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TUTORIAL

Time Averaging Methods for Multilevel PWM Power Converters: Voltage Quality and Flying Capacitors Voltage Balancing Dynamics

Presented by

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Synopsis

AC PWM phenomena are usually analyzed in frequency domain by applying Fourier transformation that involves infinite double series with Bessel function coefficients. This method requires accounting for up to 40-50 switching harmonics that makes it computationally intensive. Therefore, no simple analytical solutions for use in an everyday engineering practice are available.

The tutorial is targeted at drawing power electronics community attention to alternative AC PWM investigation methodology based on time averaging that is more adequate for the problems where detailed spectrum knowledge is not required. The tutorial is based on original unpublished research that originates to mid 1990s. The power of time domain averaging approach is demonstrated for multilevel multiphase PWM converter voltage quality evaluation and Flying Capacitor Converter (FCC) averaged voltage balancing dynamics analysis.

PWM converter voltage quality is evaluated using ripple voltage Normalized Mean Square (NMS) criterion. Ripple voltage NMS is calculated in a closed piece-wise analytical form by successively averaging on a PWM period and on a fundamental AC period. It is asymptotic in the sense that carrier-to-fundamental frequency ratio is supposed infinitely large (fundamental signal assumed constant on a PWM period). Asymptotic ripple voltage NMS solution is obtained for an arbitrary number of levels and any odd phase count. Voltage THD criterion is easily derived from the ripple voltage NMS one.

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Ripple voltage NMS has a physical meaning of (normalized) iron core PWM eddy current loss that is, under some realistic assumptions, a dominating load PWM loss mechanism. PWM common mode voltage elimination by multilevel converter PWM strategy has a penalty of essentially increasing motor PWM loss compared with optimal voltage quality nearest three Space Vector PWM.

FCC is attractive due to its natural voltage balancing property (no capacitor voltage measurement and balancing control effort is required). Though time domain approach based on stitching of analytical solutions for consecutive switching intervals is quite common for switched systems analysis, it has never been applied to FCC voltage balancing dynamics. In conjunction with a small parameter technique, this approach provides simple closed-form solutions. The small parameter assumption means low load ripple current and capacitor ripple voltage that typically holds for practical converters.

Simple closed-form voltage balancing dynamics solutions are obtained for 3-, 4-, 5-, …-level single-leg and H-bridge FCC for DC and AC PWM. They reveal dependences on load parameters, switching frequency, capacitance values, normalized DC voltage command / AC modulation index, and PWM strategy (carrier based lead / lag; phase shifted / modified level shifted). Time domain averaging provides a deep insight into voltage balancing mechanisms and an understanding of the fact that different modulation strategies can provide the optimal voltage quality and essentially differ in voltage balancing properties.

About the Speakers

Alex Ruderman obtained his PhD in electromechanical engineering from Leningrad Polytechnic University (former USSR) in 1987. Alex is currently a chief scientist at ELMO Motion Control Ltd. His research interests include power converter topologies and voltage modulation strategies; non-linear, adaptive, robust control algorithms for cogging, friction, non-sinusoidal back EMF, and backlash compensation, automatic tuning / self-commissioning etc.

Boris Reznikov obtained his MSc from Leningrad Electrical Engineering University (former USSR) in 1974. His research experience includes a study of dielectric properties of bounded water and its molecular behavior, CNC systems for different machine tools etc. Boris is currently a software leader at General Satellite Corp. His research interests include time domain averaging methods for multilevel power converters PWM strategies analysis.

Steven Thielemans obtained his MSc in electrical energy at Ghent University (Belgium) in 2006. Steven is currently working towards his Ph.D. degree in multilevel converters at Ghent University. His principle research interests include topologies and control of electrical power converters; electrical machines, FPGA controllers, energy storage devices, and electric vehicles.