EMTP® International User Conference 2025

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"Analysis of Reactive Power Regulation Issues in Wind Farms and Development of Modulation and Control Schemes in MMC-Based STATCOMs"

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Speakers: Iñaki Alarcón and Juan González

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Outline

1. Introduction
    1. About e-keme
    2. EMTP applications
    3. Reactive power regulations in the Mexican Grid Code
2. Reactive power regulation issues in Wind Farms
    1. Weak-grid characteristics
    2. Problematic associated to the disturbance
    3. Data-driven simulations
3. Development of modulation and control schemes in MMC-based STATCOMs
    1. STATCOM topology
    2. Control system development
    3. Simulation results
4. Conclusions
5. References

Introduction

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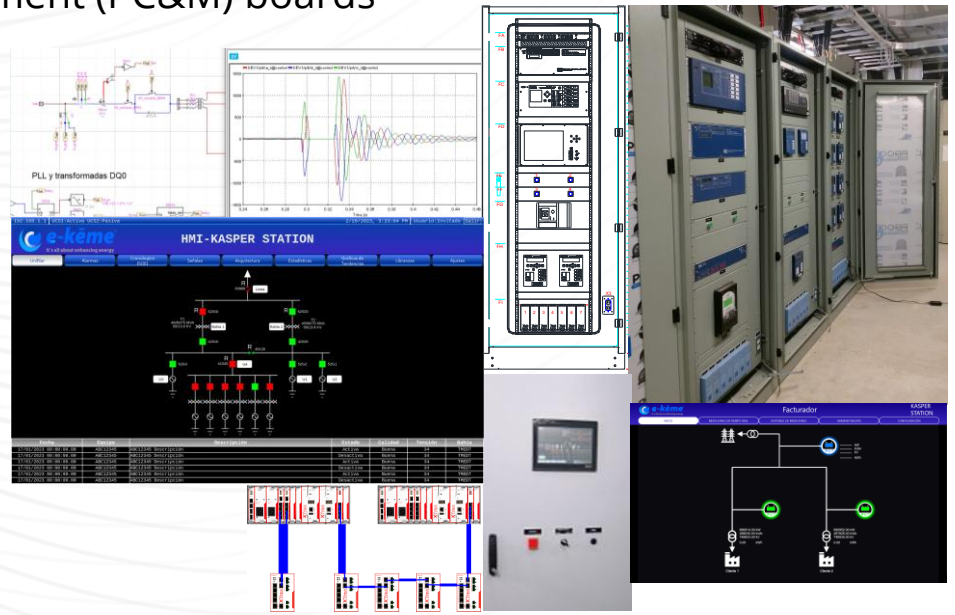
About us*

E-keme is a Mexican company focused on project development and troubleshooting in the electrical engineering field, offering the following services:

- Protection, Control and Measurement (PC&M) boards
- SCADA/HMI systems
- Specialized billing software
- Event or contingency analysis
- Communications
- Electrical studies:
  - Static
  - Dynamic



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EMTP applications

- Electrical studies
  - Temporary Overvoltage (TOV)
  - Transient Recovery Voltage (TRV)
- Switching transients (Load and capacitors)
- Microgrids
- Electrical machine modelling
- Power electronics modeling
- Renewable Energy Systems
- Large-scale power systems
- PPC tuning
- CENACE mathematical models

1. **Reactive power regulation issues associated with the operation of wind farms**
2. **Development of a STATCOM modulation and control scheme to mitigate operational issues**

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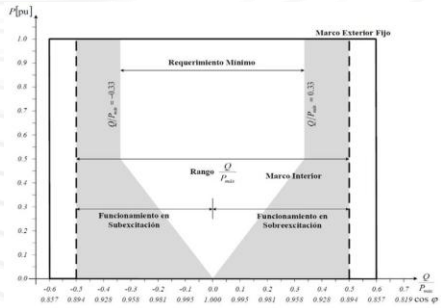
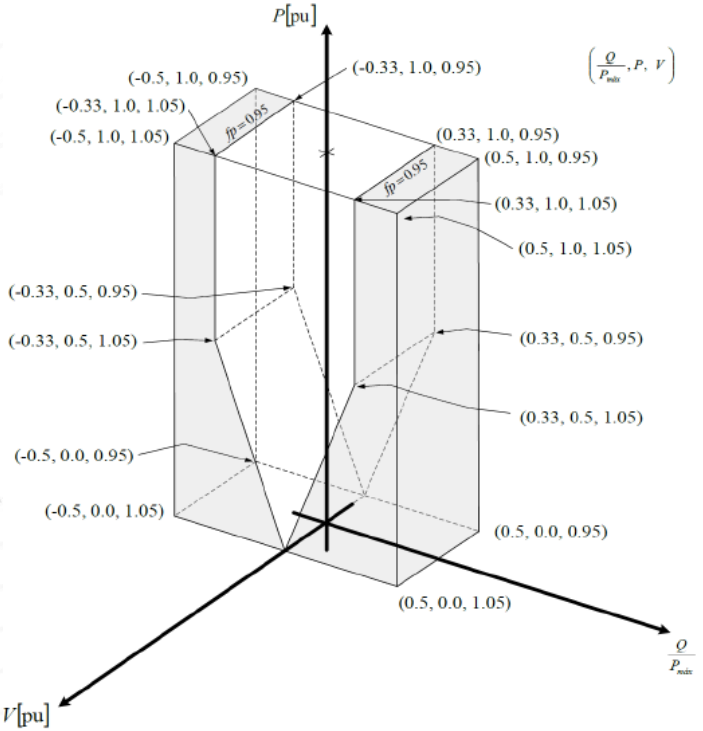
Reactive power regulations in Mexican Grid Code*

