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Report on the PhD thesis of Katarzyna Zielińska entitled
"Island operation of interleaved converters supported by kinetic energy storage"

1. Introduction

The presented Doctoral Thesis of Katarzyna Zielińska is devoted to stand-alone (off-grid) operation of microgrid. Such systems have important social benefits because still there are many people all over the world living without access to the electric grid. For these people, stand-alone installations have become a viable solution for creating small scale or large scale hybrid systems with energy storage and gas/diesel generators as part of bigger islanded microgrids. This issue is becoming more attractive for research and deployment toward transforming to smart grid and solving the problems of rural areas.

This topic - stimulated mainly by expansion of renewable energy sources, smart grids and modern control - is currently very popular in power electronics. Development of grid stand-alone (called also *island*) operation especially during fault conditions is not easy scientific task and it has been recently intensively investigated by some universities. In spite of some papers published on the topic, the field is still open, because there is no easy to use solution for tripping the overcurrent protections during a short circuit in a stand-alone microgrid, which is very important from safety and reliability point of view. Therefore, the fact that the Authoress has properly selected this interesting topic should be considered in her favour. Moreover, Katarzyna Zielińska introduced contribution in stand-alone microgrids by development of interleaved converters operation at reduced circulating current among converters and method for safe tripping the overcurrent protections during a short circuit in stand-alone microgrid, which are results of her research experience and theoretical background.

2. Contents of the Thesis

The thesis under discussion is well written as well as nomenclature used by the Authoress is correct. The considered topics are covered by theory, simulation and experimental results. The 93 pages of the thesis are organised into eight chapters and bibliography. Chapter 1 is an *"Introduction"* with background, motivation, goals and scope of the thesis. Chapter 2 *"Approaching the research problems"* is general review of stand-alone operation detection, description of chosen control method of parallel operating grid converters and presentation of chosen synchronisation method of converter connected to grid. Next chapter 3 *"Application of interleaved converters during island operation"* describe effect of modulation interleaving of parallel operating converters and gives theoretical background of this phenomenon. Moreover same chapter shows methods, which limiting circulating current among converters, which is effect of modulation interleaving and converters parameter mismatches. Finally in this chapter Authoress select coupled inductors as solution to circulating current minimization and support previous discussion by selected simulation results. Very short Chapter 4 entitled "Methodology of experimental works" presenting used computer-aided methods of rapid prototyping should be merged, in reviewer opinion, with another very short Chapter 5 "Design and construction of laboratory bench" describing used elements for lab setup. Chapter 6 "Simulation and real-world tests" shows simulation and experimental investigation of switching harmonics in the output current of converters with interleaved modulation signals as 2D graph (output current THD and interleaving angle) as well as 3D graph (output current THD, interleaving angle and modulation index). Chapter 6 explain also phenomenon shown in mentioned 2D and 3D graphs using harmonic spectrum simulation and output currents time domain simulation at various modulation indexes and interleaving modulation angles. Same chapter additionally presents results of another scientific goal i.e. tripping the overcurrent protections during a short circuit in an islanded microgrid. Chapter 7 includes control algorithm flow chart of emulated microgrid and description of method, which easily increasing the short-circuit current during islanding mode of operation by application of additional kinetic energy storage (synchronous machine). This chapter is supported by selected simulation and experimental results. Chapter 8 presents conclusions and directions of future research in the topic under discussion.

3. General Comments

Some parts of the thesis include too little description in reviewer opinion e.g.:

- very general description of control related to grid side converters e.g. VOC and almost no description of FOC;
- short description and discussion of results shown in Fig. 3.9-3.10;
- short description and discussion of results shown in subchapter 6.2;
- low number of simulation and experimental results showing operation of converters in microgrid supported by kinetic energy storage;

Besides of above general comments appears following questions:

1) There is inconsistency of modulation description in subchapter 2.2 and modulation index definition in different part of the thesis e.g.:

- Fig. 2.5 and description of this figure define maximum linear range of SVM at modulation index equal M=0,907 (above this range is defined overmodulation),
- Fig. 3.7, Fig.3.8, 3.10 shows results at M=0,98 (is it overmodulation?)
- Fig. 6.2-Fig.6.4 and Fig.6.6 shows results at M=0,95 (is it again overmodulation?).

