UNIVERSIDAD
SAN SEBASTIAN
VOCACIÓN POR LA EXCELENCIA

EVALUATION

of the PhD Thesis

"Control of a Hybrid Transformer to Improve the Power Quality in a Distribution Network."

Presented by **Mr. Alvaro Carreno**

To the Warsaw University of Technology, Poland

and to Universidad Técnica Federico Santa María, Chile.

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1. The problem to be solved and the motivation.

This thesis is dedicated to study a circuit of Hybrid Distribution Transformer in which a series converter is connected to the medium voltage side through a current transformer. At the low voltage side, a parallel converter is connected. In addition to proposing the topology, the candidate develops the algorithms to control the operation of this modern transformer with high integration of power converters.

The problem selected by the candidate is important, timely and of high scientific and industrial interest. In effect, in the last years, the scientific community has observed an important increase in the study of these called "intelligent transformers" and this trend will continue with the development of microgrids with high penetration of renewable energies.

2. The references.

The literature review is very complete, considering journal and conference papers related to different aspects of the thesis. Unfortunately, the candidate does not give the year of publication of all journal papers, making it more difficult to see in the paper is recent or not. This is very unfortunate.

3. Content of the thesis.

Chapter 1. Introduction.

In this chapter, the candidate presents the main characteristics of a modern distribution grid with high penetration of renewable energy and the problem to be studied. Here, he presents the concept of solid-state transformer and introduces the main characteristics of the hybrid distribution transformer, which is the subject of the thesis. He reviews different configurations for hybrid distribution transformers.
The candidate describes the contributions of his thesis. I will comment them in the study of each chapter. Finally, in the introduction he presents the papers published in his thesis.

Chapter 2. Model of the Hybrid Distribution Transformer.

In this chapter, the candidate presents the mathematical models he uses to describe the behavior of the transformer for three and four wire systems. He uses a state-space representation in gamma coordinates. He obtains the Bode diagrams for control purposes. The equations are presented in a very clear way. The analysis is easy to understand.

Chapter 3. Balanced Operation and Stability of the HDT.

This chapter presents the control strategy of the hybrid transformer in the dq frame of reference, operating under balanced conditions, also considering the stability of the control system. This chapter also studies the stability of the hybrid transformer. Experimental results are also provided, which validate the proper operation of the transformer.

Chapter 4. Circulating Active Power Flow (CAPF) Analysis and Efficiency of the HDT.

Circulating Active Power Flow (CAPF) presents and additional load to the power converters and in principle reduces the efficiency of the whole system. This chapter presents two strategies to reduce the CAPF: injecting reactive power and integrating a Battery Energy Storage System. In this chapter, the candidate includes the study of unbalanced operation. The theoretical studies presented in this chapter are validated by experimental results.

Chapter 5. Control of the HDT to Improve Power Quality.

This chapter proposes a strategy to improve the power quality of the distribution grid due to the action of the HDT. The strategy uses a discrete-time state feedback controller, considering estimators for the load current and grid voltage. The theoretical analysis is validated with simulation and experimental results. The results confirm that the HDT improves the power quality: voltage sags, voltage swells, power factor and current and voltage distortion.

Chapter 6. Proof of Concept: Flux regulation.

This chapter presents a strategy to keep the flux of the low frequency transformer below a certain value, to avoid saturation of the core and the circulation of inrush currents. This is achieved by controlling the voltage injected by the series converter. In this way, the transformer operates in the rated BH curve, avoiding saturation. Simulation results demonstrate that the flux can be controlled effectively.

Chapter 7. Conclusions.

In this chapter, the candidate summarizes the conclusions achieved in each of the chapters of his thesis. The main conclusion of the candidate is that the topology and the control strategy he proposed can improve the power quality of the grid and of the load, as well as improving the operating conditions of the low frequency transformer.

In addition, in this point, the candidate mentions the original contributions of his thesis.

Finally, the candidate presents the future work that should be developed to continue this research work.

4. Comments and questions to the candidate.

The candidate does not give the year and month of publication of all the journal papers he includes in the references. This is the first time that I face this situation. To see if the reference is recent, I am forced to go to full paper or to the journal, to see the year of publication. This is unfortunate and for this reason I had to invest much more time in the revision. I will appreciate that the candidate explains me why he selected this form to present the references.

Explain the difference between Solid State Transformers and Hybrid Distribution Transformers (see Fig.1.1, page 4).

In Fig. 1.9 of page 20, you say that the Hybrid Distribution Transformer "can provide virtual inertia". Can you comment how it is done?

In Fig. 1.10 page 23, you present a very interesting review of different topologies for HDT. Why did you select the topology studied in your thesis?

Please, comment on the cost of the HDT in comparison to the classical low frequency transformer.

In page 51 you mention PLL, which is not included in the list of acronyms. I assume that it phase locked loop. Is this correct?

In page 70 you mention that due to the series and parallel connection of converters, the HDT resembles a Unified Power Quality Controller (UPQC). Can you explain the differences?

Page 72. In chapter 4 you present two methods to reduce the Circulating Active Power Flow (CAPF): i) injecting reactive power for voltage control and ii) integrating a Battery Energy Storage System (BESS). How did you have the idea of the second strategy? What is the rationality behind?

Page 107. Can you comment on the efficiency of the HDT in comparison with the efficiency of the low frequency transformer?

Page 122. Please, comment on the observer you used for the capacitor voltage. How difficult was to implement the LQR algorithm (Linear Quadratic Regulator).

Can you comment on the industrial application of HDT´s? How much are they used today?

5. Evaluation of the Thesis.

The research work developed in this thesis has a high degree of difficulty and is suitable for a PhD thesis. In addition, the research topic is timely and of high interest for industry.

The theoretical analysis is clear and presented in a logic order. The figures with the block diagrams and the circuits contribute to understand the strategies. The results are presented in a very clear form.

The studies and conclusions are supported by experimental validation in a laboratory setup, what is very important in this kind of research.

The thesis has a high degree of originality and presents a contribution to existing knowledge.

As a result of this PhD thesis, the candidate has published 3 papers in high quality journals, directly related to this research topic. In addition, he published 5 papers in very good conferences. In all these papers he is the first author. This means that different parts of his work have been evaluated by peers at the highest level.

My final assessment is to recommend the approval of this thesis and allow Mr. **Alvaro Carreno** to have his public defense.

Prof. Dr.-Ing. Jose Rodriguez
Universidad San Sebastian

Santiago, July 2024.