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

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

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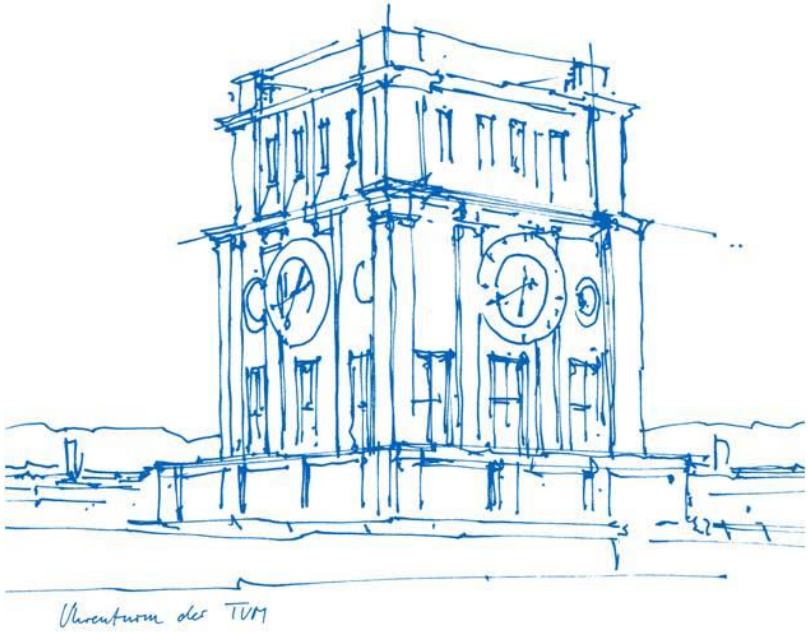
Professor: Prof. Dr.sc. ETH Zürich Marcelo Lobo Heldwein

Technical University of Munich

12, December, 2025

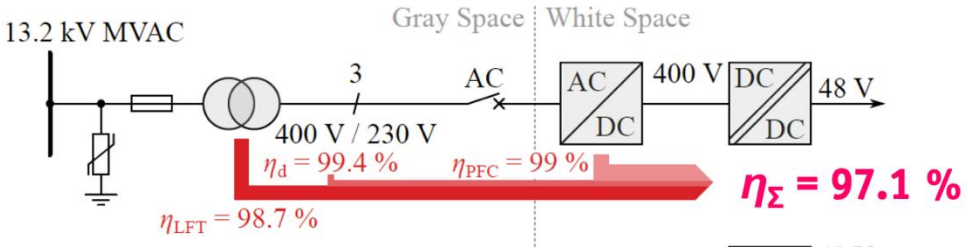


Outline

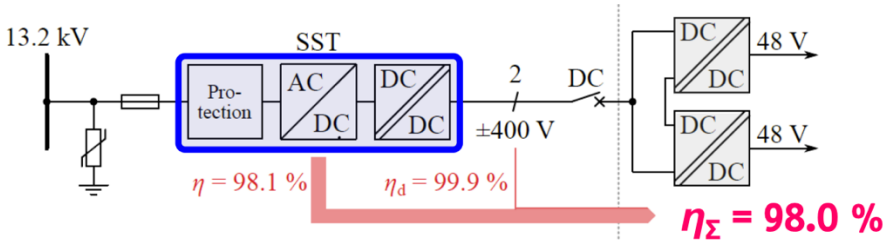
- Introduction
- Problem Statement and Research Gap
- Objective & Methodology

What is SST and its applications

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



- Solid state transformer middle voltage interface



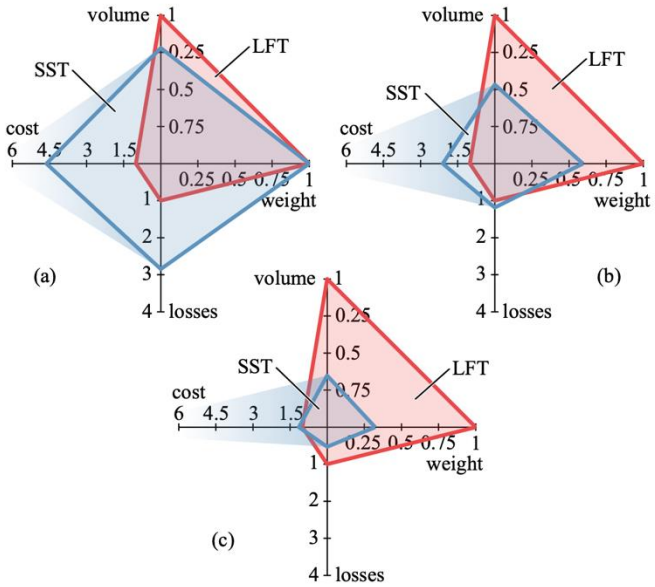
A Solid State Transformer (SST) is a power electronic converter with Middle-Frequency Transformer (MFT).

