Modulation and Control of Multilevel Converters

by

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Declaration of Originality

The work presented in this thesis is my own work and to the best of my knowledge and belief original, except as acknowledged in the text. The material contained in this thesis has not been submitted, either in whole or in part, for a degree at The University of Queensland or any other University.

Geoff Walker

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Abstract

This thesis aims to extend the body of knowledge about the modulation and control of converters to cover multilevel converters.

A general definition of a (power) converter, and subsequently a multilevel converter, is given based on a unified converter theory. Different converter structures are shown to have common features under this unified set of rules. The most common multilevel topologies found in the published literature are examined and compared. Some other example converters are also developed theoretically from the basic definition and by using the concept of duality.

Starting from the essential requirements, the different approaches to switching power converter modulation are explained and compared. In particular, aspects of modulation which are required or desirable for multilevel converters are discussed. Sine-triangle carrier modulation is identified as the most promising technique to pursue for both technical and pedagogical reasons.

Natural and uniform sampled sine-triangle modulation are examined and contrasted in detail. The modulators' transfer function and spectral properties are examined mathematically, and then confirmed both with simulations and software and hardware implementations. The natural sampling process is shown to have a flat, distortionless transfer function, which uniform sampling cannot achieve. Uniform sampling is invariably implemented digitally, either in software or hardware, with many associated advantages, while natural sampling does not lend itself to a digital implementation. The advantages and short-comings of each technique are

generally exacerbated by multilevel converters. A digital implementation of naturally sampled PWM would seem the perfect solution.

Re-sampled Uniform, a technique for achieving natural like sampling digitally is suggested. The success of this approach is demonstrated as improvements are shown for three implementations, one in software and two in hardware. Some unexpected effects are commented on in the subsequent analysis of the results.

Further improvements to carrier based PWM are possible by randomising the carrier period, and by modulating the zero sequence component in a three phase converter. The carrier period can be varied without causing distortion of the desired modulating waveform. It blurs the sharp spectral harmonic terms associated with the carrier into a continuous spectrum with lower peak amplitudes. The successful technique for generating multilevel random modulation also demonstrates that the separate sub-cycles can be treated as PWM switch periods in their own right. This has significance for space vector modulation, re-sampled uniform, and alternative modulation techniques.

In a three phase converter with no neutral connection, any voltage which is common to all three phases does not cause any current to flow. Such a zero sequence component may be deliberately introduced to increase the maximum possible modulation depth and hence converter utilisation, lower the switching rate, and possibly lower distortion. A number of possible zero sequence components for multilevel modulation are tested using simulations. Only the increase in maximum modulation depth is a significant advantage. The distortion (spectral) benefits are minimal, and discontinuous switching cannot be implemented in some topologies.

These different approaches to improving the modulation of multilevel converters have been applied using sine-triangle PWM. The outcomes of this research can be generalised to other methods of PWM, and also to conventional two-level converters.

Original contributions

This thesis offers a definition of the term "multilevel converter".

It reviews all currently published multilevel converter structures without bias, offering the advantages and disadvantages of each. Additionally, it proposes a number of new multilevel topologies based on the theory of duals.

The many possible pulse width modulation (PWM) strategies are reviewed with particular regard to their comparative suitability for the modulation of a general multilevel converter. Carrier based techniques are shown to be the clear choice for both technical and pedagogical reasons.

Natural and uniform sampled PWM are compared again with a specific focus on their relative suitability for multilevel modulation. The new demands placed on these PWM techniques by the new opportunities opened by multilevel converters are examined. The mathematical expressions for these PWM techniques, extended to describe the multilevel waveforms, are examined at the very low (even fractional) pulse numbers which only become relevant for multilevel converters. The need for a digital implementation of natural sampling is demonstrated.

Three different implementations of this new technique called "resampled uniform" are proposed, simulated, develeped, implemented, measured and analysed. The first is a software technique implemented on a microcontroller. The other two are hardware techniques — one is an EPROM based look up table, and the second is a digital counter / comparator implementation in a large programmable logic device. Their advantageous use for multilevel converters is demonstrated. Their rel-

ative merits are contrasted. Many examples of the flexibility of the EPROM based hardware approach are offered.

The technique for the extention of random modulation to multilevel converters is developed, simulated, implemented, and measured. The digital programmable logic device implementation of resampled uniform is randomised by varying its clock frequency at the beginning of each new cycle. Results are gathered from a low power five level flying capacitor converter, in addition to the logic level based results. These additional results show that the power converter does not cause significant distortion of the logic level signals at the output of the multilevel modulator.

Zero sequence vectors have been applied to conventional three phase converters, but not previously to multilevel converters. Multilevel converters offer new degrees of freedom to the creation of zero sequence vectors. The application of zero sequence vectors to multilevel converters is simulated and the results analysed.

Publications

G. Walker, G. Ledwich, " Bandwidth Considerations for Multilevel Converters" IEEE Transactions on Power Electronics, Vol.14, No.1, pp. 74–81, Jan/Feb 99.

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Contents

List of Figures