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Professor Wojciech Paszke,
Chair of PhD Panel

Dear Professor Wojciech Paszke,

PhD Thesis: Modulation Algorithms of Power Electronic Converters for Shaping of Conducted Interference

PhD Candidate: Hermes Jose Loschi

This PhD thesis describes an investigation into the conducted electromagnetic emissions (EMI) from a DC-to-DC convertor. This is a timely research topic as these devices are proliferating with the increasing use of renewables and energy storage on grids, and are used widely in electric transport applications, and in these applications, they are working close to communication systems. The work specifically aims to determine whether modifications to the modulation strategy can reduce emissions from the device, and to understand how EMC measurements need to be made especially when random modulation is employed.

The thesis provides theoretical background to the investigation – the generation of modulation signals for power convertors and the appropriate standards and typical equipment used for measuring EMI. The thesis then presents a new versatile device developed in the research for creating pulsewidth modulated (PWM) signals for DC-DC convertors base on National Instruments programmable equipment. The algorithms for creating deterministic or random PWM are described and demonstrated.

Chapter 5 presents the equipment used to experimentally evaluate the EMI associated with one and two DC-DC convertors driven by various modulation schemes, and then describes and interprets the results obtained. The final chapter presents the individual chapter summaries and then some directions for future work.

The thesis is presented to the standard expected of PhDs – the structure, use of language and presentation of graphs etc are all very good. There are an appropriate number of references. The research has certainly presented some novel findings with regard to informing the use of random modulation as a mechanism for reducing EMI from DC-DC convertors and this is evidenced by several conference and journal papers published from

this work. However, I have several recommendations which I believe would improve the quality of the thesis presented as a technical document.

On page 12 the candidate briefly mentions the previous use of random PWM as a mechanism for reducing acoustic noise in power electronic systems. They should consider discussing this in more detail: there are definitely similarities in the way random modulation techniques have been developed for the two mitigation requirements, and an interesting result from acoustic noise mitigation is that the approach transforms the perceived noise from a "tone" to a "hiss" which becomes a subjective interpretation by the end user (e.g. age has an influence on hearing range). In a similar way the EMI from the convertor will cause problems dependent on the application being considered and therefore there is probably more discussion of the nature of the victim of the EMI needed to understand the EMI and EMC in this work.

Within the introduction there needs to be a stronger justification for using random modulation and in particular a better justification that it does not require any changes to other parts of the system. There is an argument that the inductors/capacitors designed for a specific (deterministic) switching frequency will be suboptimal when operating with a wider range of switching frequencies. The assumptions made in this work need to be clearly justified – perhaps around page 61.

The author should also mention resonant switching techniques as an approach to EMI reduction, i.e. changing the actual switching characteristics of the DC-DC convertor itself. Whilst these can be expensive, they are also used as an alternative option.

On page 20 the candidate should describe in more detail why windows are normally used as part of the transformation to frequency domain as at present he just states that windows rea required. He should also mention the effect of aliasing for sampled data systems and how this has been eliminated from the experimental work presented here.

On page 31 I would recommend that the candidate provides more detail about the QP measurement – why is it used, what advantages does it provide – as this technique is used for the final results presented in this thesis.

Section 4.2.7 is an important section with regard to the findings of the thesis (deliberately shaping the frequency spectrum) and takes up a significant section of the experimental results. I think that this section could be expanded and improved to include a more detailed discussion of potential applications, and the trade-offs between the advantages and disadvantages of using this approach (e.g. losses, moving EMI to other frequencies etc). This section is quite short and lightweight at the moment.

On page 60 I would suggest that the candidate is not modifying the "control" of the DC-DC convertor. The word control suggests control loops usually associated with feedback and voltage or current control. The techniques described here are focussed on modifying the modulation in the system, not the control.

In Chapter 5 the results focus on measurement of the frequency spectrum of the output voltage using techniques informed by EMI standards. This is not the same as measuring EMI. There is also an argument that the conduced emissions associated with the input current are equally as important as the output voltage as far as EMC is concerned. I am not requesting that the work be repeated with measurements for this parameter, however I do suggest that the candidate better justifies why the work only focusses on the measured output voltage, and maybe some interpretation of findings could be included which discusses what the equivalent findings would be for the input side.

On page 64 "Deadtime" is introduced. This a term which defines the delay between turning off one switch and turning on the second device to prevent a "shoot through" fault and is normally defined as a time (10s of nanoseconds) rather than a percentage. Can the discussion of deadtime be clarified to better reflect this?

Are the DC-DC convertors bespoke, or commercial devices. If they have been designed specifically for this project can the circuit diagram and the PCB layouts be included as an appendix so that the reader can understand the possible EMC pathways.

For the work described on page 65, are the two convertors fed from the same PWM signal? From a later discussion it seems that they are fed from separate FPGAs but the approach should be more clearly described here. You should include in you discussion the potential for a) synchronising the PWM waveforms (i.e. with the same fo and phase) or not having them in phase and b) the ability to have slight changes in fo. These are important to understand any "natural" PWM cancellation with two convertors operating with Deterministic PWM.

On page 65 the justification for measuring or assessing only Vout is weak. This should be strengthened. Also, Fig 5.1 suggests the input is being measured rather than the output whereas the texts says that Vout is being measured. Please clarify.

On page 68 the reference to work with a DC motor is spurious. It detracts from the focus of the chapter (the results of this work) and there are other issues associated with EMC for a DC motor e.g. the action of the commutator.

On page 71 I do not understand how the spectra show that a "voltage variation is more rapid in time". The spectra are static – can the author please clarify what they mean by time dependency in this context.

For all the results can the author add the specific load conditions i.e. input voltage, output voltage and output load/current.

On page 72, Figures such as 5.12 should have a colour scale associated with them.

On page 92, not all readers (including me) will be familiar with "box and whisker" plots. I would recommend that the author add a short description in the text of what these are in general and what they are intended to show in terms of displaying results for presumably multiple measurements.

Notwithstanding these comments I would commend the thesis as a document which meets the standards and expectations for a doctoral degree.

Yours faithfully

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