Compliance with:

- Minimum reactive power requirement
- Power factor
- Reactive power regulation
- Voltage regulation
  - Direct control
  - QV control
- Power factor regulation
- Contingency support
- Real time monitoring and communication





In case of non-compliance there are sanctions

**"Mexican Grid Code 2.0". DOF - Diario Oficial de la Federación. Available: https://dof.gob.mx/2021/CRE/CRE_311221.pdf.*

Reactive power regulation issues in Wind Farms

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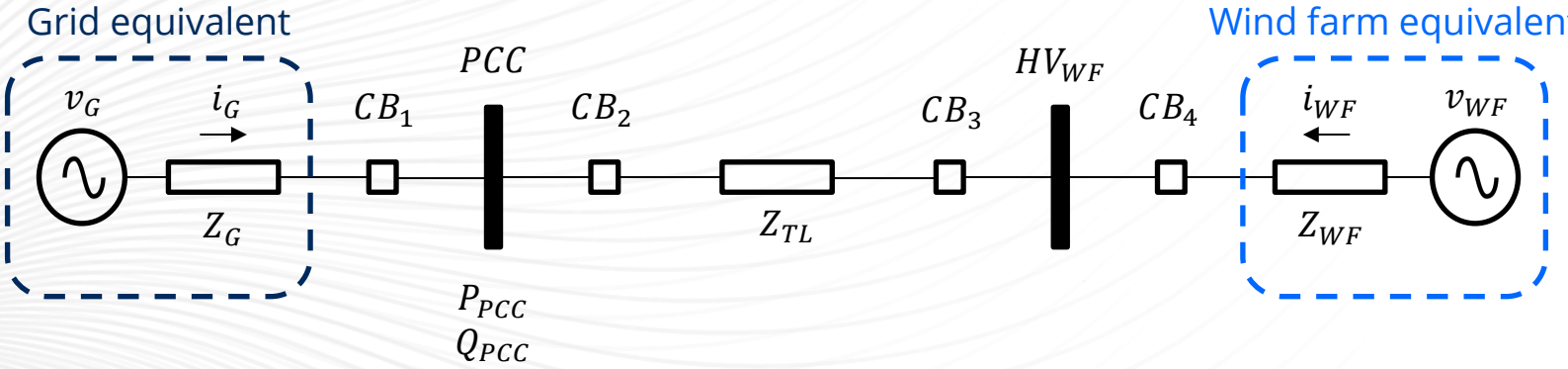
Weak-grid characteristics

