

REVIEW

on the thesis "Energy Router for Hybrid Microgrids for efficient and robust energy and power management" of Mohammadreza Azizi, submitted for the degree of Doctor of Philosophy in specialty 141 "Electrical power engineering, electrical engineering and electromechanics"

1. Relevance of the chosen topic of the dissertation research

The increasing distribution of renewable energy sources and development of zero-emission building (ZEB) concepts move towards AC/DC or hybrid power supply systems. In this context, hybrid AC/DC microgrids and low-voltage DC subsystems are viewed as a main direction to improve efficiency and resilience of the future buildings. Such conceptual movement from the passive AC consumption to fully (or partially) controllable hybrid structures requires a new considerations and development in both theoretical and technical fields. In the concept of hybridization, the development of interface converters between dc buildings and ac grids is one of the important and critical tasks.

Therefore, the topic of this thesis is timely and valuable, and can be viewed as important research direction in the field of distributed energy resources. A solution for an inverter that acts as an energy router and allows to connect both AC and DC elements corresponds to the current state of the art and definitely justifies the topic selected.

2. Assessment of the validity and reliability of scientific propositions, conclusions and recommendations

The main scientific and technical results are grounded on application of modern and classical research methods such as: theoretical electrotechnics, analytical modeling and design of the switching power converter systems; flatness-based control, time-domain simulation studies and laboratory experimental testing using a laboratory prototypes. The author uses the simulation platforms MATLAB/ PSIM/

PLECS for modeling and control verification; Altium and embedded development environments for laboratory prototypes implementation.

The main proposals, treatments of the thesis are well justified, clearly presented and validated from the theoretical point of view as well as supported by the simulation and experimental results. All results obtained by both simulation and experimental tests are convincing and, in general prove, the critical assumptions formulated in the document. The basic evidence base looks as adequate for such kind of research, all-important conclusions are logically followed from the presented results.

3. Structure and content of the thesis

In general, this thesis is well written and organized, and consists of: Introduction, Five technical chapters, Conclusions, References, and Appendix. The manuscript comprises 149 pages and includes 57 figures, 13 tables, and a bibliography of 169 references.

Chapter 1 presents an analytic review of power-electronics solutions relevant to PV-integrated residential buildings and motivates ER technology as a flexible interface among PV, storage, DC loads, and the AC grid.

Chapter 2 provides a comprehensive discussion of DC integration challenges, with emphasis on known problems, such as: protection, leakage current mechanisms, and grounding configurations at the AC/DC interconnection point.

Chapter 3 proposes the single-cell three-phase ER based on a common-ground inverter, including schematic design, passive elements selection and embedded solid-state circuit breaker.

Chapter 4 develops the control architecture across the levels and propose a flatness-based control approach for low-level control loops, with discussion of PR control as an alternative for grid-current harmonic mitigation, and discussion of possible high-level EMS concepts is given.

Chapter 5 presents simulation and experimental results for DC mode, grid-forming and grid-following operation, and tests under dynamic conditions.

Reviewed thesis is written using scientific language, the presentation line is clear with good use of references, figures and scientifically correct terminology.

4. Scientific novelty of the obtained results

The scientific novelty of the thesis results can be formulated as follows:

1. The concept, topology and control of inverter for hybrid AC-DC microgrids, acting as energy router have been developed in this thesis. ER topology is based on a Single-Cell Three-Phase concept is proposed as interlink solution between a residential DC distribution grid and a three-phase AC grid, with the objective of mitigating phase imbalance without a full three-cell conversion stage.
2. A novel non-isolated common-ground structure is developed for AC and DC sides, safety and leakage currents are analyzed for this configuration.
3. Cascaded two loops control system is constructed using concept of flatness control in order to improve the dynamics of the ER during transients.

5. Theoretical and practical significance of the results of the dissertation research

Results of the dissertation research provides the theoretical background for design, investigation and practical implementation of the energy routers for hybrid AC/DC systems of different configuration. Some of the proposed solutions in the field of protection, correct grounding and leakage currents have much more wide significance including application for DC power supply systems.

The thesis outcomes are relevant for researchers and engineers working on residential hybrid microgrids, building-integrated LVDC, and converter-based grid interfacing.

6. Completeness of the dissemination (publications)

The results of this PhD thesis have been sufficiently presented for scientific audience: in four international IEEE conference papers, and three articles in journals indexed in Q2 Scopus. Level of publications is sufficient to proof the applicant's qualification. The presented material of the publications is consistent with the scope of the dissertation. These publications sufficiently guarantee a reviewed

quality of the thesis contents and meet formal requirements of the doctorate programs.

7. Academic integrity.

No violations of academic integrity or plagiarism suspicions are found in this work. Based on the presented manuscript, the reference to other works published in literature are clearly cited and correctly stated.

8. Remarks, Limitations, and Critical Comments.

After intensive study of the thesis manuscript this reviewer has some comments and suggestions:

1. The solution claims "Single-Cell Three-Phase," but since the device cannot exchange power with all three phases simultaneously, this might cause instantaneous unbalance even if the average balance is improved. The candidate should discuss the limitations of this approach compared to a true three-phase converter, specifically regarding neutral current stress.
2. Presentation of the FBC (as it is given) for schematic diagram Fig.4.3 and mathematical model (4.9)-(4.11) does not seem enough transparent.
3. The paper uses FBC for the DC voltage loop but retains a PR controller for the current loop. Since the mathematical model for the LCL filter is well-known, why not apply FBC to the current loop as well to achieve a fully nonlinear control structure? Would this further improve THD under distorted grid voltages?
4. Well known that as all power-based controller, selected FBC relies heavily on the system model. In real-world scenarios, DC-link capacitance can degrade over time, and load resistance is unknown or time-varying. How robust is the controller against parameter mismatches?
5. While FBC application is interested, have you consider other model-based control like Model Predictive or Deadbeat control?

These comments can be considered more as suggestions for future research activity of the candidate. They don't have any significant impact on general highly positive evaluation of the presented thesis.

9. Final Evaluation and Assessment of the Thesis

The dissertation of the Mohammadreza Azizi presents complete and coherent scientific work that addresses an important and timely topic in power electronics and hybrid AC/DC microgrids. The author demonstrates solid theoretical knowledge, appropriate research methodology, and the ability to implement and experimentally validate the theoretical findings. The dissertation results have scientific novelty, practically relevant, and sufficiently disseminated. They correspond to specialty, 141 "Electrical Power Engineering, Electrical Engineering and Electromechanics", provide reliable and valuable contribution to field of power electronics.

As result, I conclude that the thesis: meets the established requirements for a Doctor of Philosophy dissertation in specialty 141 "Electrical Power Engineering, Electrical Engineering and Electromechanics", comply with national regulations and institutional rules and therefore I recommend that Mohammadreza Azizi be awarded the degree of Doctor of Philosophy.

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