Key Advantages:

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

Next-Generation Datacenter MV Interfaces — Will Solid-State Transformers Meet Their Waterloo?
–Johann W. Kolar, Jonas E. Huber

What is SST and its applications



Comparison of SST and Low Frequency Transformer(LFT)
Solution 10kV/400V

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

J. E. Huber and J. W. Kolar, "Volume/weight/cost comparison of a 1MVA 10 kV/400 V solid-state against a conventional low-frequency distribution transformer,"

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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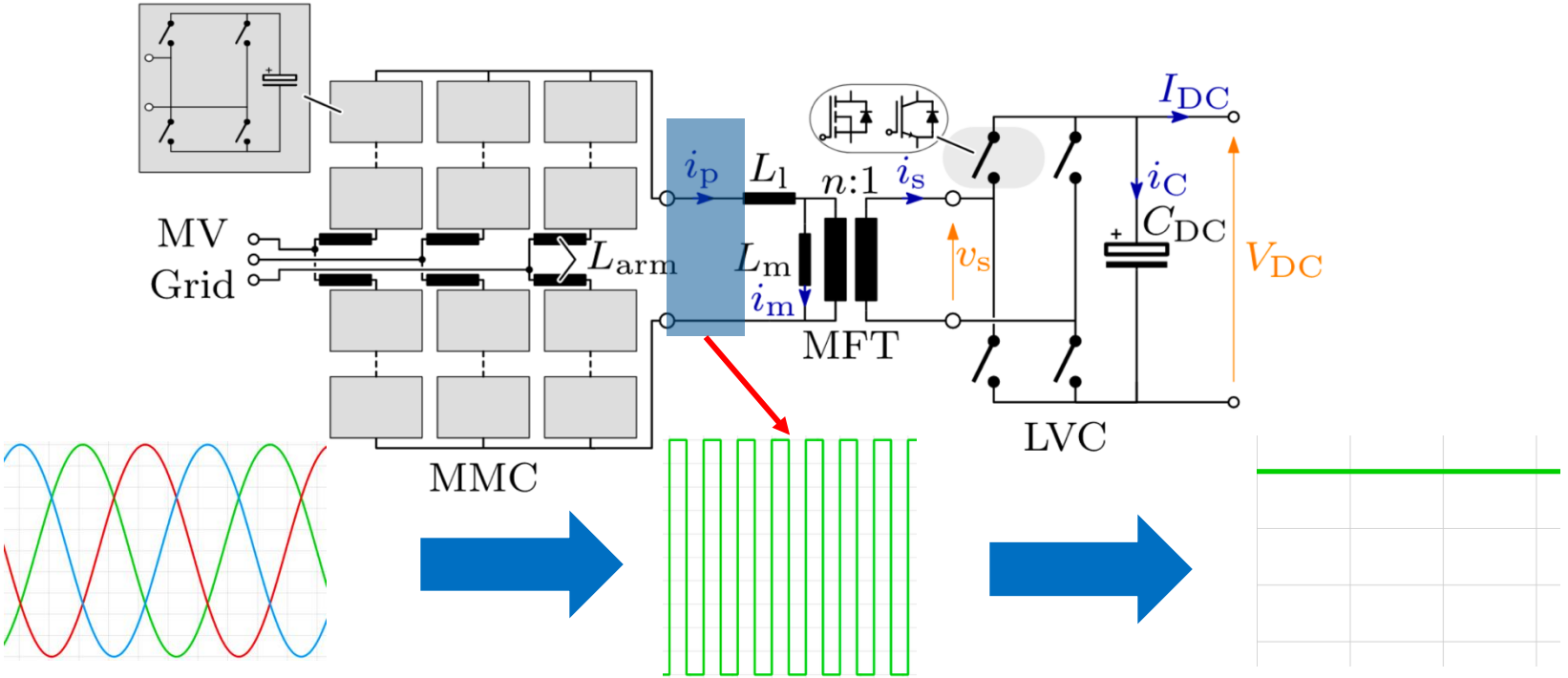
Topology Analysis
-Modular Multilevel Converter (MMC)-SST



