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種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

専攻： Department of	電気電子工学 専攻	申請学位（専攻分野）： Academic Degree Requested	博士 （ 工 学 ） Doctor of （ Engineering ）
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

The dissertation entitled "Study of Modular Multilevel Cascaded Inverters for Utility-Scale Photovoltaic Systems" discusses the application of modular multilevel cascaded inverters (MMCI) to future utility-scale PV power plants. Inverters in conventional utility-scale PV systems are characterized by an low-voltage (LV) three-phase ac-output that require bulky and lossy output filters as well as line-frequency LV/MV transformers. Large systems in the >100-MW range incorporate hundreds of units within one installation. MMCI-based PV inverters feature a modular and scalable structure that can generate three-phase medium voltage (MV) multilevel voltage waveforms and produce very high output powers in the >50-MW range with one inverter while requiring neither harmonic filters nor step-up transformers. MMCI-technology offers for more efficient, more cost-effective and more reliable utility-scale PV systems allowing a higher energy yield at smaller footprint.

This work discusses both star-connected (SSBC) and delta-connected (SDBC) circuit topologies. It is investigated and shown how both circuits can optimally harvest electric power from a large number of individually interfaced and distributed PV solar arrays, even when the power generation among the PV solar arrays is imbalanced. The main objective of this research is the investigation of the operational behavior, when the power generation among distributed PV arrays connected to the SSBC or SDBC inverter are severely imbalanced. One major focus of this dissertation is, therefore, on identifying and highlighting the benefits of the SDBC inverter over the SSBC inverter in utility-scale PV applications. The approach sought in this dissertation is analytic, numerical and experimental.

The following items are the key research elements of this thesis:

- **Theoretical analysis and comparison of intercluster power balancing methods.**
  Both inverter circuits consist of three clusters that may experience unequal power generation of different degrees during any time of operation. For the SSBC inverter, different methods based on harmonic zero-sequence voltage injection are analyzed and compared on a quantitative basis with respect to power-balancing capability. The SDBC inverter relies on a different but analogous control method, the zero-sequence current injection. A quantitative comparison with the SSBC inverter shows that the SDBC inverter offers superior operating characteristics allowing it to operate under a much wider range of power-distribution imbalances.

- **Proposal and analysis of level-shifted permuted-carrier pulsewidth modulation (LSPC-PWM) for enhanced power balancing capability among bridge cells.**
  Conventional phase-shifted pulsewidth modulation (PS-PWM) is limited in power-balancing capability and introduces harmonic distortions in output voltages and output currents when is applied to an SDBC inverter operating under power-distribution imbalances. A newly introduced LSPC-PWM modulation strategy applied to an SDBC inverter allows both an extended power-balancing capability and a high harmonic performance that is unaffected by power-distribution imbalances. Moreover, it is shown and supported by theoretical analysis how the power-balancing capability of the SDBC inverter can be enhanced even further by utilizing harmonic zero-sequence currents injected into each cluster.

- **Experimental implementation and performance verification of SSBC and SDBC inverters under very high power imbalance ratios.**
  A 10-kW, six-cascade downscaled experimental setup with 18 isolated dc power sources is prepared for experimental verification of the operational performance and power-balancing capability of both SSBC and SDBC inverters. The high amount of individually controllable dc power sources enables investigation of the various different power-imbalance situations among both clusters and bridge cells. The high cascade number further allows experimental investigation of secondary effects that emerge with higher cascade numbers such as harmonic degradation of current and voltage waveforms.

The dissertation is structured as follows:

- **Chapter 1** gives an introduction into the development of photovoltaics over the past years and motivates the research topic.

- **Chapter 2** gives an in-depth introduction of the structure and functioning of contemporary utility-scale photovoltaic systems including contemporary PV inverter topologies. It explains important technical aspects that are fundamental to the understanding of the concept of applying modular multilevel cascaded inverters to photovoltaic systems.

- **Chapter 3** provides a literature review on modular multilevel cascaded inverters, major circuit configurations and their main applications. The second part is dedicated to discussing modular modular multilevel cascaded inverters for PV applications that are discussed in technical literature.

- **Chapter 4** provides a theoretical discussion and comparison in intercluster balancing between SSBC and SDBC inverter. Both qualitative and quantitative evaluation metrics are introduced to assess the power-balancing capability of both circuits.

- **Chapter 5** discusses the 10-kW, six-cascade downscaled experimental system with 18 individually controllable dc power sources that is used for experiments of both SSBC and SDBC inverters. Experimental waveforms are presented that show good agreement with the results from the theoretical investigation of chapter 4.

- **Chapter 6** discusses and compares the conventional method intracluster balancing method based on PS-PWM and a proposed method that is based on LS-PWM. It is shown that the new method offers several benefits in an SDBC inverter, such as a largely improved power-balancing capability and an insusceptibility towards harmonic distortion at the ac side during power imbalances.

- **Chapter 7** summarizes the findings obtained in this research.