IECON'08 Tutorial Proposal

1. Tutorial Title

Multilevel Converters Voltage Quality and Motor PWM Loss Time Domain Evaluation

2. Presenter Contact Information

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3. Abstract (Description) – 500 words

During the past 10-15 years, there were many developments in the field of multilevel and matrix converters. Converter topology and modulation strategy selection for practical applications must involve physically meaningful voltage quality evaluation criteria. Multilevel AC converter output voltage frequency domain analysis to obtain voltage Total Harmonic Distortion (THD) requires double Fourier transform application (Holmes D.G. and Lipo T.A. Pulse Width Modulation for Power Converters: Principles and Practice, Hoboken, NJ: John Wiley, 2003). Calculating double Fourier integral and interpreting the results is not easy. For matrix converter, output voltage and input current spectrum analysis requires calculating triple Fourier transform that is practically impossible.

The objective of the Tutorial is to have the participants exposed to such PWM converter output voltage figure of merit as Normalized Ripple Voltage Mean Square (NRVMS), an integral indicator of the modulated voltage "smoothness", that is a viable alternative to THD frequency domain calculation. While NRVMS is about squared voltage THD under the assumption that carrier frequency is much higher than a fundamental one, it may be easily calculated in time domain in a closed form. NRVMS makes it easy to compare in a systematic way numerous converter topologies and modulation strategies.

By definition, ripple voltage has zero mean value on PWM period. NRVMS criterion may be easily calculated in a closed piece-wise analytical form by successively averaging (integrating) squared ripple voltage:
- on PWM period (that will do for DC type PWM);
- on input fundamental period (required for matrix converters only);
- on output fundamental period (for AC PWM).

We provide a closed from NRVMS expression as a function of modulation index for 3, 4, 5, 6 … and an arbitrary number of levels N.

For three-phase (multiphase) converters, level shifted carrier based voltage modulation strategies advantage over phase shifted ones is that they don't compromise NRVMS (obtained for single-phase converters) in high modulation indices region. This fact that was originally observed using frequency domain analysis has a simple intuitive time domain explanation.

For multiphase PWM converters, it is shown that with phase count increase (3, 5, 7, ...) star-connected load phase voltage quality is compromised. This result looks like a kind of unexpected paradoxical one because, according to the engineers' folklore, the higher phase count is always better.

Understanding PWM loss mechanisms is important for improving efficiency and reliable modeling of electrical machines. Though extensive theoretical and experimental PWM loss research has been undertaken, at present there is no electrical machine PWM loss theory and characterization experiment accepted by engineering community.

We show that NRVMS criterion has a physical meaning of (normalized) electrical machine PWM eddy current core loss. Under some realistic assumptions, PWM eddy current core loss is a major electrical machine PWM loss mechanism that is dominating over PWM copper and hysteresis core losses. This way, NRVMS criterion is useful for electrical machine PWM loss practical elaboration.

Suggested practical motor PWM loss evaluation approach is comprised of PWM loss characterization experiment and further scaling PWM loss for different DC bus voltages and modulation indices using simple NRVMS formulas. Possible ways to account for magnetic saturation and saliency impact on motor PWM loss are demonstrated.

It is shown that multilevel converter common-mode voltage (induced shaft voltages - bearings currents) elimination comes at the expense of dramatic (of the order of magnitude) PWM loss increase.

PWM switching frequency impact on motor PWM loss is studied. Theoretical results are in a good agreement with published experimental data. Finally, some practical ways for motor PWM loss reduction are discussed.

4. Presenter Background / Biography

Dr. Alex Ruderman was educated in the former USSR. He obtained his MSc with Honors from Leningrad Electrical Engineering University (1980) and PhD from Leningrad Polytechnic University (1987).

Dr. Ruderman is a chief scientist at ELMO Motion Control and a senior lecturer at Bar Ilan University. His research interests include power converter topologies and voltage modulation strategies; non-linear, adaptive, robust, and artificial intelligence motion control algorithms for cogging, friction, and backlash compensation, automatic tuning / self-commissioning, mechanical resonance suppression etc.

In 2005, Dr. Ruderman was on academic visits to UK (Royal Society funded):
- the Universities of Glasgow, Sheffield, Manchester-UMIST, Liverpool John Moore, Cranfield - UK Defense Academy, and Glasgow; and US:
- the Universities of Wisconsin – Madison, Illinois – Chicago, Illinois – Urbana-Champaign, and Illinois Institute of Technology.

Alex is an international committees' member and a reviewer for several international power electronics and motion control conferences and journals.

Dr. Ruderman's recent Tutorials record:
1. "Electrical Machines PWM Loss Evaluation Basics", 15th Int. Conference on Electrical Drives and Power Electronics EDPE'05, Dubrovnik, Croatia, September 2005.
2. "Electrical Machines PWM Loss Evaluation Basics", 12th Int. Power Electronics and Motion Control Conference EPE-PEMC'06, Portoroz, Slovenia, August 2006.
3. "Multilevel and Matrix Converters Voltage Quality and Motor PWM Loss Evaluation", 38th Power Electronics Specialists Conf. PESC'07, Orlando, FL, June 2007.

5. Intended Audience

Motor, drive, and power electronics researchers and engineers interested in electrical machines and power electronics interaction effects, multilevel and matrix converter topologies and modulation strategies comparative evaluation.

Basic knowledge of electrical machines, power electronics and pulse width modulation is expected.

Relevant topics as listed in the conference call for papers: Power Electronics, Electrical Drives and Machines.