Skoltech
Skolkovo Institute of Science and Technology

Thesis Changes Log

Name of Candidate: Rahim Samanbakhsh

PhD Program: Engineering Systems

Title of Thesis: Design of Power Converters for Renewable Energy Sources

Supervisor: Prof. Federico Martin Ibanez

The thesis document includes the following changes in answer to the external review process.

Dear Jury Members,

Thank you for your thoughtful and professional comments on my thesis. I have thoroughly studied all of the observations, comments, recommendations, and changes proposed by the jury members. Accordingly, the thesis has been revised to include the suggested improvements.

Reviewer: Prof. Vladimir Terzija,

Comments:

1. References should be given in the Table of Contents.
2. List of symbols should be given in alphabetic order
3. ANPC missing in the list of symbols. Make sure that all abbreviations are included in the list.
4. Typos, e.g. in "However, the input three DC sources should be constant, if the DC voltages are reduces, output voltage will be lower." (should be reduced).
5. Typose, e.g. in "Chapter 2 and 3 These" (should be Chapters).
6. Check the format of Figure 4.10.
7. Chapter 7, Conclusions – disappointingly weak. Short, without proper conclusions, summarizing the work done. More information must be provided.
8. Chapter 7, Future work: "In future works, the combination of multilevel inverter and Z-source converter topologies can be studied." – no justification why this is important is given.

Response: Thank you for the very positive review of my PhD research and constructive comments. All comments are implemented in the PhD thesis file.

Reviewer: Prof. Ramiro Velázquez

In sum, M. Rahim Samanbakhsh has submitted a high-quality research work that presents original contributions, relevant to the field of power converters which demonstrate a mastery of the subject. The cited bibliography is pertinent and shows the wide spectrum of the literature review conducted. The methods used to design, implement, and validate his ideas are scientifically rigorous and show the candidate's skills in power electronics. His work resulted in two operational devices (MLI and ZSI) sufficiently reliable that can be promising to field of grid-connected renewable energy sources connected.

Comments:

1. The Introduction and Conclusion should not be considered as chapters. The structure of the
manuscript should be: Introduction, Chapter I, …, Chapter V, and Conclusion.
2. The Abstract should include the keywords.
3. Page 18: "beats all of them" change to "surpasses them all".
4. All over the thesis: dc and ac (in lower case) are used indistinctly as DC and AC (in capital letter). Please uniform them all in capital letter.
5. Page 53: "to help you choose" change to "to assist designers in choosing the right topology"
6. Fig 4.1. There is a disturbing little text inside the Sine-triangle modulation box.
7. Equation 4.2: vag change to Vag**
8. Page 98: "2-M sin ut" change to: 2-M sin (ut)"
9. Fig 5.1a. Elements are identified as E_n3, S_n5, T_n4, yet the text says: E_3, S_5, T_4. The "n" should not be in the figure.
10. Eq 5.9: the constant value 5.87x10-3 is not explained.
11. Fig 5.12: units missing in the y-axis
12. Check carefully the layout of the final version. Same text font and same line spacing across the document. Figures with their labels right after them (and in the same page).

Response:

Thank you for the very positive review of my PhD thesis and constructive comments. Your affirmative comments on my research give me the confirmation that I am on the right track and encourage me to further investigate the Power Electronics field.

All changes have been implemented according to the comments in the Ph.D. thesis file.

Reviewer: Prof. Henni Ouerdane

Comments:

The main issue is in the writing. I would like to see a better written thesis so that the text would be on par with the scientific achievements. The level of English (vocabulary and grammar) should be improved. Vague statements should be avoided. Some references should be added in the Introduction chapters next to statements that are made and sound like opinions. One should also refrain to copy-paste part of the abstract in the Introduction or Conclusion chapters. The table of content should be completed to include sections and subsection of each chapter. Note that a title to section 4.3 is missing. In the publication list, a proper referencing also indicates the year of publication. The Conclusion chapter can be expanded, notably to explain in some more details the future work that is envisaged. I do not see the point of having Figure 7.1 and 7.2 next to a statement like "In future works, the combination of MLIs and ZSCs topologies should be studied".

