Chair of High-Power Converter Systems
TUM School of Engineering and Design
Technical University of Munich

Master Thesis Initial Report - Research on Modulation and Control Optimization for MMC-SST

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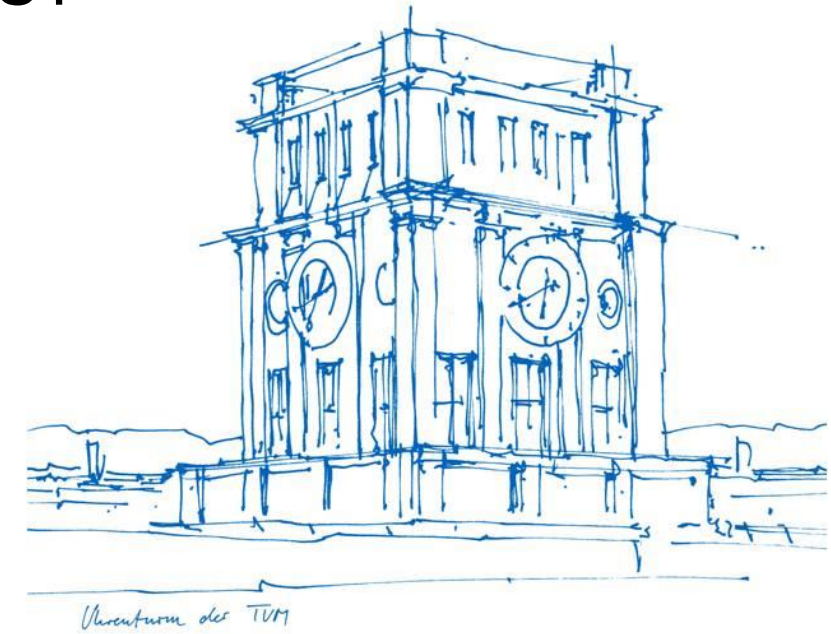
Professor: Prof. Dr.sc. ETH Zürich Marcelo Lobo Heldwein

Technical University of Munich

12, December, 2025

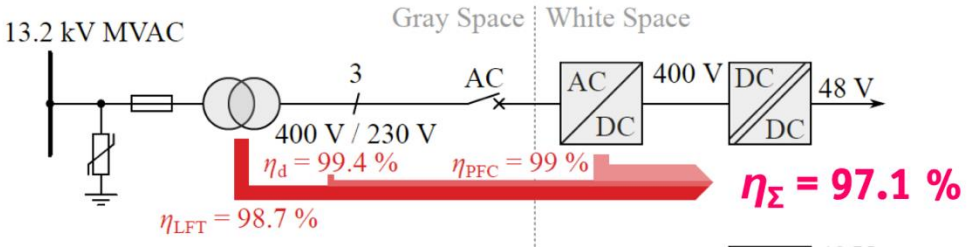


Outline

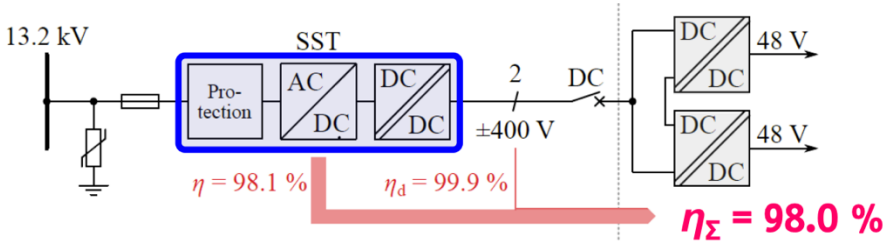
- Introduction
- Problem Statement and Research Gap
- Objective & Methodology

