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Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Rahim Samanbakhsh

PhD Program: Engineering Systems

Title of Thesis: Design of power converters for renewable energy sources

Supervisor: Assistant Professor Federico Martin Ibanez, Skoltech

Name of the Reviewer: Professor Ramiro Velázquez

I confirm the absence of any conflict of interest	**Date: 24-10-2022**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.

If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.

Reviewer's Report

Reviewers report should contain the following items:

- Brief evaluation of the thesis quality and overall structure of the dissertation.
- The relevance of the topic of dissertation work to its actual content
- The relevance of the methods used in the dissertation
- The scientific significance of the results obtained and their compliance with the international level and current state of the art
- The relevance of the obtained results to applications (if applicable)
- The quality of publications

The summary of issues to be addressed before/during the thesis defense

The PhD dissertation proposed by M. Rahim Samanbakhsh concerns the engineering sciences (power electronics and electronic systems design) applied to the design of converters that could lead to a more efficient utilization of renewable energy sources.

The manuscript is well written, it is easy to understand, and pleasant to read. It is organized into five chapters, preceded by an Introduction and followed by a Conclusion. *A list of keywords is advisable to identify the main topics and elements.*

The main goal of the research conducted by M. Samanbakhsh is to design improved ways to transfer energy from renewable sources (such as photovoltaic panels and wind turbines) into the grid. For this purpose, two concepts of power converters were explored: a 15-level inverter and a Z-source converter. Both were designed, prototyped, and validated experimentally.

The Introduction presents the general context of renewable sources and their pertinence in the world economy. The discussion focuses on grid-connected renewable sources highlighting the value of power converters. Two configurations are further discussed: Multilevel inverters (MLI) and Voltage source inverters (VSI). Their advantages and drawbacks are introduced which serve as framework of the research directions of this work. The thesis outline closes this section. *The Introduction should not be considered as a Chapter.*

Chapter II presents a comprehensive literature review of MLI. Here, M. Samanbakhsh recalls their main purpose (generate a sinusoidal voltage from multiple voltage levels) and a key feature: the greater the number of levels, the less the harmonic distortion in the resulting sinusoidal waveform. Several MLI topologies are detailed: NPC, flying capacitor, cascade H-bridge, asymmetric cascade H-bridge, asymmetric Hybrid MLI, and ANPC. The chapter concludes with a very helpful and pedagogical comparison among topologies. *This Chapter should be Chapter I.*

In turn, Chapter III reviews the literature addressing Impedance or Voltage source converts. Their main purpose (voltage increase) is discussed together with their challenges (cost, reduced efficiency, and waveform distortion). M. Samanbakhsh reviews several topologies: VSC, CSC, ZSC, ZSI, qZSI, I-ZSI, SL-ZSI, SL-qZSI, among others. Similarly, the chapter concludes summarizing the key features of such topologies in a comparative table which allows to analyze them in a practical way. *This Chapter should be Chapter II.*

Chapter IV reviews the control of power converters. The discussion pertinently narrows the problem to a switching problem (on/off). Although simple, this control mode induces both undesired efficacy and power loss. M. Samanbakhsh focuses his attention on PWM methods to reduce low-order harmonics. First, for MLI, two voltage-source techniques are detailed: sine-triangle and space vector modulation. Second, for Z-source inverters, modulation techniques are classified in five categories each with its own subcategories. *This Chapter should be Chapter III.*

Chapter V introduces the MLI proposal. M. Samanbakhsh conceived a basic unit involving three DC sources and ten switches that produce a 15-level sinusoidal output. Its operation principle is clearly described. The power loss effect is carefully examined through conduction and switching losses. Simulation results show that the MLI produces an outputs waveform with very low distortion and that upon the use of PWM-based nearest level control (NLC), it is possible to minimize power losses. The chapter further examines the performance of such basic unit in a cascade structure and compares it with others available in the literature. Results shows that the proposal offers better characteristics than other previously reported. A prototype was implemented, and simulation results were experimentally validated showing the feasibility of the design. *This Chapter should be Chapter IV.*

Chapter VI presents the Z-source converter proposal based on switched networks (SN-ZSI). Its structure is simple: four capacitors, four inductors, and five diodes. It offers a higher modulation index (M) and a lower duty cycle (D) compared to other topologies (such as qZSIs, cascaded ZSIs, and SC/SL-ZSIs) while achieving high voltage boost factors with lower voltage stress across the switches. As with the MLI, power loss was carefully examined by each component (capacitor, inductor, and diode) and the overall efficiency was determined and found higher than most of the topologies considered. Both simulation and experimental results confirm the advantages offered by the proposal. *This Chapter should be Chapter V.*

The Conclusion and future work section resumes the description of the contributions formulated by M. Samanbakhsh and underlines some possible extensions of his research work. *The Conclusion should not be considered as a Chapter.*

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.

On the other hand, the research work has been reported in five journal publications and three conference papers. All five journals are Q1 and Q2 WoS/Scopus indexed (top journals) while conferences paper are part of the proceedings of IEEE high visibility conferences.

For the above reasons, I give a very favorable opinion to M. Rahim Samanbakhsh to present his work by means of a formal thesis defense to obtain the PhD degree of Skolkovo Institute of Technology.

Ramiro Velázquez

Professor, Universidad Panamericana

Summary of suggested modifications:

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 V_{ag}*

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).

Provisional Recommendation

☒ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*

☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate’s thesis according to the recommendations of the present report*

☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*