Response:

Thank you for the positive review of my PhD thesis and constructive comments. All changes have been implemented according to the comments in the Ph.D. thesis file.

Reviewer: Prof. Pallavee Bhatnagar

I congratulate the Author and the Supervisor for their research work. Both the converters which are proposed by the authors are novel up to my knowledge and the work proposed is well validated experimentally. There are no major comments or issues in the research work and thesis except few minor observations which I have mentioned page wise and chapter wise. I would advise the author to incorporate following suggestions in the thesis.

Thank you for the positive review of my research and for focusing my attention to the important issues related to the fundamental of Power Electronics. Following your comments, I have improved some part of my PhD thesis.

Comments:

1. Abstract is well written with few grammatical mistakes

Response: Thank you! Changed.

2. Page 12 some formatting errors are there

Response: Corrected.

3. Page16_17_Chapter 5 why uppercase is used?

Response: Corrected.

4. Page18_This proposed converter was validated in the lab and the results were published_ Try to rewrite in present tense like: The proposed converter is validated …… (similar corrections are required at many places)

Response: Thank you! Changed.

5. Page 22_Voltage source inverters (VSIs) have been extensively applied in various power electronic applications, including, among others, distributed generations, energy-storage systems, and uninterruptable power supplies (UPS) [3, 4].????? Rewrite this.

Response: Thank you! Changed.
Voltage source inverters (VSIs) have been extensively applied in various power electronic applications, such as distributed generations, energy-storage systems, and uninterruptable power supplies (UPS) [8, 9].

6. Page 23_However, the input three DC sources should be constant, if the DC voltages are reduces, output voltage will be lower. In the Abstract it is written that: The structure has three unequal input sources and ten switches that can generate a 15-level output voltage. Please clarify.

Response: Thank you for your comments.
In the first sentence, “However, the input three DC sources should be constant, if the DC voltages are reduces, output voltage will be lower.” I mean that, it is better not have voltage fluctuation in the inputs (fixed voltage-constant), if we have drop voltage, consequently the output voltage will be decrease.

In the second sentence (Abstract), “The structure has three unequal input sources and ten switches that can generate a 15-level output voltage.” I mean that, for working the topology properly the inputs must be according bellow formula:

$E_2=2*E_1$, $E_3=2*E_2$

which shows that the inputs are not equal.

7. Page 49_ In some cases, a three-level approach is inappropriate, and a five level inverter produces better results. As a result, a four-level inverter is the most inappropriate approach. Clarify.

Response: Thank you! Changed.
In some scenarios, a three-level method would be inadequate; however, a five-level inverter would result in component complexity. Therefore, a four-level inverter is the most optimal approach.

8. Chapter 2 is well written except that there is no 15 level topology reviewed although literature is available on 15 level inverters also. Since the proposed topology is on 15 levels it is appreciated to involve some review on 15 levels inverter also.
And
9. Chapter 2_ in the comparison presented in this chapter no comparison at a level of 15 is made

Response: Thank you for the nice comments.

In fact, you are right and I agree with you, however, I present the 15 levels of converters in the chapter 4(new arranged) of the thesis (Chapter of Proposed Multilevel).

10. Page_57_That is, a currency converter cannot be used instead of a voltage converter, and vice versa. ???? Correct this.

Response: Thank you! Corrected.

11. Page_59_In the following, this section discusses the impedance source (abbreviated as Z-source) converters introduced in the last few years. ???? Rewrite.

Response: Thank you for the correction.
The following section discusses recent developments in impedance source converters (abbreviated as Z-source).

12. Page 69_71_..... Figure 3.12: Trans Quasi Z-Source Inverter, Figure 3.13: General topology of Improved Trans Z-Source Inverter [20]……_ should draw these figures instead of copying it.

Response: Thank you for the comment. All mentioned figures, are changed.

13. Chapter 3 is rest fine

Response: Thank you for the opinion.

14. Page_82_PWM makes simpler to control the output voltage than other methods and does not require any extra par_ rewrite.

Response: Thank you! Corrected.
PWM simplifies output voltage control rather than other methods and does not require any additional parts.

