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Study of Hardware Design and Control of H-Bridge Cell Based HVDC Circuit Breaker Test Benches (Outline)

単相フルブリッジ変換器を用いた HVDC 用直流遮断器評価装置の設計と制御に関する研究（要約）

The dissertation is divided into seven chapters. Chapter one introduces the issues associated with renewable energy generation and distribution that could be solved through the use of high-voltage direct-current (HVDC) transmission technology, the challenges of research and development of multiterminal HVDC grids, and the possible solution based on HVDC circuit breakers with an emphasis on HVDC circuit breaker testing. Chapter two presents the literature review and summarizes four different approaches to HVDC circuit breaker testing that include conventional charged capacitor and inductor based, more advanced ac short circuit generator based, and power converter based circuit breaker test benches. The power converter based test bench is taken as the foundation of the research efforts presented in this dissertation with the conventional charged capacitor and inductor based test benches serving as inspiration for the initial research and the ac short circuit generator based test bench used for subsequent research. Chapters three through six present the research that constitutes the bulk of this dissertation. Chapter three presents the circuit configuration of the first proposed power converter based test bench. The proposed test bench was designed to mimic the operation of the conventional charged capacitor based test bench because of the similarities between the simulated and real world fault conditions, but with the large output current benefits of conventional charged inductor based test benches. The circuit configuration is shown first and it is followed by an explanation of the charging circuit, operating principle, and hardware design considerations. The power converter used in the construction of the test bench is composed of H-bridge cells that allow control over the output waveforms and increase the equivalent switching frequency, which was an intentional design decision meant to increase the controllability of the test bench. The mathematical analysis of the control method was done in order to avoid, as much as possible, the trial-and-error approach of parameter adjustment. Consequently, only the equivalent series resistance of the circuit needs to be obtained experimentally, but controller gains and system bandwidth can be obtained from simple equations. The numerical analysis is also used to derive the numerical steady state error compensation method that eliminates or mitigates steady state errors of the output waveforms, which increases the accuracy of the obtained results. The assumptions and analyses are verified by software based simulations with the final confirmation obtained experimentally on a down-scaled system. Chapter four presents a modified circuit configuration of the initial test bench that is meant to address the problem of the high number of semiconductor switches necessary to construct the required number of cells of the power converter. Essentially, some of the power converter cells are replaced with capacitors to offset the required number of cells up to 80% at the cost of reduced testing flexibility. The circuit configuration is shown first and it is followed by an explanation of the modified charging circuit, operating principle, and hardware design considerations. The mathematical description of the system remains the same, which means that additional theoretical analyses are not necessary. Simulation results

and data from the experimental system are shown to confirm the validity of the idea. Chapter five presents a new circuit configuration derived from the operating principle of the conventional ac short circuit generator based test bench. This proposed design addresses the issue of energy requirements of the previously proposed test benches by separating the test bench into two circuits. The circuit configuration is followed by an explanation of the operating principle and hardware design considerations, control method, simulation results, and data from the experimental system that show the validity of the idea. Chapter six presents the modified version of the test bench from chapter five. This test bench is reconfigurable on-line, which means that it can integrate high voltage output and large current output capability while maintaining low energy requirements. The circuit configuration is followed by an explanation of the operating principle and hardware design considerations, control method, simulation results, and data obtained from the experimental system. Chapter seven is the final chapter that concludes and summarizes the results and ideas presented in the dissertation. However, there are also four appendices that explain several important pieces of information that are outside of the scope of the main research. Appendix A introduces the definition of the Z transform that is a necessary tool in the analysis of digital systems and the most common methods used to obtain the Z domain system transfer functions. Examples are provided for better understanding. Appendix B explains the difference between two terms – system order and system type – because the distinction is extremely important for the analysis of steady state error behavior. Appendix C clarifies the process of obtaining the real optimal controller gain parameters, which is a necessary step because theoretical modeling cannot consider all phenomena that could potentially occur during system operation. Appendix D shows several photographs of the experimental test benches and provides an explanation of the various components used during assembly.