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Research on High Energy-Efficiency and Fast Dynamic Response Technologies for Grid-Connected Inverter
高 能 量 效 率 與 快 速 動 態 響 應 的 並 網 逆 變 器 之 研 究

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ABSTRACT

In today's environmentally conscious world, there is an urgent need to find ways to improve existing electric power system and explore new sustainable eco-energy technology. One of the emerging trends in the electricity industry is a shift from large centralized to small distributed energy resources (DER) located at the point of consumption. DER has many advantages over traditional energy technologies. For examples, they improve asset utilization, power quality, and power system reliability and capacity.

With regard to eco-energy source, the most promising candidates currently available are solar and wind energy. A typical hybrid DER technology consists of several power processing units for conditioning the solar panels and wind turbines, such as tracking of the maximum power point, interfacing with the secondary energy storage device and delivering the processed energy of high quality form to the electric grid. Specifically, the energy generated by the solar panels and wind turbines is firstly converted into a dc form with regulated voltage or current. Then, the energy will be converted into an ac form by a *grid-connected inverter* for the electric grid. Thus, the performance of the inverter critically determines the performance of the entire system. An inverter consists of two key components. They are the power conversion stage and controller. The power conversion processes the main power from dc source to the ac form. It is composed of a high-frequency switching network and an output filter. The controller dictates the states of the switch in the switching network so as to provide output of high power quality and good static and dynamic responses.

The aims of this thesis are to explore, identify and make contributions to issues related to methods of *driving and snubbering the switch*, *modulating the switching pattern* and *controlling the switching instants* that influence the energy efficiency and the static and dynamic power quality of grid-connected inverters.

The introduction chapter addresses literature reviews and recent advancements on grid-connected inverter technologies. It will starts with a perspective view of a grid-connected inverter. Issues under investigation will include structures and operating principles of typical grid-connected inverters, effects of the circuit parasitic elements on the switching trajectories and losses, effects of the modulation techniques on the conversion efficiency and effects of the output filter characteristics on the dynamics behaviors.

Without modifying the basic structure of the inverter, a lossless passive snubber that can instantly improve the switching trajectories and reduce the switching losses of the switch will be addressed in chapter 2. The key feature of this snubber circuit is that it does not introduce extra voltage and current stress on the switch. Moreover, it has a wide soft-switching range, as compared to prior art approaches. This is particularly important because the operating point of the inverter varies over a line cycle. As will be derived in the chapter, the snubber circuit has further be generalized to become a snubber cell suitable for other types of power converters, such as power factor corrector, two-switch flyback converter, etc.

On the controller side, the pulsewidth modulation method determines the output quality and conversion efficiency of the inverter. Unipolar and bipolar switching schemes are two popularly chosen schemes for controlling the switching patterns of the switches in the inverter. It will be studied in detail in Chapter 3 that these two schemes have their respective advantages and drawbacks in terms of their output harmonic contents, pulse dropping effects and energy efficiency. Then, a hybrid switching scheme that hybridizes the advantages of unipolar and bipolar switching schemes will be proposed.

To achieve fast dynamic response, a time-domain boundary control utilizing a second order switching surface will be investigated in Chapter 4. The distinct feature of the proposed control method is its good dynamic response that the inverter can reach the steady-state in two switching actions after large-signal disturbances, such as power demand change, dynamical load change, etc. Moreover, the new method is applicable for situations at startup, transient and steady-state modes of operations.

Apart from the switching network and control methodology in the inverter, it will be discussed in Chapter 5 that the output filter also determines the dynamic behaviors. Apart from the L- and LC-type filters, LCL-type structure is also a popular choice for the output filter because the physical size is small and the dynamic response is good. However, the key problem associated with LCL filter is the sustained oscillations when there is a sudden external disturbance. The typical way of alleviating the problem is to use passive or active damping methods to suppress the oscillation, but they are either lossy or exhibit slow dynamic response. A new concept that utilizes the natural oscillation of the filter, but without the sustained oscillation, to achieve fast dynamic response will be presented in the Chapter.

The driving circuit has been found to be critical in determining the switching loss in a switch. In chapter 6, a comprehensive analytical model will be derived. Based on the model, the operation of a MOSFET-Diode-Snubber structure will be discussed. The best value of the gate drive resistance is derived. The model later combines the ant colony optimization algorithm to search the best part number of the MOSFET and diodes, and the best values of the resistors and capacitors for the snubber to achieve low switching loss and low voltage stress on the switch.

Finally, the conclusion and contribution of this thesis will be given in Chapter 7. Moreover, some suggestions for further investigation will be provided.

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