requirements: PC projector for PowerPoint presentation