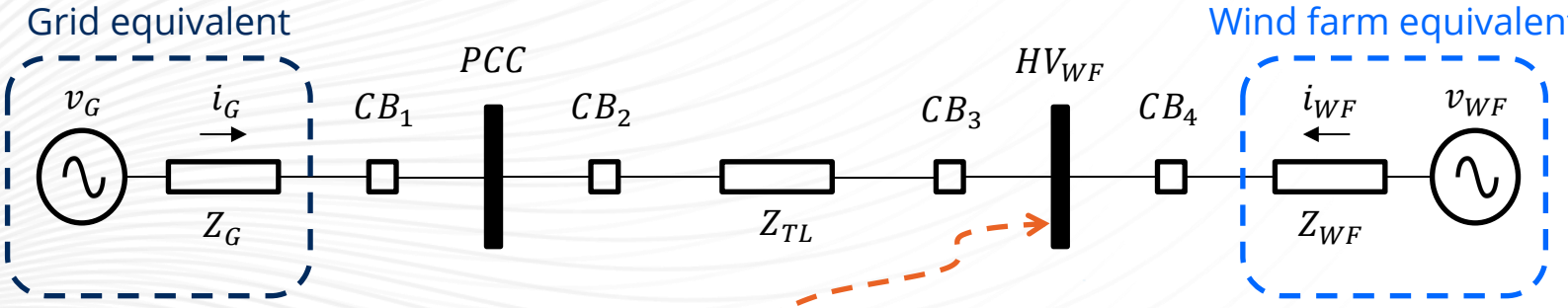


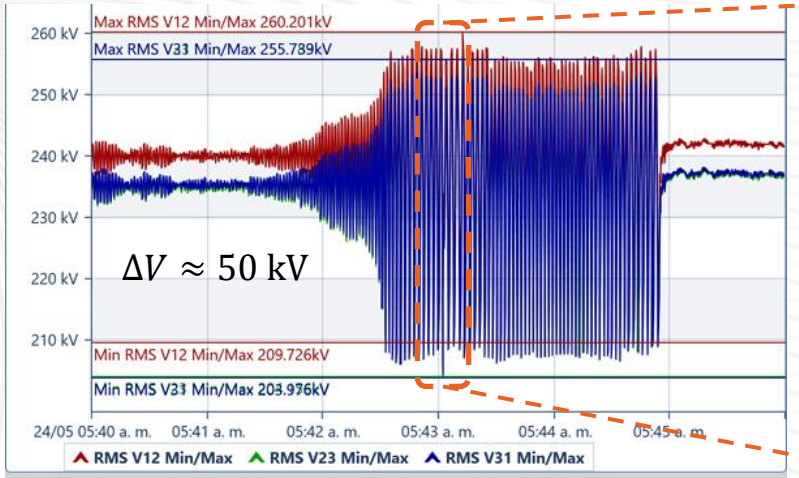
Main:

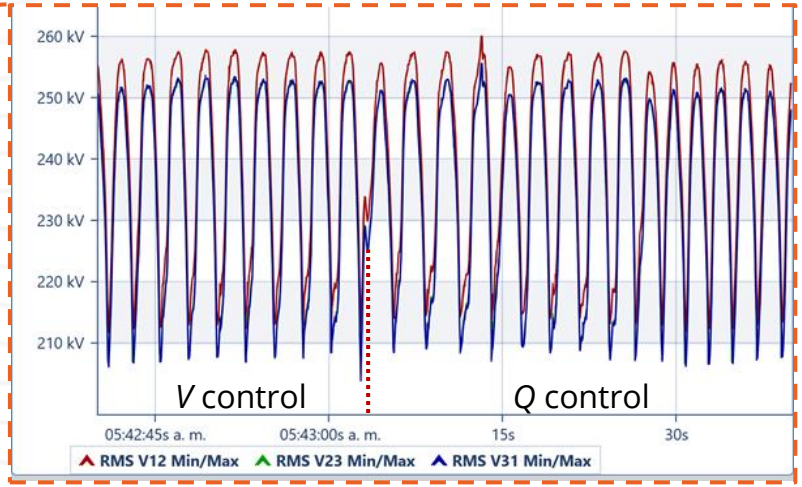
- Low short-circuit power
- High grid impedance
- Sensitivity to load or generation variations
- Greater difficulty in maintaining voltage and frequency stability

Mlilo, N., Brown, J. & Ahfock, T. Impact of intermittent renewable energy generation penetration on the power system networks – A review. Technol Econ Smart Grids Sustain Energy 6, 25 (2021). https://doi.org/10.1007/s40866-021-00123-w