15. Page_85_"Here are some basic descriptions for reference when explaining the modulation scheme. Initially, the duty cycle is demarcated by changing and scaling the commanded voltage, considering multiple voltage levels. The adjusted duty cycles are-" Can't understand what is conveyed. Please explain.

Response: Thank you! Simplified.
In order to describe the modulation methods, some fundamental definitions will be presented. A duty cycle is defined by scaling the commanded voltages with modifications to account for multiple voltage levels. The formula of duty cycles:

16. Page90-91-92_.....98_ 4.2.1.2 Space vector modulation_..... figures and equations are mostly copied, either rewrite and redraw or cite them.

Response: Thank you! Corrected.
The references are inserted.

17. Page_123_ There is a difference in the efficiency theoretically calculated and simulated value. Calculations and comparisons in section 5.5 and 5.6 are done for different parameters??

Response: Thank you for your close attention. As you mentioned, they are for different parameters.

18. Page 123-124 There is a difference in the peak value of voltage in the simulation results in Fig.5.7: 84 volts shown and rms value choosen Vorms =56V (Peak= 56√2) Clarify.

Response: Actually, it was mistype. Thank you very much for identifying it. Corrected.
Vo_{rms}=59V

19. Page_127_Rewrite equation 5.19. (It is copied) Style and font must be same. Also on the same page somewhere it is written E1 somewhere E1

Response: Thank you! Corrected.

20. Page_131_Table 5.4 Comparison of several cascaded multilevel topologies (Nl= Number of levels) while at all other places in the table NL is written???

Response: Thank you! Corrected.

21. Page_132_Table IV includes the conventional cascaded H-bridge converter (CHB), multilevel DC links (NCML) [9], Table IV???

Response: Thank you! Corrected. Table IV is Table 4.4.

22. Page_135_Table 4.5 shows a comparison of several multilevel topologies. It can be seen that the proposed topology offers better characteristics than the other structures. Table 4.5 is wrongly written.

Response: Thank you for the comments. As I thought that, the conditions for topologies are not same, so we cannot decide which one in better. I changed the passage according bellow:
Table 4.5 shows a comparison of several multilevel topologies. It can be seen that the proposed topology has reasonable characteristics. However, to have more accurate comparison needs to consider same conditions (Inputs, components, and control methods) for all topologies.

23. Page_134_Figure 5.10 Comparative studies: The number of (a) DC links, (b) switches, and (c) TSV in terms of the number of levels. It is well explained.

Response: Thank you for the thoughtful comments.

24. Page-135_Table VI lists the converter's main components. Where is table VI? Please correct it.
Response: Thank you! Corrected. Table VI is Table 4.6.

25. Page_137_Figure 5.11 Hardware to create multiple DC sources (a) Multi tap transformer, (b) DC/DC converters [19], [28], (c) Prototype of the proposed structure. This experimental setup is highly confusing. Kindly clarify: from where you are taking main DC supply? Are you converting ac into dc using multi-winding transformers and then converting them into dc using ac to dc converters? Or you are using power supply as shown in figure 5.11 c to generate 12, 24 and 48 volts. Please explain. As in the figure both the configurations are seen. Please explain different parts in figure c as you have explained in figure 6.16.

Response: Thank you for the thoughtful comments.
In the proposed converter, it is the important to consider isolated inputs. In this case, it works properly. I used power supply, which has isolated inputs.

Description for Figure 4.11.c:

Figure 4.11.c shows the prototype, and Table 4.6 lists the converter's main components. The prototype has three parts: the first one is the control part, which is based on the AtmelSAM3X8E ARM Cortex-M3 microcontroller. In this controller, Table 4.1 is used for programming and generating the signals to trigger the switches in order to obtain a sine wave in the output. The second part is the driver stage, which includes isolation and negative bias. The last part is the power section, containing the proposed structure to convert DC voltage sources to AC voltage on the load. This part needs isolated DC inputs.

26. Chapter-6 is well written and well explained; the proposed topology is well explained and validated experimentally.

Response: Thank you for the decent comments.