What is SST and its application

- State-of-art middle voltage interface for AC-DC



- Solid state transformer middle voltage interface

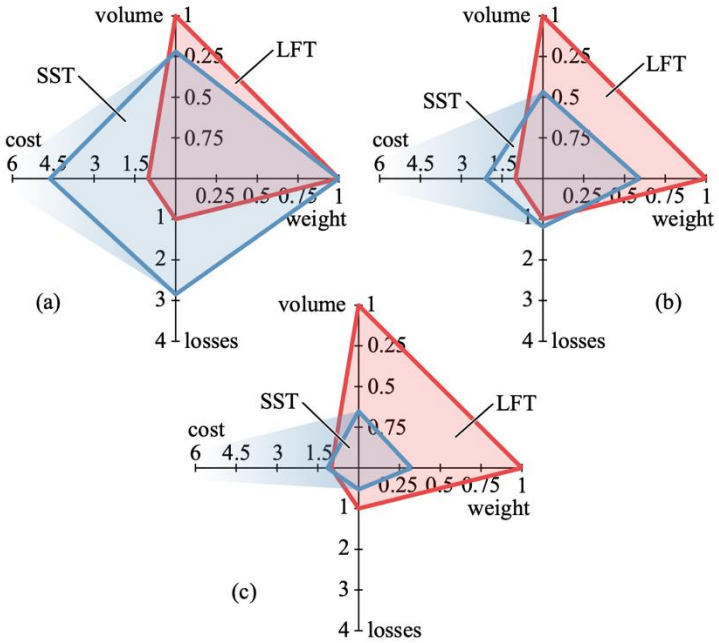


A Solid State Transformer (SST) is a power electronic converter with Middle-Frequency Transformer (MFT).

Key Advantages:

- Volume/Weight reduction (due to high frequency).
- Full power flow control (Active/Reactive).
- Higher efficiency for AC-DC application

What is SST and its application



Comparison of SST and Low Frequency Transformer(LFT)

Solution

a) AC-AC

b) 50% AC-AC and 50% AC-DC

c) AC-DC

Server-farms
up to 450 MW
99.9999% / 30s/a
$1.0 mio. / shutdown
Running costs > initial costs

Source: REUTERS/Sigtryggur Ari

- Data Center

- Super Charge station

E.g., Porsche FlexBox incl. cooling
Local battery buffer (140kWh)
320kW → 400km range in 20min

Source: Porsche / Mission-E Project

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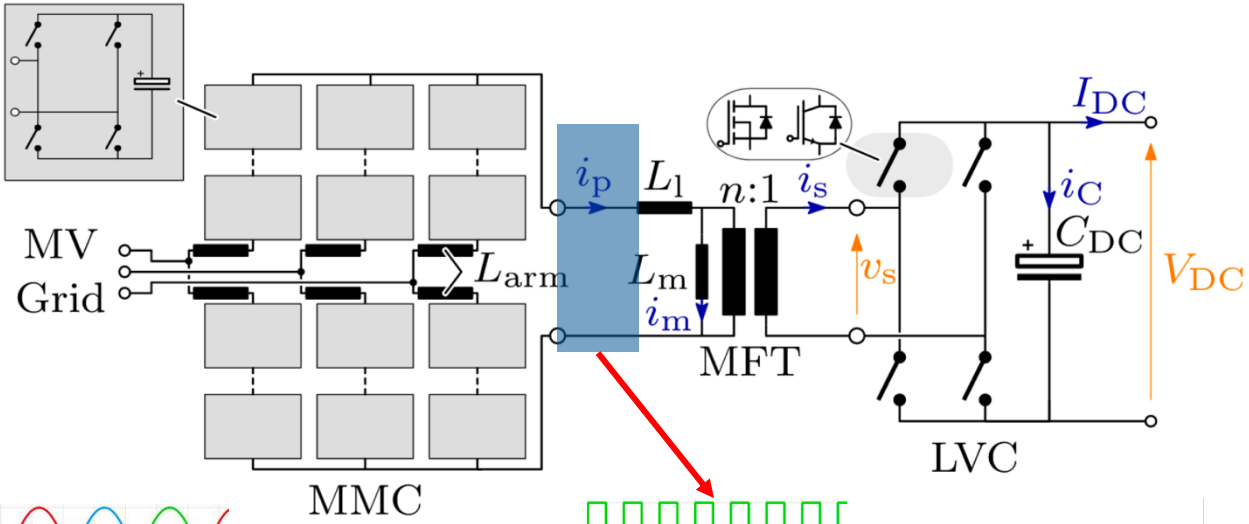
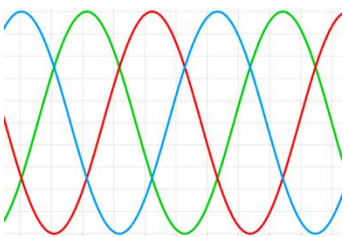
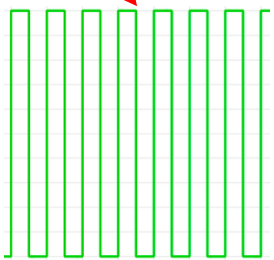
Topology Analysis
-Mudular Multilevel Converter (MMC)-SST