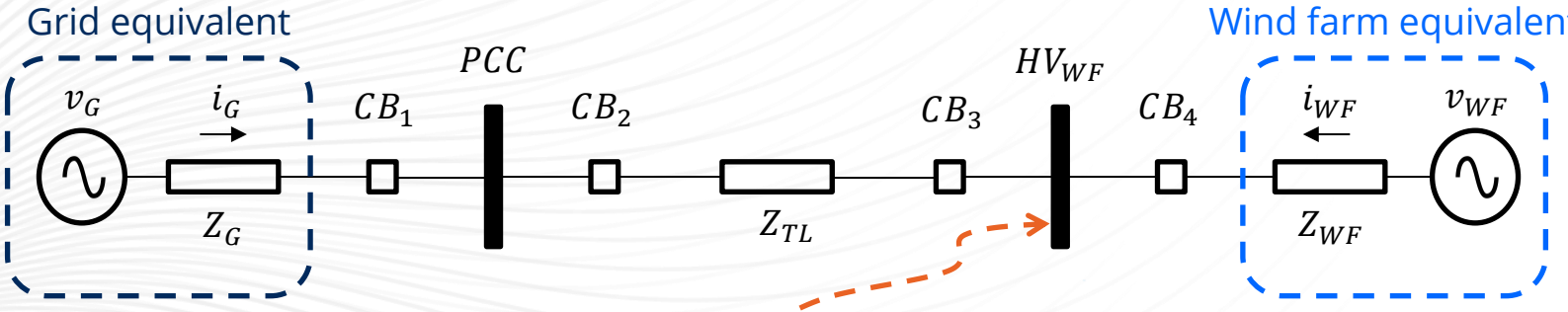
Weak-grid characteristics

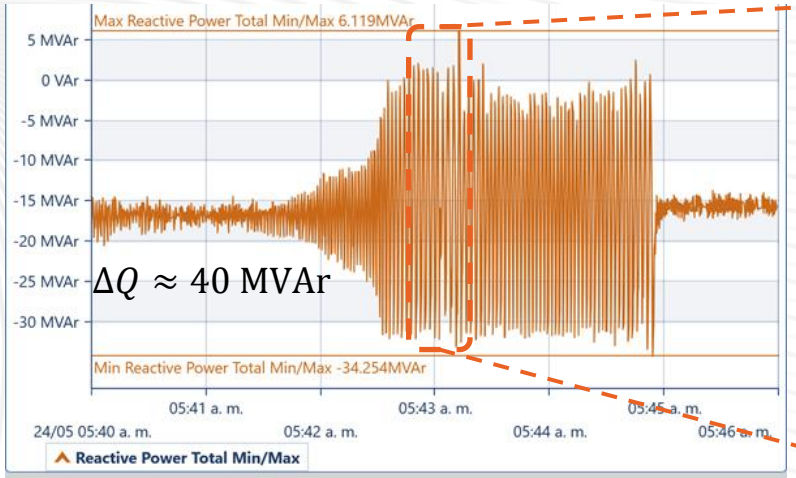


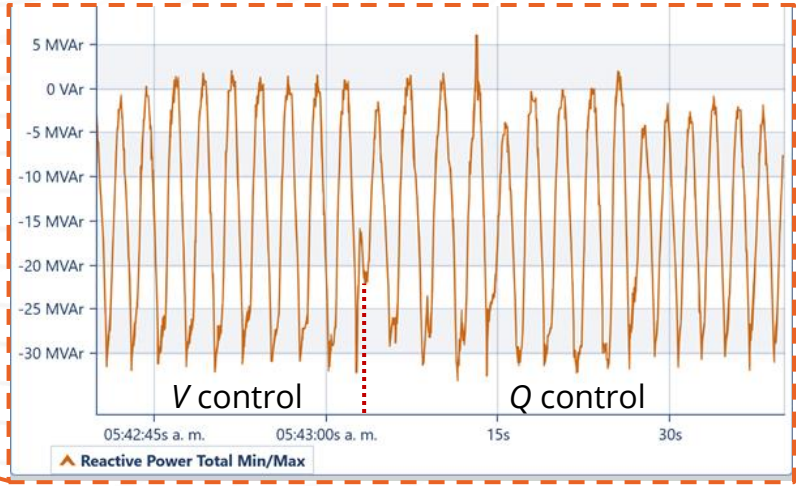




Weak-grid characteristics



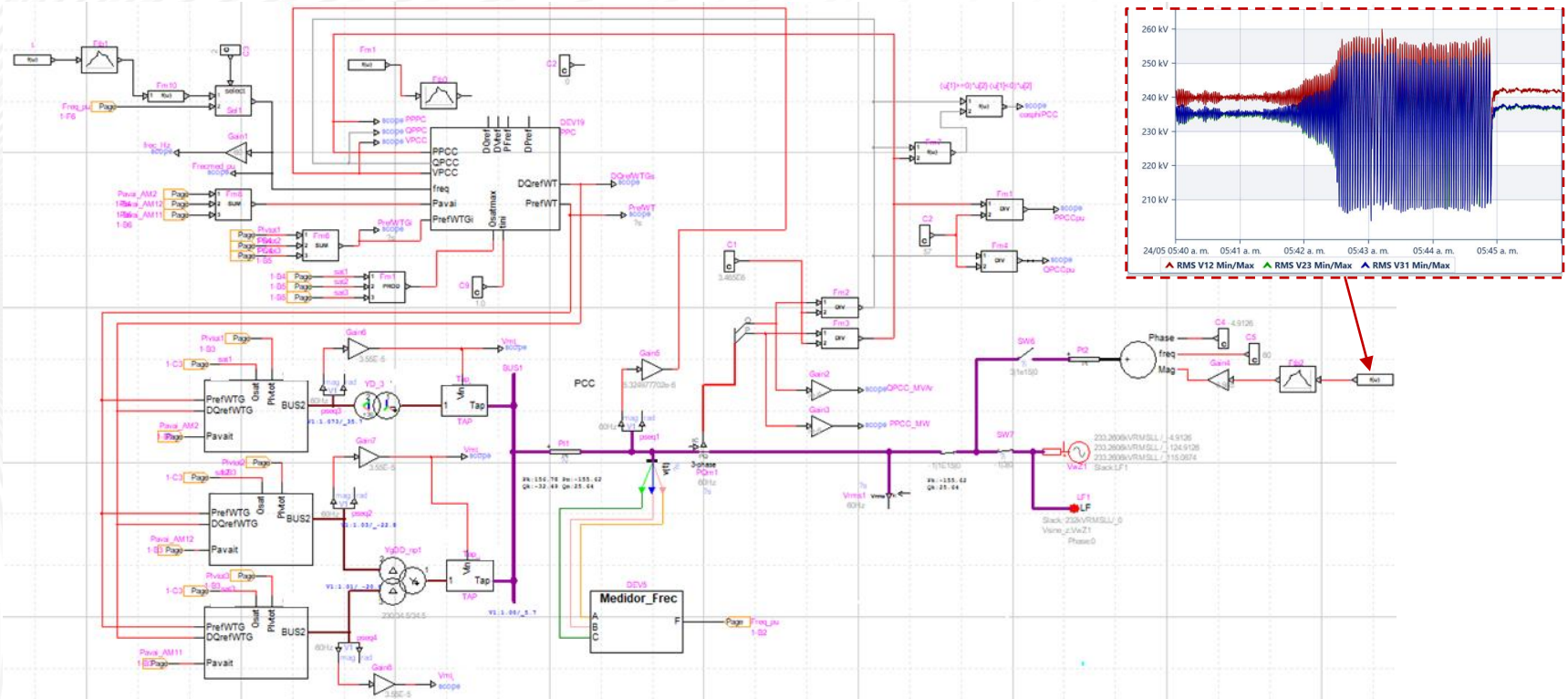




Problematic associated to the disturbance

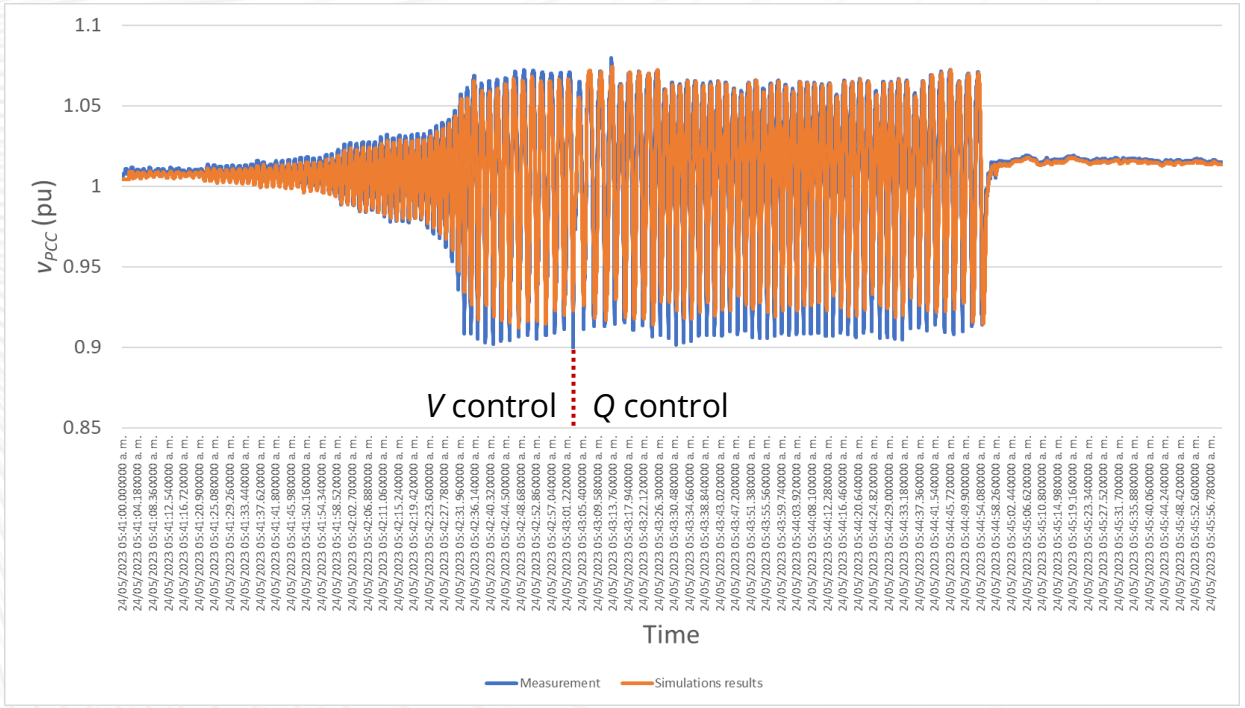
1. Is the WF the root cause of the disturbance in the system?
   - Through an analysis of the short circuit ratio at the PCC, it was determined that although the plant generates oscillations of 40 MVAr, it does not produce voltage oscillations of 50 kV.
   - Subsequently, it was informed that there was a disturbance in the system that caused the trip of a transmission line.
2. Is the WF in compliance with the objectives established in the Mexican Grid Code?

