Prof. Gopakumar K
Indian Institute of Science
Department of Electronic Systems Engineering
(department post address)
Bangalore-560012,
India

Date: 16th April,2019

Review Report
of the Doctoral Dissertation
Island operation of interleaved converters supported by kinetic energy storage
by Katarzyna Zielinska,

1 THESIS

1.1 EVALUATION OF THE DISSERTATION SUBJECT

The Doctoral Thesis under review is a very comprehensive work devoted to the issues of selection of appropriate control methods and solutions for the island-operated microgrid during steady and transient operation. The research also includes the area of microgrid power electronic converters. The research focuses on two important aspects of this type of operation in the microgrids. (1) Elimination of higher order switching harmonics occurring in the AC output current of power electronic converters. These higher order harmonic eliminations are of more importance for island mode operation due to the mainly resistive impedance of the microgrid. (2) To ensure the selectivity of tripping the circuit breakers during a short-circuit in the microgrid. The solution to this problem is achieved by using a synchronous machine with an increased moment of inertia. The energy stored in this machine is an additional source of short-circuit current. The dissertation is a comprehensive concept of the operation of a microgrid with the possibility of its switching to island mode. The microgrid examined consists of a photovoltaic panel, two interleaved converters operating in parallel and a VOC/FOC/droop control system, resistive load and a periodically connected synchronous machine with increased moment of inertia.

I consider the choice of the problem of distributed energy resources as very accurate. The development of these research topics is recognised as a priority action by leading research centres.

These studies meet the progress needs of modern societies to improve the use of natural resources by developing technologies that allow their effective use in local environments. The

development of microgrid technology is an action in this area. These grids can reduce transmission losses and increase energy security and flexibility as well as the quality of voltage. Moreover, development of this technology will have a positive impact on sustainable development of societies, increasing the number of jobs and thus helping to solve many social problems. For these reasons I consider that the choice of the research issues of the dissertation is very relevant. At the same time, I consider the scope of the investigation to be very extensive and the author's research in this respect a very ambitious action.

1.2 AIMS

The main aims of the dissertation include:

1) To eliminate higher order switching harmonics occurring in the AC output current of power electronic converters. These higher harmonics elimination is particularly important for island mode operation due to the mainly resistive impedance of the microgrid.

2) To ensure the selectivity of tripping the circuit breakers during a short-circuit in the microgrid.

3) To Develop an algorithm for emulating microgrid and implementation of power electronic converters for (a) VOC for power grid mode, (b) droop control during island mode operation, and (c) FOC for accelerating and braking the synchronous machine.

4) To Develop a method for switching the system into island mode operation, which additionally supplies the shorted circuit.

1.3 STRUCTURE

The thesis consists of an introductory part with the table of contents, the abstract and key words which take up ten pages. The substantive part of the dissertation is contained on the following 75 pages organised in eight chapters, and past liturature. Chapter 1 is introduction which deals which describes about the subject of dissertation, existing problems with islanded operation which are of interest to various research centers, aims and thesis of dissertation and finaly the scope of dissertation. In chapter 2 author explains the method of approaching the research problem. A brief overview of island mode detection is given, and also describes the method used to synchronise the converter with the power grid. The appropriate choice of solutions based on the available literature and previous laboratory tests are also explained in this chapter. In chapter 3 a comprehensive description of parallel interleaved converters. The author pays particular attention to the role of the interleaving angle between triangular carrier signals depending on the modulation index in the control of three-phase converters. Chapter 4 and Chapter 5 describes the laboratory bench activation and formulation of the methodology of experimental work. Detailed information about the layout and construction of microgrids capable of island mode operation is also given. Chapter 6 contains a description of the simulation and real-world research performed at the test bench. This chapter is divided into two substantive parts, i.e. steady- and transient-

state tests. Steady-state tests focus on the analysis of the formation of switching harmonics in the output current. Transient-state research in the first instance confirms the lack of circuit breaker selectivity during a short-circuit in an islanded microgrid, without the participation of additional synchronous generators. In Chapter 7 author discusses about the analysis and founding leading to the formulation of conclusions of the research thesis. This chapter contains the most important algorithms and diagrams closely related to the thesis. Chapter 8 author concludes the research work providing the scopes for future research work.

