



Power Electronics to Improve the Performance of Modern Power Systems: Case Study on Partially Rated SST

Final Project Report

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Power Systems Engineering Research Center
*Empowering Minds to Engineer
the Future Electric Energy System*



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Power Systems Engineering Research Center

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Executive Summary

As the power industry updates distribution and transmission assets as needed, it is prudent to consider the alternatives and new applications that may become available due to advances in the technology and material science. Among these technologies is power electronics. Power electronics have been in the technical vocabulary for a few decades and can offer significant advantages in stability, speed, and power flow control. However, their applications are still limited due to factors such as limited ratings, relatively high cost, high losses, potential problems in meeting basic impulse level requirements, and lack of operational experience. In this project, we discuss a two-pronged research effort: (i) an explorative study on the requirements of power electronics (e.g., ratings, basic impulse level, lifetime, and maintenance) and necessary improvements in this technology to enable its use in power systems and (ii) an application design study of partially rated power electronics-enabled transformers for load tap changer applications. The goal of this project is not to apply power electronics to every task in power engineering; rather, it is to: (i) identify which tasks and applications (and to what extent) can benefit from power electronic solutions and (ii) explore the technologies that would accomplish the identified task.

Part I: Study on the Available Technologies and Identification of their Advantages and Shortcomings

Power electronics can offer significant advantages in stability, speed, and power flow control. However, their applications are still limited due to factors such as limited ratings, relatively high cost, high losses, potential problems in meeting basic impulse level requirements, and lack of operational experience. Even with these challenges, in recent years, the industry has commissioned several new power electronics-based projects. A recent example is the modular multilevel converter (MMC) high-voltage DC (HVDC) 200 kV, 400 MW underwater line completed by Siemens and the California ISO as the Trans Bay Cable project in San Francisco in Nov. 2010. Several other new HVDC lines and flexible AC transmission system (FACTS) installations are also underway. In recent years, power electronics devices have received significant renewed attention as an enabling technology due to several breakthroughs with the promise of wide bandgap (WBG) devices, especially high-voltage Silicon carbide (SiC) switches. These advances have the potential to improve the efficiency, power density, and thermal management of power electronics devices. Additionally, these advances can make future power electronics superior to their legacy power system counterparts in certain applications. This part provides a compendium of required/recommended specifications, characteristics, and necessary improvements for power electronics devices and a survey of available technologies, broken down by different power system applications. Emerging technologies such as wide bandgap devices as well as niche and unconventional applications such as mobile and truck-mounted FACTS devices are also studied. It is discussed that while power electronics are limited in their blocking voltage, switching frequency, efficiency, and workforce and cost-effectiveness, there are applications for which power electronics are the only (or the most dominant) application. These applications include integration of renewables and power routing. Several areas for further research, including operation of an all-converter power system as well as use of solid-state transformers (SST) for power transfer limit improvement are also discussed.

Part II: The Role of Basic Impulse Insulation Level in the Application of Power Electronics at the Distribution Level

Basic Impulse Insulation Level (BIL), also termed Lightning Impulse Withstand Level (LIWL) is discussed in this part. The application area is in power electronic controls and devices in power distribution systems (e.g., 15 kV class). The topical coverage includes the following:

- A literature survey of this topic
- Identification of the BIL requirements and the connection with the applicable codes and standards
- Methods to attain the BIL requirements
- A discussion of safety.

Part III: Partially-Rated Solid-State Transformers Based on the Modular Multilevel Converter

The increasing penetration rate of dynamic sources such as renewable energy resources together with the emergence of new dynamic loads such as electric vehicles, necessitate more flexible, efficient, and economical operation of the power grid. To maximize utilization of the power system infrastructure in an efficient and economical way, significant efforts have been made to actively control real and reactive power flows, compensate voltage sag/swell, and filter current harmonics based on power electronics. To this end, among the proposed power electronics-based solutions, solid-state transformer (SST) has become one of the emerging technologies. However, the application/deployment of SST has been limited due to high cost and reliability issues. To combine the flexibility provided by the power electronics and reliability of the conventional magnetic transformer, an alternative method, i.e., partially-rated solid-state transformer (PSST), has emerged, in which a power electronics converter is integrated into the conventional magnetic transformer. Even if the power electronics part of the PSST fails, the conventional magnetic transformer is still able to transfer power, thereby preserving the reliability aspect. Furthermore, since the majority portion of power in a PSST is still transferred by the main magnetic part, the power electronics part does not need to be fully rated. The power electronics part of a PSST can be realized by a DC-AC or an AC-AC converter. Since the AC-AC converter, including the back-to-back connected AC-DC-AC converter, has two AC ports, it is capable of simultaneously adjusting the voltage and current of the grid. Therefore, an AC-AC converter-based PSST can provide most functionalities including power flow control, voltage sag/swell compensation, and current harmonics filtering. In this report, two PSSTs based on the emerging Modular Multilevel Converter (MMC) topology along with their supporting control strategies are proposed and investigated for power flow control and active power filtering. The proposed PSSTs borrow the features of the MMC and combine them with new control strategies to enable the MMC-based PSSTs. Simulation studies in the PSCAD/EMTDC software environment are carried out to validate the performance and effectiveness of the proposed MMC-based PSSTs and their supporting control methods.

Project Publications:

- [1] Q. Yang and M. Saeedifard, "An AC-AC Modular Multilevel Converter-based Partially-Rated Solid-State Transformer for Power Flow Control," *IEEE IECON*, 2018.
- [2] Q. Yang and M. Saeedifard, "An AC-AC Modular Multilevel Converter-based Partially-Rated Solid-State Transformer," Submitted to *IEEE Journal of Emerging and Selected Topics in Power Electronics* (under review), 2018.
- [3] A. Teymouri, A. Mehrizi-Sani, and C.-C. Liu, "Cyber security risk assessment of solar PV units with reactive power capability," in *IEEE Ind. Electron. Soc. Annu. Conf. (IECON)*, Washington, DC, Oct. 2018.

Student Theses:

- [1] Armin Teymouri, *Power electronics converters for renewables applications under sensor malfunctions*, PhD, Washington State University, May 2020 (expected).
- [2] Qichen Yang, *Control of the DC-AC and AC-AC Modular Multilevel Converters under Abnormal Conditions*, PhD, Georgia Institute of Technology, December 2018 (expected).