IEEE-PEMC 2018 Tutorial Proposal

1. Title of Tutorial

Time Domain Power Quality Evaluation for Grid-Tied Inverters

2. Abstract

The Tutorial addresses voltage and current Total Harmonic Distortion (THD) calculation for grid-tied inverters with both high frequency PWM and low frequency synchronous switching. On theoretical side, THD is historically being analysed in frequency domain probably due to its frequency domain definition. The author systematically develops voltage and current THD time domain evaluation approach. Such analysis is based on Parseval theorem (Rayleigh energy equality) and requires calculation of voltage and current waveform mean squares. For PWM, this approach originates from the 1988 paper by Prof. H.W. van der Broeck; for synchronous optimal modulation, it was first independently suggested in 1977 papers by Profs. S. Halasz and G. Buja.

For PWM inverters, the analysis uses a realistic asymptotic assumption - large apparent switching-to-fundamental frequencies ratio. For voltage THD, simple closed-form formulas are obtained for single- and three-phase multilevel inverters; for current THD - for single-phase multilevel voltage source inverters with inductance dominated RL-load and in the presence of LCL-filter and for current source inverters with CL-filters. Most recent contribution includes current THD optimization for cascade H-bridge inverter with 4 and more bridges for phase shifted PWM by non-equal DC sources switching sequence (carrier order) selection. This is relevant for distributed generation.

For low frequency synchronous modulation, minimal THD problems are formulated in time domain as constrained optimization ones. The natural generalisations include: combined minimal THD and Selected Harmonic Elimination (SHE) problem formulation that some degrees of freedom are spent on SHE while the rest – on THD minimization; combined minimal THD and Selected Harmonic Mitigation to meet international standards (TDD) with a minimum coupling inductor.

Each subtopic is illustrated by an in-depth analysis of simple representative demo cases. The presentation is self-explanatory intended for an entry / intermediate level audience.

3. Topical Outline (Provisional Schedule)

3.1. Time Domain Evaluation of Voltage and Current THD for PWM Inverters (1 hour)

3.1.1. Voltage THD for Single- and Three(Multi)-Phase Multilevel Inverters (15 min)
3.1.2. Current THD for Single-Phase Multilevel Inverters (15 min)
3.1.3. Current THD in the Presence of LCL-Filters (15 min)
3.1.4. Current THD Optimization by DC Sources Switching Sequence for a Cascade H-Bridge Inverter with Phase Shifted PWM and Non-Equal DC sources. (15 min)

3.2. Time Domain THD Optimization for Low Frequency Synchronous Modulation (Optimized Pulsed Patterns) (2 hours)

3.2.1. Voltage THD Minimization for a Single-Phase Multilevel Inverter with a Staircase Modulation (15 min)
3.2.2. Current THD Minimization for a Single-Phase Multilevel Inverter with a Staircase Modulation (15 min)
3.2.3. Voltage and Current THD Minimization for a Single-Phase Multilevel Inverter with a Staircase Modulation and Non-Uniform Levels Distribution (15 min)
3.2.4. Voltage and Current THD Minimization for a Three-Phase Cascade Inverter with a Staircase Modulation (15 min)
3.2.5. Voltage and Current THD Minimization for a 2-level Single-Phase Inverter with Different Amounts of Switching (15 min)
3.2.6. Voltage and Current THD Minimization for a 2-level Three-Phase Inverter with Different Amounts of Switching (15 min)
3.2.7. Combined Selective Harmonic Elimination and THD Minimization (15 min)
3.2.8. Combined Selective Harmonic Mitigation and THD Minimization to meet grid code requirements with minimal coupling inductance (15 min)

4. Instructor

Dr. Alex Ruderman, Associate Professor
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5. Instructor Bio

Alex Ruderman (M'07, SM'17) was born in Leningrad, USSR, in 1957. He received his M.Sc. degree with Honors from Leningrad Electrical Engineering Institute (1980) and Ph.D. degree from Leningrad Polytechnic Institute (1987) (in electrical and electromechanical engineering respectively).

In 1995-2003, Alex worked for Intel Corporation Microprocessor Development Center (Haifa, Israel) as a research scientist investigating into microprocessors thermal stabilization, fast static timing calculations including cross-talk, power delivery and power minimization related issues. In 2006, he joined Elmo Motion Control, Petach Tikva, Israel, the makers of compact intelligent servo drives, as Chief Scientist (Elmo drives are allegedly used by NASA in Mars Curiosity mission).

Since 2013, Alex is Associate Professor at Nazarbayev University School of Engineering, Electrical and Electronic Engineering Department. He is a Director of Power Electronics Research Laboratory (PERL). Alex is a regular reviewer for IEEE Transactions on Industrial Electronics and Power Electronics and a program / advisory / scientific committee member for several international Power Electronics Conferences. His major research focus is on simple time domain methods applied to analysis of multilevel inverters - he authored more than 50 conference and journal papers on the subject. Alex was a member of IEEE Power Electronics Technical Committee (PETC) (2010-2013) and since 2013 is Associate Editor for the IET Journal of Power Electronics.

6. Instructor Tutorial 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. http://www.ro.feri.uni-mb.si/epe-pemc2006/authors/Tutorial_Ruderman.pdf
3. "Multilevel and Matrix Converters Voltage Quality and Motor PWM Loss Evaluation", 38th Power Electronics Specialists Conference PESC'07, Orlando, FL, June 2007.
4. "Time Averaging Methods for Multilevel PWM Power Converters: Voltage Quality and Flying Capacitors Voltage Balancing Dynamics", IEEE Int. Symposium on Power Electronics ISIE'10, Bari, Italy, July 2010. http://www.isie2010.it/sites/www.isie2010.it/files/Ruderman-ISIE10_Tutorial_Ruderman.pdf
5. "Multilevel Converters Analysis by Time Domain Averaging: Multiphase PWM Voltage Quality and Flying Capacitors Voltage Balancing Dynamics", 8th Int. Conference on Power Electronics – ECCE Asia (ICPE'11), Jeju, Korea, May 2011.
6. "Natural Balancing in Multilevel Converters – What You Always Wanted to Know but Had No Chance to Ask", 17th Int. Conference on Power Electronics and Motion Control (IEEE-PEMC'16), Varna, Bulgaria, September 2016.