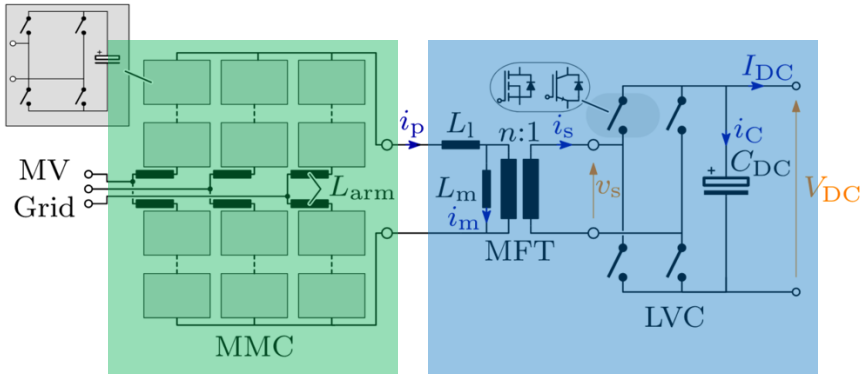
10kV 50Hz Middle Voltage AC



Middle Frequency square wave

800V DC Voltage

Existed Modulation Method



MMC AC-AC Stage

- Nearest Level Modulation
- ✅ Very Low Losses
- ❌ Poor Waveform Quality (High THD)

DC/DC Stage Challenge

- Pulse Width Modulation
- ✅ Good Harmonic performance
- ❌ Huge Switching Losses

- Phase Shift modulation
- ❌ Limited Phase Shift control for the MFT to ensure Zero Voltage Switching (ZVS).

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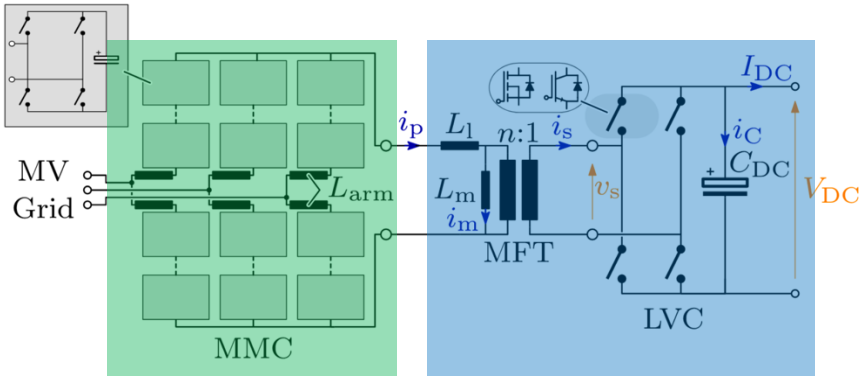
Objectives

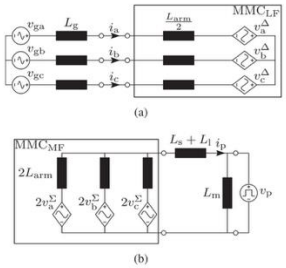
Core objective: Develop a Optimized Modulation and Control Scheme for MMC-SST

Specific Goals (Key Performance Indicators):

1. Minimize f_{SW} in SMs: Reduce switching losses in the MMC arms.
2. Maximize MFT Efficiency: Ensure high-frequency operation in the isolation stage.
3. Capacitor Voltage Balancing: Maintain stable DC voltages across all sub-modules without excessive sorting actions.
4. Wide range ZVS for DC-DC stage: Develop modulation scheme that has a wider range for ZVS than PSPWM.

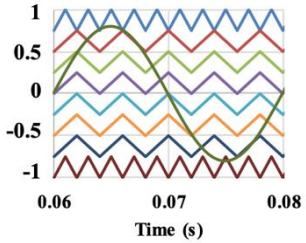


Methodology



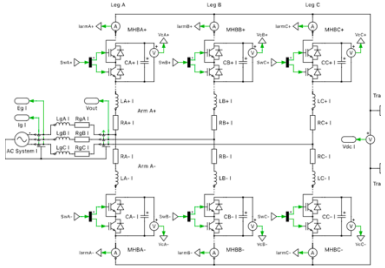
Mathematical modeling

- AC-AC MMC
- DAB
- Analysis of existed modulation and control methods for MMC-SST



Research on modulation and control optimization

- **Hybrid modulation** scheme for MMC AC-AC stage
- **Pulse amplitude control (PAC)** for the DAB DC-DC stage for wide range ZVC
- C code to implementing **voltage balancing** for submodules.