Data-driven simulations in EMTP



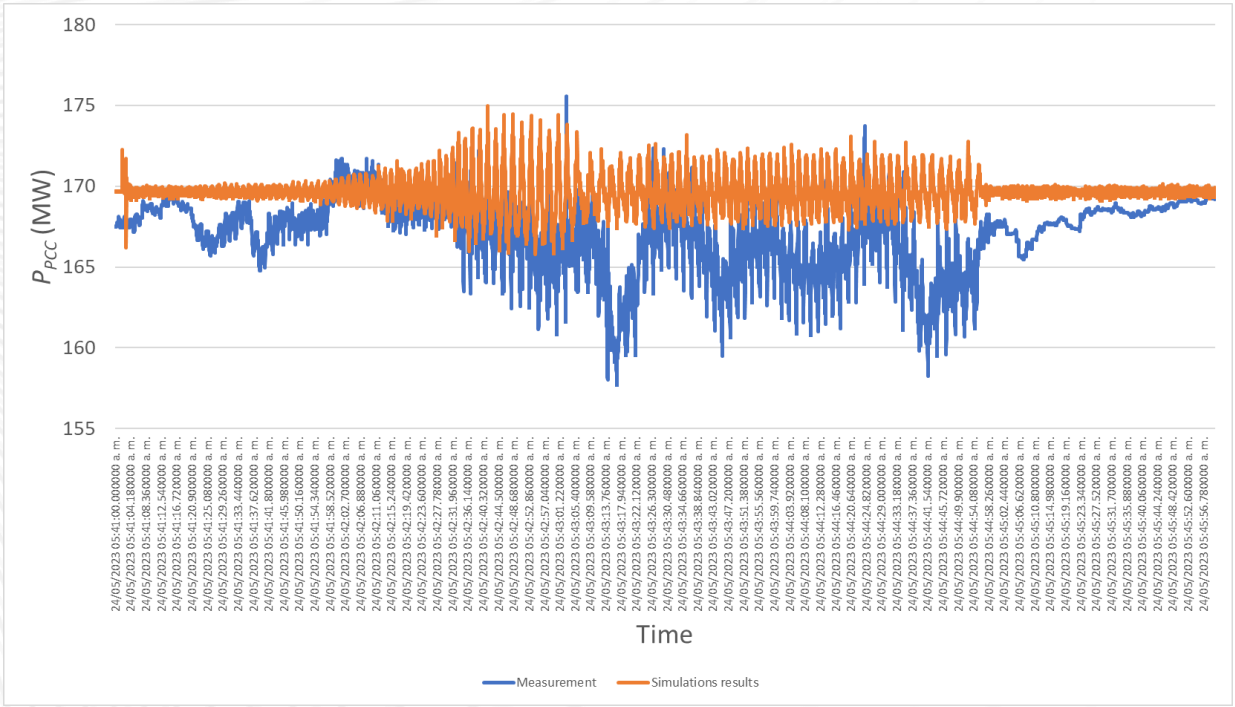
Data-driven simulations in EMTP

- Grid voltage (v_{PCC})



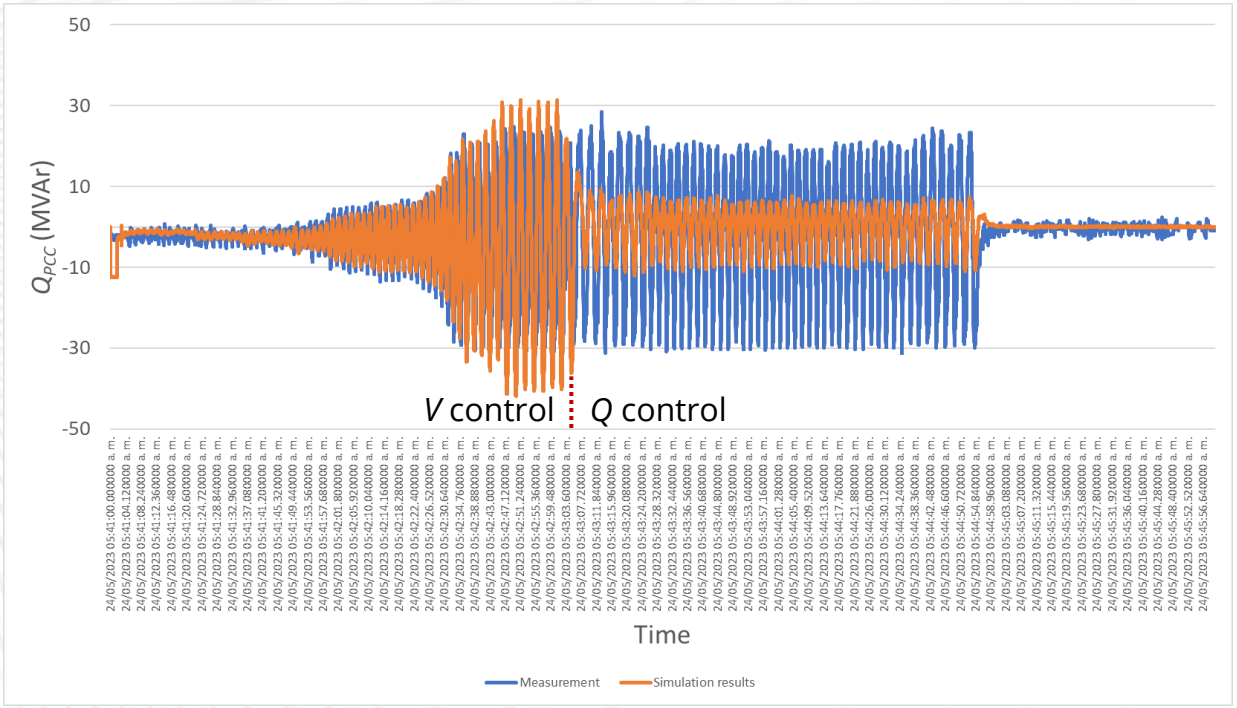
Data-driven simulations in EMTP

- Active power at the PCC (P_{PCC})



