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Thesis Outline

The aim of this doctoral dissertation is on practical realization and demonstration of the operating feasibility of the back-to-back (BTB) system using modular multilevel cascade converter (MMCC) based on double-star chopper-cell (DSCC) for power distribution systems and investigate the fault-ride-through (FRT) capability of the transformerless system under unbalanced grid conditions. The approaches are via design, implementation, performance demonstration, and analysis. Attention is paid to the following issues:

■ Control of the BTB system without common dc-link capacitor

The three-phase 200-V, 10-kW, 50-Hz downscaled DSCC-based BTB system with phase-shifted PWM is designed, constructed, and tested to verify its operating principles and performance in steady and transient states. Neither dc-link capacitor nor voltage sensor is required for regulating the dc-link voltage and controlling the dc-link current. Following this, the research focuses on the modeling and analysis of control of dc-link voltage and current of the two DSCCs.

■ The Transformerless BTB system working as a loop-power-flow controller

The transformerless BTB system is expected to be applied to the 6.6-kV utility distribution systems in Japan with many distributed power generators working as a loop-power- flow controller. Based on 6.6-kV three-phase three-wire ungrounded system, the transformerless BTB system produces an amount of zero-sequence current circulating in the system. This zero-sequence current is required to be mitigated satisfactorily for avoiding malfunction of grounding-detection relays. The aim of this research is to show the feasibility of the 200-V, 10-kW transformerless DSCC-based BTB system working as the loop-power-flow controller. The BTB system is intended for installation on a 200-V, 40-kW power distribution simulator consisting of two radial feeders under normal voltage condition. The zero-sequence current is needed to suppress in an acceptable value by the combination of a current-feedback controller and a common-mode choke connecting to the common dc link.

■ FRT capability of the transformerless BTB system

The BTB system should be equipped with low-voltage ride-through (LVRT) and/or zero-voltage ride-through (ZVRT) capability during voltage sags that are caused by grid faults. The research aims to provide experimental verification of the transformer DSCC-based BTB system under voltage sags in which the most severe conditions of single-phase, two-phase, and three-phase voltage sags with a voltage depth of 100% are applied to the system for testing.

This dissertation is divided into seven chapters and is organized as follows:

■ Chapter 1: Introduction

This chapter has provided the introduction and briefly describes the global energy scenario and impact to the global warming. The chapter explains the operation paradigms of power systems. It also talks about the modern scenario of the electrical grid using VSC-based FACTS devices and BTB systems, especially the BTB application for distribution systems working as a loop power flow controller. Following that, this chapter states the aims of the research and also provides an outline for this dissertation.

■ Chapter 2: Literature Review

This chapter has provided an overview of modular multilevel cascade converters with focus on the modular multilevel cascade converter based on double-star chopper cell (MMCC-DSCC). Research trend in the DSCC has been presented and discussed in details. Modelings, modulation techniques, control methods have been briefly reviewed. The DSCC applications have been discussed and provided some examples in term of DSSC-based BTB systems for the HVDC transmission projects in some countries. Finally, the fault-ride through capability and fault tolerance of the DSCCs have been reviewed briefly.

■ Chapter 3: Operating Principles and Control Methods of DSCC

This chapter has discussed the operating principles and control methods of DSCC. A detailed description of the power control and capacitor voltage balancing control are provided. This chapter has also described the phase-shifted-PWM technique including the sampling method used in this research.

■ Chapter 4: Design and Experiment of the DSCC-based BTB System

This chapter has described a grid-level high-power BTB (back-to-back) system using two modular multilevel cascade converters based on double-star chopper cells (MMCCDSCC) without common dc-link capacitor. A three-phase 200-V, 10-kW, 50-Hz BTB system with phase-shifted PWM has been designed, constructed, and tested to verify its operating principles and performance. Experimental and simulated waveforms have agreed well with each other not only in steady states but also in transient states. The simulation program developed in this paper is so reliable that it is applicable, particularly to investigations into low-voltage-ride-through (LVRT) capability and fault tolerances encountered in the operation of actual systems. Modeling and analysis have been done for the single power conversion system unifying the two DSCCs that take the equal responsibility for regulating the dc-link voltage and controlling the dc-link current. Concerning the transient response of the dc-link current to a small step change in active-power reference from 8 to 10 kW, the time constant derived by analysis has been in a good agreement with those measured from both experiment and simulation. Experimental results have confirmed the effectiveness of a self-starting/restarting procedure.

■ Chapter 5: The Transformerless DSCC-Based BTB System for Power Distribution Systems

This chapter has described an application of a modular multilevel cascade converter based on double-star chopper cells (MMCC-DSCC) to a transformerless back-to-back (BTB) system working as a loop-power-flow controller. It is intended for installation on the 6.6-kV Japanese power distribution systems. A three-phase DSCC-based BTB system rated at 200 V and 10 kW which can be considered as a downscaled system, has been designed, constructed, and tested to verify the operating principles and performance of the BTB system. Moreover, a three-phase 200-V, 40-kW power distribution simulator consisting of two radial feeders has been designed and implemented to verify the operating performance of the whole system. The zero-sequence current circulating between the two feeders can be suppressed as small as 10 mA in rms by the combination of achieving current feedback control and connecting a common-mode choke to the common dc link. The experimental results have confirmed that the transformerless DSCC-based BTB system has the capability of mitigating the power-flow imbalance between the two feeders.

■ Chapter 6: Fault-Ride-Through Capability of the Transformerless DSCC-Based BTB System Under Unbalanced Grid Conditions

This chapter has described a back-to-back (BTB) system for power distribution systems using modular multilevel cascade converters based on double-star chopper cells (DSCC), devoting itself to the analysis during voltage sags. A control method is proposed to suppress both overvoltage and overcurrent of the DSCC-based BTB system during the sags. The validity and effectiveness of the control method developed in this paper have been confirmed by experiments using a 200-V 10-kW downscaled system designed and developed in the authors' lab, and simulation using a software package "PSCAD/EMTDC." The results obtained from experiments and simulations show that the DSCC-based BTB system is equipped with zero-voltage ride-through (ZVRT) capability even under the most severe voltage sags.

■ Chapter 7: Conclusion

This dissertation contains extensive theoretical analysis and experimental results from the study of back-to-back (BTB) system using modular multilevel cascade converter based on double-star chopper-cells (MMCC-DSCC) for power distribution systems. Hereinafter, it is called just as the "DSCC." Basic design concepts of DSCC-based BTB system, with and without a line-frequency transformer, have been presented for the 6.6 kV power distribution feeders with many distributed power generators, working as the so-called "loop power flow controller." This dissertation reviewed the various types of MMCCs family with focus on the DSCC topology and its research trend in recently. The DSCC has become the most attractive topology for medium/high-power applications on both distribution and transmission systems, especially for voltage sourced converter BTB system (VSC-BTB). Firstly, the operating principles and control methods of DSCC have been discussed and analyzed in detail. After that, the three-phase 200-V, 10-kW, 50-Hz downscaled DSCC-based BTB system with phase-shifted PWM is designed, constructed, and tested on a 200-V, 40-kW power distribution simulator consisting of two radial feeders to verify its operating principles and performance.