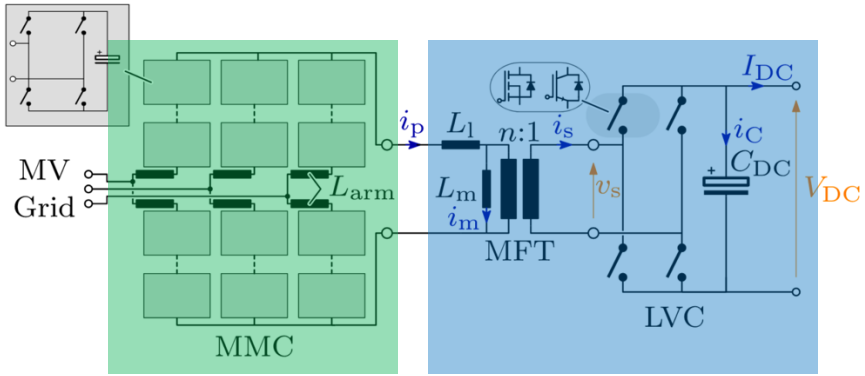
10kV 50Hz Middle Voltage AC

Middle Frequency square wave

800V DC Voltage

K. Pouresmaeil, J. Duarte, K. Wijnands, M. Roes and N. Baars, "Single-Phase Bidirectional ZVZCS AC-DC Converter for MVConnected Ultra-fast Chargers,"

Existed Modulation Method



MMC AC-AC Stage

- Nearest Level Modulation (NLM)

✅ Very Low Losses

❌ Poor Waveform Quality

- Pulse Width Modulation (PWM)

✅ Good Harmonic performance

❌ Higher Switching Losses

DC/DC Stage Challenge

- Phase Shift modulation (PSPWM)

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

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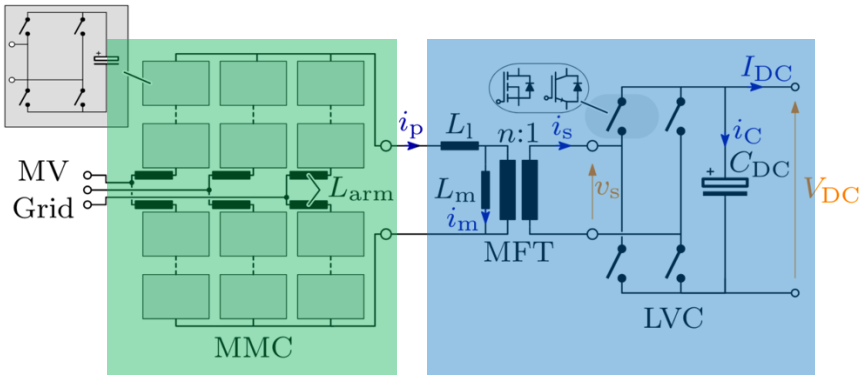
Objectives

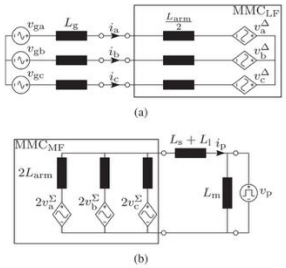
Core objective: Develop an Optimized Modulation and Control Scheme for MMC-SST

Specific Goals (Key Performance Indicators):

1. Minimize f_{SW} in Sub-Modules (SMs): Reduce switching losses in the MMC arms.
2. Maximize MFT frequency: Ensure high-frequency operation in the isolation stage.
3. Capacitor Voltage Balancing: Maintain stable DC voltages across all sub-modules and minimize the ripple.
4. Wide range ZVS for DC-DC stage: Develop modulation scheme that has a wider range for ZVS than PSPWM.