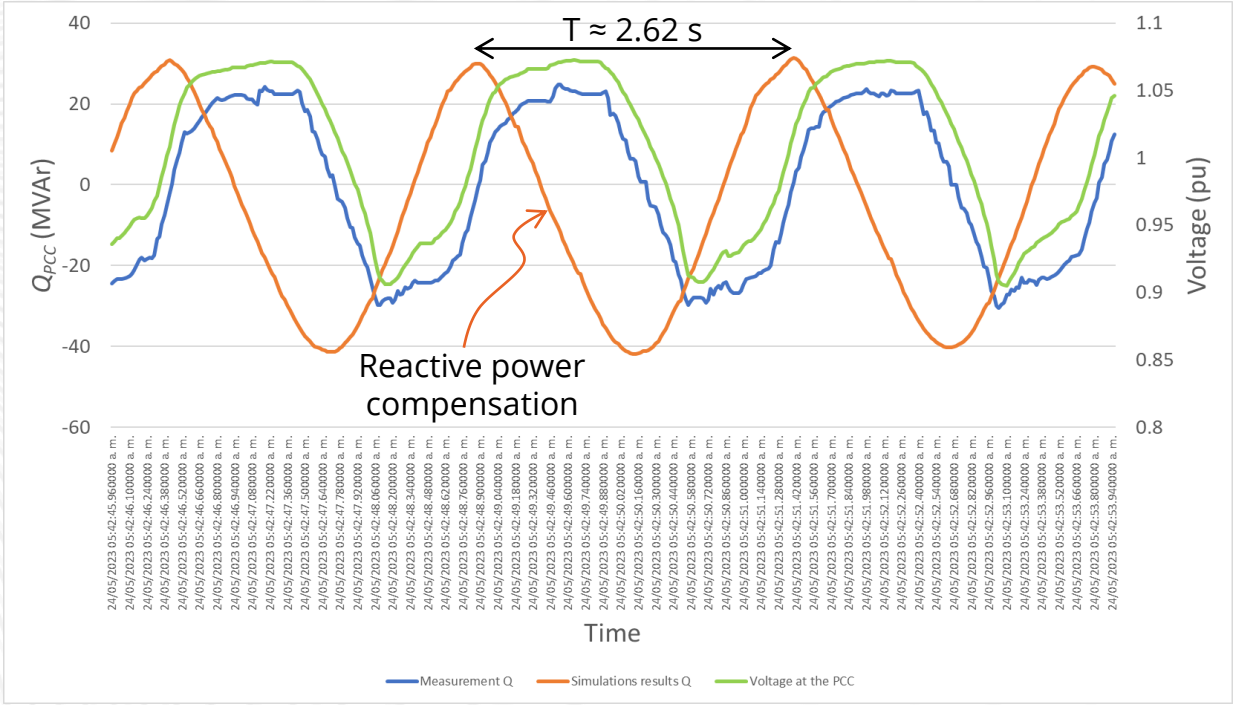
Data-driven simulations in EMTP

- Reactive power at the PCC (Q_{PCC})