27. Plagiarism report can also be included (not mandatory)?
Response: Thank you for your comment.
The education team checked the plagiarism report before submitting it to the jury members.

Reviewer: Prof. Elena Gryazina
Thank you for the very positive review of my PhD research and comments.

1- p. 130 Description of the Algorithms is not strict enough. Algorithm usually has the set of inputs (and initials values for input variables, if necessary), outputs and the set of steps through which needed to obtain the values for output variables.

Response: Thank you for your close attention and comment.
As you mentioned Algorithms is not strict enough, however we have one important limitation from load side, which is load-working voltage. According this voltage can be find the maximum output voltage of converter, then the value of input voltages can be find.

2- In the Thesis you emphasize the applicability of the proposed inverter for industrial loads. What do you mean by that and what's the difference between industrial and non-industrial (I assume, residential?) load?

Response: Thank you for your comment and questions.
In industrial loads, the total harmonic distortion (THD) is high and the load is highly inductive (L>>R, Power factor= Cos (Φ) <1). However in non-industrial load, the THD is low and the load is highly resistive(R>>L, Power factor=Cos (Φ) ≈1).

Reviewer: Prof. Petr Vorobev

1. Specific need for 3 DC sources for the multilayer inverter: what would be the power distribution between them, and how this affects the harmonics?

Response: Thank you for your comment and questions.
To measure power distribution, needs to find duration of switching pattern. In below the figures shows the voltage and current for the proposed topology.

