AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Electronics and Communications Engineering Department

Digital Control Techniques for Grid-Connected Inverters

A Thesis

Submitted in partial fulfillment of the requirements of the degree of

Master of Science in Electrical Engineering

Submitted by

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B.Sc. of Electrical Engineering

(Electronics and Communications Engineering)

Thebes High Institute of Engineering, 2008

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STATEMENT

This dissertation is submitted to Ain Shams University for the degree of Master of Science in Electrical Engineering (Electronics and Communications Engineering).

The work included in this thesis was carried out by the author at the Electronics and Communications Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

No part of this thesis was submitted for a degree or a qualification at any other university or institution.

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ABSTRACT

Ahmed Abd Alrahman Ahmed, Digital control techniques for grid-connected inverters, Master of Science dissertation, Ain Shams University, 2013.

This thesis demonstrates the design of a control algorithm for the grid-connected inverter, which is considered an important section in renewable-energy conversion systems. The thesis is arranged into four main parts:

Firstly, the main hardware topologies of the renewable-energy conversion systems are presented. Then the block diagram of the grid-connected inverter and its control objectives are discussed.

Secondly, this thesis introduces a comprehensive study of the three-phase grid-connected inverter with grid side controller. Initially, the stand-alone three-phase inverter is discussed. This is followed by a presentation of the mathematical model of the grid-connected inverter. After that, the possible current control strategies for the grid-connected inverter are studied. Then the PWM techniques of the three-phase inverter are addressed. After that, the synchronization algorithms for the grid-connected inverter are introduced. Finally, a discussion of grid filters topologies for interfacing the distributed generation with national electricity grid is provided.

Thirdly, the stand-alone and the grid-connected inverter systems are modeled based on the theoretical basics presented in the previously. These systems are then simulated to verify the effectiveness of its control structure and to determine its performance parameters using PSIM simulation package.

Finally, complete experimental versions for both the stand-alone and the grid-connected inverter are presented. The major differences between the simulation model and the experimental version are clarified.

Keywords: grid-connected inverter, synchronous PI controller, SVM, PLL.

SUMMARY

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This thesis demonstrates the different issues of implementing a control algorithm for the grid-connected inverter. The thesis is divided into four chapters organized as follows:

Chapter One: is an introduction to renewable-energy and its applications. A brief review on the state of the contribution of renewable-energy sources like solar energy, wind energy, and biomass in the Egypt strategy of energy are presented. In addition, it discusses the structure of distributed generation systems. Moreover, the hardware topologies of PV systems and wind turbines systems for grid connection are presented. Finally, the block diagram of the grid-connected inverter, which is the goal of the thesis, is provided and its parts are showed.

Chapter Two: presents a comprehensive study of the three-phase grid-connected inverters. Firstly, the basic construction of the three-phase inverter is introduced. Secondly, the mathematical model of the grid-connected inverter is presented. The closed loop current control techniques are studied, namely: hysteresis current controller, predictive controller, and linear PI controller. Then their performances are compared. It is found that the linear PI controller is more suitable for the grid-connected inverter application, since it offers an excellent steady-state response with zero steady-state error, low current ripple, and highly sinusoidal waveform to the grid-connected inverter. In addition, the controller is insensitive to system parameters since the algorithm does not need system models.

Thirdly, the most common PWM techniques are addressed, and then the SPWM and SVM along with a comparison between them are discussed. The SVM is chosen for the grid-connected inverter application because SVM has many advantages such as constant switching frequency, well-defined output harmonic spectrum, optimum switching patterns, and excellent dc-link voltage utilization.

Fourthly, the importance of the synchronization, for control purposes, of a grid-connected power generation system is presented. In addition, it is reported that several synchronization algorithms are capable of detecting the phase angle of the grid voltage, namely: zero crossing

detection, filtering of grid voltages, and PLL technique. It is concluded that the PLL is the best choice for the grid-connected inverter application. This is because the PLL can successfully detect the phase angle of the grid voltage even when noise or higher-order harmonics exist in the grid voltage. Finally, the grid filter that is used in the connection of an inverter to the utility grid is discussed. Three types of grid filter are addressed, namely: L-filter, LC-filter, and LCL-filter. The LCL-filter is chosen for the grid-connected inverter application, since it is effective in the reduction of switching frequency harmonics of the power inverter. In addition, it reduces the dependence of the filter on the grid parameters.

Chapter Three: in this chapter, the stand-alone and the grid-connected inverter systems are modeled based on the theoretical basics presented in the previous chapter. These systems are then simulated to verify the effectiveness of its control structure and to determine its performance parameters using PSIM simulation package. In the first part, a model for the stand-alone three-phase inverter is developed. The gating signals for 180º conduction are simulated, and the simulated output waveforms of the three-phase inverter are shown. In the second part, the SVM algorithm for three-phase inverter is simulated. The four steps that are used to implement the SVM algorithm are analyzed, and its results are given. In addition, the simulated output waveforms of the three-phase inverter with SVM are shown. In the final part, a model for the grid-connected three-phase inverter is constructed, and the parasitic elements of the constituting power components are taken into consideration. This simulation model includes the current controller, SVM, grid-filter, and PLL. All simulation results validate the theoretical studies performed in *chapter 2*.

Chapter Four: presents complete experimental versions for both the stand-alone and the grid-connected inverter. The major differences between the simulation model and the experimental version are clarified. In the first place, the stand-alone inverter is implemented and tested. Then the experimental results are presented. All experimental results validate the theoretical and simulation studies that are done in *chapter 2* and *chapter 3,* respectively. In the second place, a comprehensive implementation of the three-phase grid-connected inverter is introduced. The experimental results are shown after testing every part of this circuit. Additionally, the differences between the simulation and the experimental results are analyzed. Agreements are found between the simulation and experimental results when the parasitic resistances of the power components of the inverter circuit are taken into consideration.

Finally, the thesis ends by extracting conclusions and stating future work that might be done based on this work.

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