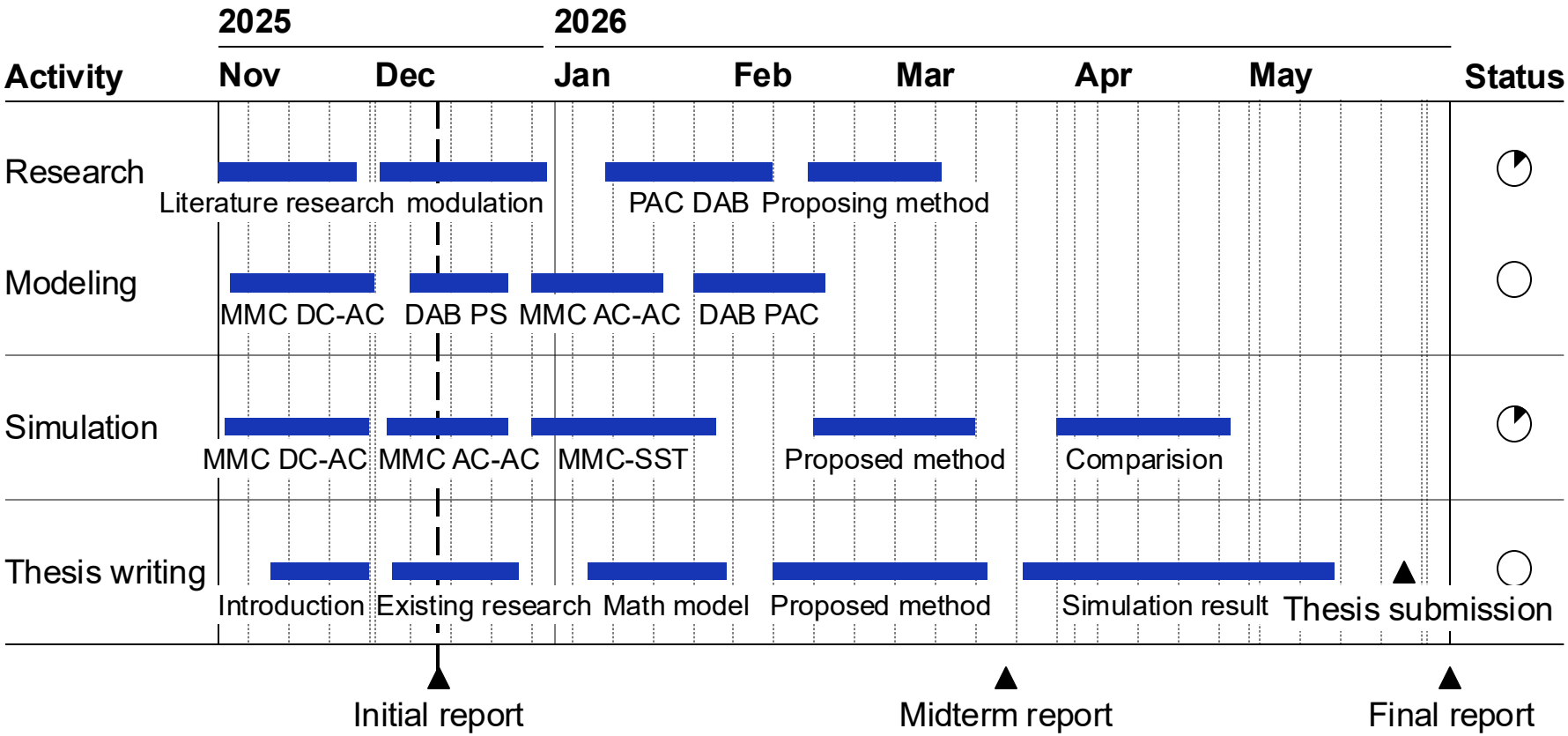
Simulation verification using PLECS

- Verifying the method using PLECS
- Compared the proposed method with the existing

Expected Outcome

- **Theoretical Model:** Mathematical derivation of the modulation strategy.
- **Simulation Model:** A complete, running MMC-SST model in PLECS.
- **Performance Comparison (The Evidence):**
  - Efficiency
  - THD Analysis
  - Switching Count Reduction
- **Contribution:** A novel balancing algorithm that decouples sampling frequency from switching frequency.

Timeline


2025
2026
Activity
Nov
Dec
Jan
Feb
Mar
Apr
May
Status
Research
Literature research
modulation
PAC DAB
Proposing method
Modeling
MMC DC-AC
DAB PS
MMC AC-AC
DAB PAC
Simulation
MMC DC-AC
MMC AC-AC
MMC-SST
Proposed method
Comparision
Thesis writing
Introduction
Existing research
Math model
Proposed method
Simulation result
Thesis submission
Initial report
Midterm report
Final report

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Thank You & Questions

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