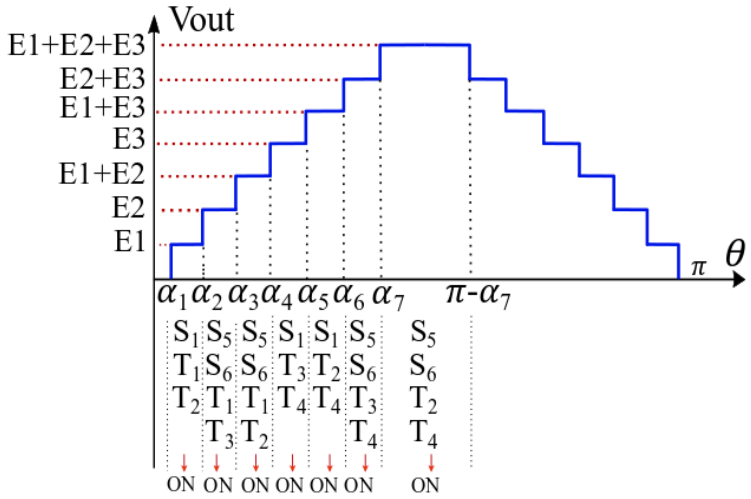

Figure 4.1 Switching pattern

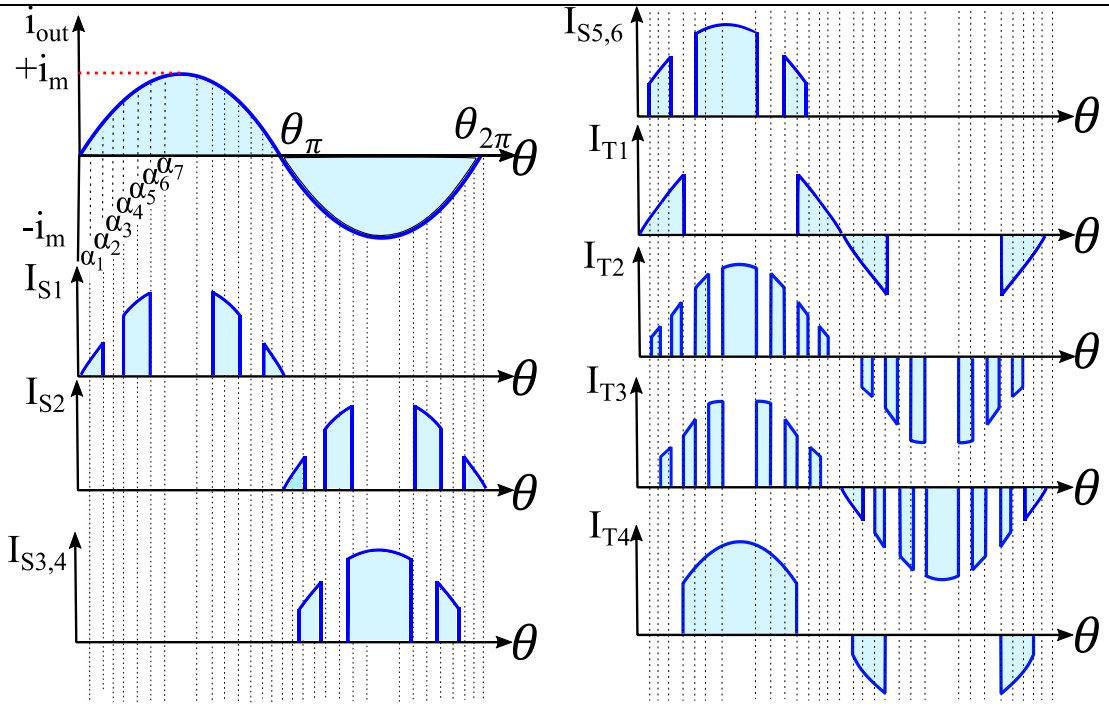

Figure 4.3. Current waveforms through the switches.

Now we have voltage and current of inputs, therefore can be calculate the power of each inputs:

$$P_{E1} = \frac{1}{T}\int_0^{t_{on1}} v_{(t)1} i_{(t)1}\, dt \qquad (1)$$

$$P_{E2} = \frac{1}{T}\int_0^{t_{on2}} v_{(t)2} i_{(t)2}\, dt \qquad (2)$$

$$P_{E3} = \frac{1}{T}\int_0^{t_{on3}} v_{(t)3} i_{(t)3}\, dt \qquad (3)$$

According to Figures (4.1, and 4.3), the area of current and voltage are not the same for each input, therefore can be concluded that the power distributions are not symmetric. However, as the inputs are isolated, it does not have an effect on output voltage harmonics.

2. PV voltage can change quite rapidly and in a big range. Are you supposed to quickly regulate the DC-DC converter step-up ratio to keep all three DC inputs to your converter constant? Must then these converters to have large range of step-up coefficients?

Response: Thank you for your close attention and questions.

In multilevel inverters, it is important to keep the voltage in constant value. However if we have fluctuation in voltage it is essential to have extra stage to compensate the voltage. In future work of this thesis I proposed the connection of Multilevel and Z-source. Also, I run the simulation for connection of both converter. Figure 6.2 illustrate the simulation results for the combination of both converters. In this figure, can be seen that the drop voltage is applied for E1 (40V to 5V) which is one of the inputs for the multilevel inverter, so, due to that the output voltage of the multilevel inverter is reduced from 256V to 234V. To compensate for the drop voltage, the proposed Z-source converter increased its output voltage from 58V to 91V to fix the total output voltage (VTout=VMout+VZout) at 311V.

As you mentioned it is important to have large boost gain to compensate the drop voltage.

3. How do the switching losses for your proposed multilayer compare with classical inverters?

Response: Thank you for your question.
In multilevel inverters, the switching losses are very low compared to classical inverters, which is why recent advance converters (Multilevel converters) are emerge. Because is works in low switching frequency.

4. For the multilayer converter, what kind of switches are needed? How many quadrants you need for the operation?

Response: Thank you for your questions.
To select the switches, it is important to consider the voltage, current and frequency. In my topology, I used IGBT (FGH40N60SFDTU). The switches work in two quadrants.

5. For nearest level control technique, are there any drawbacks?

Response: Thank you for your question.

The disadvantage of NLC techniques become apparent, with low quality output voltages and currents resulting in high total harmonic distortion.

6. In formulas 6.25 and 6.26 is D a constant, of it depends on the operation?

Response: Thank you for your question.

D is depend on the operation, I mean it directly depend on boost factor gain.

I would like to thank the members of the PhD jury for their useful comments, corrections and suggestions.

Best Regards
Rahim Samanbakhsh