1.4 Research Methodology

Research methodology involves:

- identification of main problems occurring during island mode operation and developing and selecting solutions, the use of which will allow to improve the quality of the energy generated and increase the reliability of selective interruption of the current flow during short-circuits,
- development of mathematical models of converters with changing control methods: VOC (Voltage Oriented Control), FOC (Field Oriented Control) and droop control in the MATLAB/Simulink environment allowing simulation and prototype testing,
- development of an algorithm for controlling interleaved converters and machines with an increased moment of inertia and implementation of this algorithm with the use of a Texas Instruments DSP TMS320F28035 microprocessor,
- development and construction of a test bench emulating a fragment of the power grid during island mode operation.
- performing laboratory tests verifying theoretical results on the basis of tests performed at the test bench designed by the author,
- analysis of the results obtained and conducting a discussion on the direction of further work in the field of the study.

1.5 Main Achievements

The main achievements of the dissertation are:

- In formulating the concept and design of a microgrid with the possibility of island mode operation,
- development of mathematical models, planning and performing simulation tests and preparation of requirements for the laboratory test bench,
- launching the laboratory test bench consisting of:
  - a photovoltaic panel emulator,
  - two parallel converters with VOC control system, with the possibility of interleaved mode operation and switching into the FOC control system in order to accelerate and brake the synchronous machine with increased moment of inertia,
  - resistive loads allowing for carrying out load tests,
  - kinetic energy storage in the form of a synchronous machine with flywheels on the shafts which increase the moment of inertia,

- development of the author's concept of a state machine for controlling events during transition of the system into island mode operation, connection and disconnection of systems and operation modes depending on needs, initiation of control tests, including tests detecting island mode operation and re-connection to the power grid and many other decisions,
- development of simulation models of VOC, droop control and FOC control system, simulation tests during short circuits in a multivariate structure with/without a synchronous machine with an increased moment of inertia, power electronics converters, microgrid, systems enabling transition to island mode or re-synchronisation to the power grid,
- performing a series of tests in the steady state to determine the control properties for interleaved operation, showing the influence of the interleaving angle and the modulation index on THD in the AC output current and voltage,
- performing of transient tests during short-circuits and documenting the benefits of using an additional machine with an increased moment of inertia during island-operated microgrid.

1.6EVALUATION OF THE SCIENTIFIC RESULTS

1.7 GENERAL COMMENTS

The doctoral dissertation submitted is a valuable achievement. It is distinguished by very extensive research issues, which comprehensively present a solution to the problem regarding short circuit current handling and their role in a microgrid. The solution proposed in the dissertation is a good idea with huge application possibilities.

1.8 DETAILED COMMENTS

Despite careful editing, the dissertation contains a few editorial and stylistic mistakes. Examples are shown below.

- It would be better if waveform figures have legends (example Fig 7.19,7.20,7.21)
- Phrase “actual result” in page 39 needs to be checked
- In page 22, reference d-axis current is written as i_{sqref} but in figure it is shown as i_d*
- Please look at 1.3 chapter, sentence:
  “Chapter 1 is introduction which deals which describes about….”
  It is obviously an oversight. Also kindly look into structure formation off sentences in other chapters also.

Kindly answer some of the querries below.

1. To what extent the application of multilevel converters in interleaved systems will improve the quality of power supply ?
2. During island operation mode, the synchronous machine is accelerated and then connected to the islanded microgrid using one of the parallel converters. Does the control switch from FOC to VOC not cause serious transient states?
3. What kind of issues should be addressed to extend a system of two interleaved converters to a greater number of converters?

2. FINAL CONCLUSION

The thesis under discussion is well written and understandable. Also, the nomenclature and terminology used by the author is correct and commonly accepted in the power electronic community. The addressed topic of "Island operation of interleaved converters supported by kinetic energy source" is covered systematically and many aspects of both theory and practice are widely discussed. The thesis contains a high intellectual potential and is written with a strong theoretical rigour and is elegant in form.

Summing up, the author has demonstrated acquisition of substantial knowledge of power electronics converter operation at micro-grid systems, their control and the ability to carry out experimental research. Therefore, without any doubts and with full enthusiasm, **I recommend the candindate for the award of the PhD (Doctor of Philosophy) degree in Electrical Engineering and consider the content of thesis is of a good standard.**

Prof. K.Gopakumar
DESE(Department of Electronic Systems Engineering)
Indian Institute of Science
Bangalore-560012, INDIA