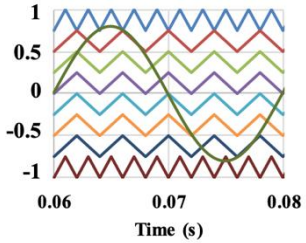


Methodology



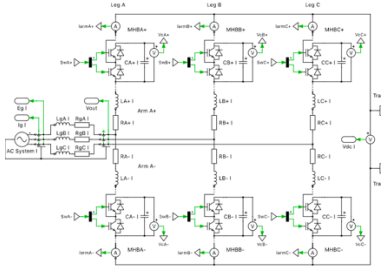
Mathematical modeling

- AC-AC MMC
- DAB
- Analysis of existing 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 ZVS
- C code to implementing **voltage balancing** for submodules.



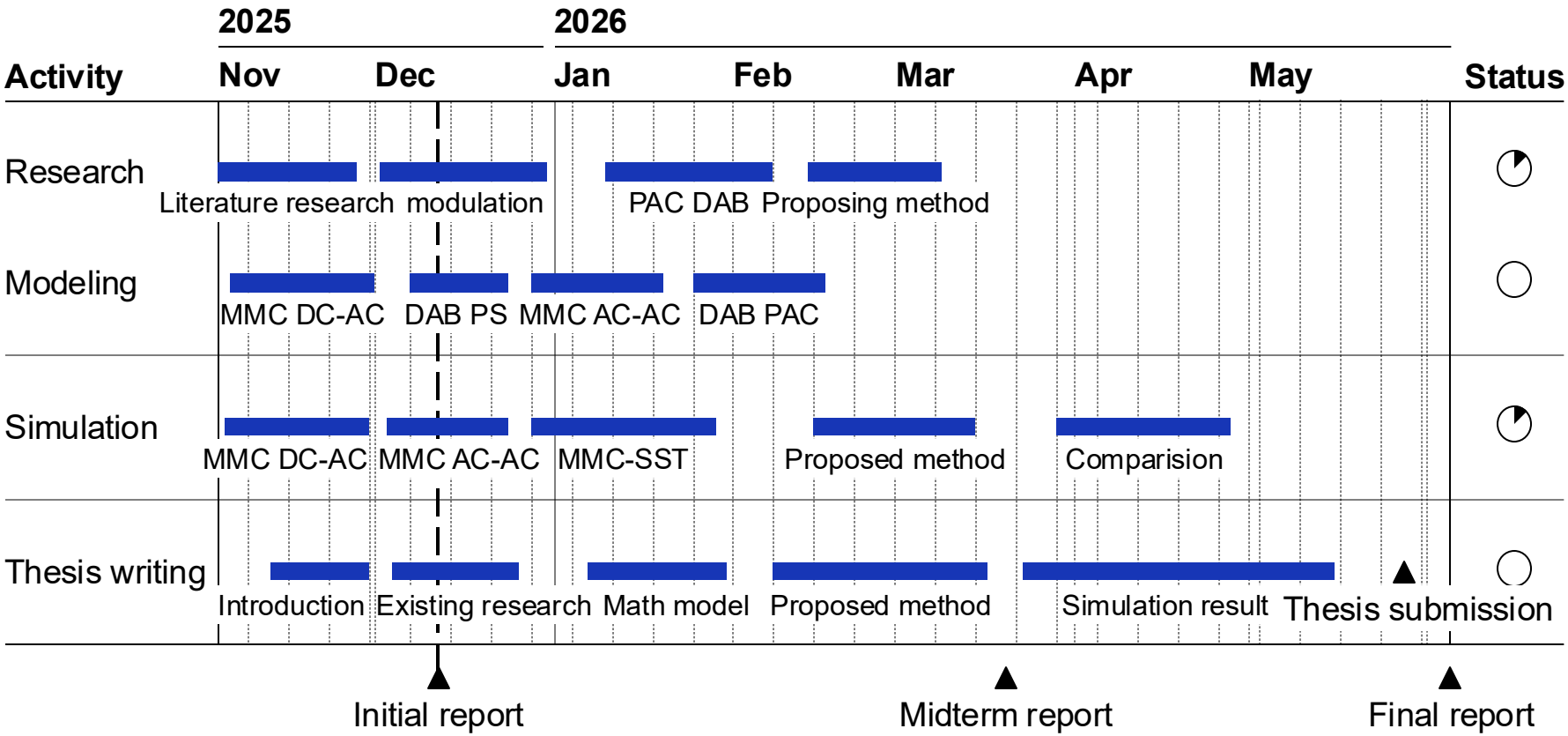
Simulation verification using PLECS

- 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

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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