Could Authoress comments above and define modulation index? Could Authoress comments also sentence "The difference between SVM and Sine PWM control lies in the difference of the modulating signal which is compared with a carrier signal." (Page 25 of thesis)?

2) Could Authoress comments sentence "The system of two converters connected in parallel with a common DC bus and the possibility of an interleaving mode operation.... A common DC bus has been chosen as the worst case linked with circulating currents between the converters, which was minimised during the research."(Page 28). Why this case was selected, if parallel operating converters with separated DC bus are very common in microgrids? How looks a problem of circulating current between converters with separated DC buses?

3) Could Authoress comments more detail Fig.3.3?

4) It is written on page 35 "The third solution guarantees the highest efficiency in suppressing circulating currents between converters.....". How it is proven? Is there references proving this sentence?

5) Why same signals are not shown in Fig. 3.11 similarly to Fig.3.8?

6) How power factor of load has influence for results shown in Fig. 6,2 and Fig. 6.3?

4. Detailed Comments

1) Page 6. I don't understand meaning of "To this end.....".

2) Page 7. I should be rather "....mierzy się ....." instead ".....zmierza się.....".

3) Page 7. Phrase „.....dotyczy wystąpienia pracy wyspowej..." sounds not good . It should be better to use expression „.....dotyczy pracy wyspowej".

4) Page 7. Phrase „.....niezależnej pracy fragmentu sieci..." sounds not good . It should be better to use expression „.....autonomicznej pracy fragmentu sieci".

5) Page 7. There is ".....opartą na modele matematyczne i symulacje...". Should be ".....opartą o modele matematyczne i symulacje..." or better ".....bazującą na modelach matematycznych i symulacjach..."

6) Page 7. Phrase „Stworzono algorytm pracy fragmentu sieci z udziałem sieciowych przekształtników energoelektronicznych." sounds not good. It should be better to use expression „Stworzono algorytm do sterowania fragmentem sieci elektroenergetycznej z udziałem sieciowych przekształtników energoelektronicznych.

7) Page 8. What does „passive power" means? Do you mean "reactive power"?

8) Page 12. The expression "The meeting of this condition requires...." sounds not good. It should be better to use expression "The fulfilment of this conditions requires....."

9) Page 12. There is "- ensuring high energy efficiency and high functionality", there is not defined what the high functionality means.

10) Page 13. Twice is cited [9].

11) Page 20. It is not clear, what Authoress means in sentence "The DPC method ....does not require the use of ... continuous p and q control systems."

12) Page 20. There is "The basic requirements of the VOC method is the stable voltage on the DC bus and the sinusoidal current of the converter at its output." Is it means that other control methods e.g. DPC, doesn't fulfil this basic requirements?

13) Page 21-22. There is no correlation of Fig. 2.1 and equation 2.1, where power is calculated once using the voltages and currents in *abc* coordinate system and other in synchronous rotating *dq* coordinate system.

14) Page 31. Equations 3.2 twice define $v_b(t)$.

15) Expression "*real-world*" is used very rare in technical power electronics publications. It is rather used "*experimental*", "*practical*" etc.

16) Page 60. Probably, there is mistake in expression ".....contactors SC1, SC2 and SC3 shown in Figure 6.8"

17) Page 70. There is "When the CB4 three-phase contractor is closed the entire system operates in island mode..." Is it correct?

5. Assessment and conclusions

In spite of the above-mentioned comments, I support the dissertation. In my opinion the presented PhD thesis includes important contributions. Among them the following are original achievements:

- ✓ development of the concept of a state machine for controlling events during transition of the system into autonomous mode of operation and re-connection to the power grid,
- ✓ determination of the control properties for interleaved operation of converters, showing the influence of the interleaving angle and the modulation index on THD in the AC output current and voltage,
- ✓ development of proven method for safe tripping the overcurrent protections for island-operated microgrid during short-circuits using an additional machine with an increased moment of inertia.

Moreover thesis include numerous simulation and experimental results which prove the validity of developed models and proposed methods. It should be stressed that some of theoretical consideration given in the thesis are proven by relevant laboratory and simulated investigations.

The level of achievements is good and the work meets demands of PhD thesis. The Authoress has proved good knowledge of power electronics including modern theory of control as well as capability in the future to work independently of supervision. Therefore, I recommend her as candidate for Ph.D. degree in Electrical Engineering and thus allow presenting his thesis at relevant seminar.

Mariusz Malinowski