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| 著者(和文) | TITICHAIWORAKORNN |
| Author(English) | NUNTAWAT THITICHAIWORAKORN |
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# Thesis Title

Study of Modular Multilevel Cascade Converters Based on Double-Star Bridge-Cells (MMCC-DSBC) for Large-Scale Wind Turbine Systems

# Thesis Conclusion

This thesis presents the MMCC-DSBC which is a member of MMCC family classified by Prof. Akagi. Although most research scientists in this field have paid their attention to the DSCC for HVDC transmission systems and medium-voltage motor drives for fans and blowers, the DSBC has some distinctive conversion capabilities different from the DSCC which make it suitable for wind turbine system applications:

- It has a buck-boost function of dc input voltage. In other words, it can convert a variable dc input voltage to a constant-magnitude ac voltage where the magnitudes of the input dc voltage and output ac voltage are independent from each other. This makes the DSBC suitable for a wind turbine system using a PMSG and a six-pulse diode rectifier which has some advantages over the conventional system using a BTB converter in terms of cost, reliability, and conversion efficiency.
- It has a direct ac/ac conversion capability from a single-phase ac voltage to a three-phase ac voltage without intermediate dc link (or direct single-phase to three-phase frequency changer). This capability makes the DSBC suitable for a high-power wind turbine system using a PMSG, three DSBCs, and three line-frequency transformers. This system is an improvement from the system using the DSBC in dc/ac mode with a diode rectifier, because the generator current in this case has lower harmonic components which makes the generator torque smoother. Moreover, the power flow in this case is bidirectional. This means that motoring of the generator is possible. The motoring operation is helpful during turbine startup when the tip-speed ratio (TSR) is low which sometimes makes the turbine torque produced by the wind too low for startup. Hence, the motoring of the turbine can make the turbine startup faster.

Control methods for the DSBC for both dc/ac and ac/ac modes have been developed in this study, including the methods for regulating and balancing the dc-capacitor voltages in the DSBC. Experimental verifications of the DSBC in dc/ac mode has been performed, confirming that the DSBC is effective in converting a variable dc input voltage to a constant-magnitude ac voltage. Experimental verifications of the DSBC in ac/ac mode has also been performed, confirming that the DSBC is effective in converting a variable

frequency ac voltage to a constant-frequency ac voltage, provided that the two frequencies are different. In other word, the DSBC can work as a frequency changer. The line-to-line output voltage of the DSBC in both dc/ac mode and ac/ac mode is multilevel PWM waveform having much less harmonic components than the traditional two-level PWM waveform. This makes the waveform of the line current close to sinusoidal.

A reduction of number of total cells in the wind turbine system using the DSBCs in ac/ac mode is possible by replacing each DSBC by a cell-reduced topology called "FBBC" and using an open-winding PMSG. This results in a reduction of total number of bridge cells to about half, which brings a substantial reduction in the system cost and system control complexity. The number of total components is even lower than that of the conventional MMC-based BTB converter. Thus, the cell-reduced system is an interesting alternative to the conventional system using a BTB converter. Verification of the cell-reduced system has been performed by component-level computer simulation using "PSCAD/EMTDC" software package. The simulation results, both in transient state and steady state, show that the cell-reduced system is effective for large-scale wind power production. Moreover, experimental verification of an FBBC has also been performed and a comparison between experimental and simulation results of a single FBBC helps to confirm the reliability of the simulation of the complete three-phase system.

## Thesis Contents