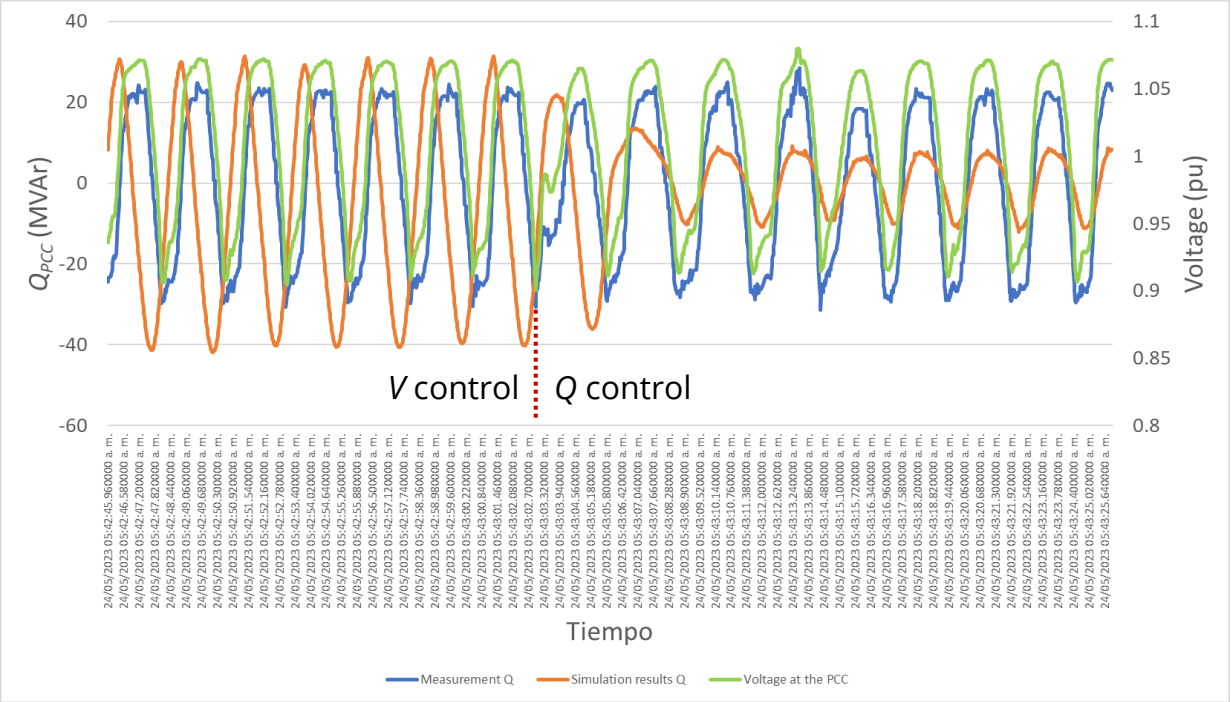
Data-driven simulations in EMTP

- Comparison between Q_{meas}, Q_{sim} and v_{PCC} in voltage control mode.



Data-driven simulations in EMTP

- Comparison between Q_{meas}, Q_{sim} and v_{PCC} in control mode change.



Development of modulation and control schemes in MMC-based STATCOMs

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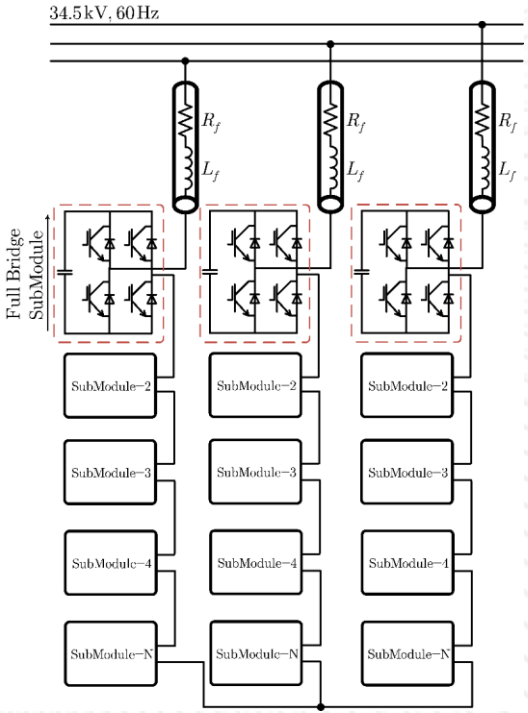
STATCOM topology



Advantages:

- Reduced harmonic distortion
- Modularity and scalability
- High efficiency
- Enhanced control of active and reactive power

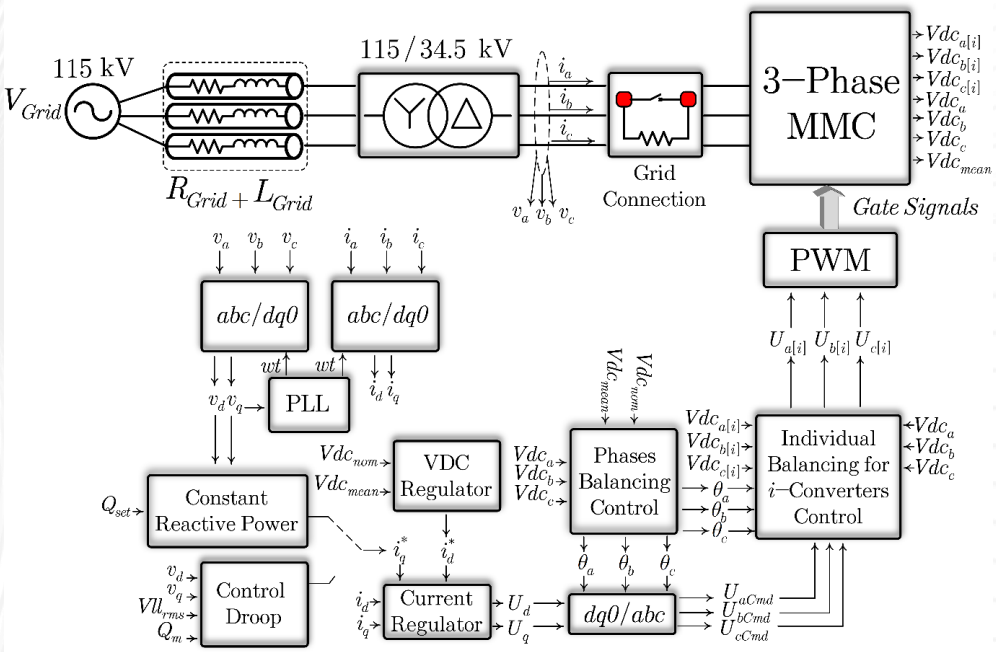
Disadvantages:

- High complexity in control and modulation
- Increased cost and component count
- Capacitor voltage balancing challenges
- Large physical footprint

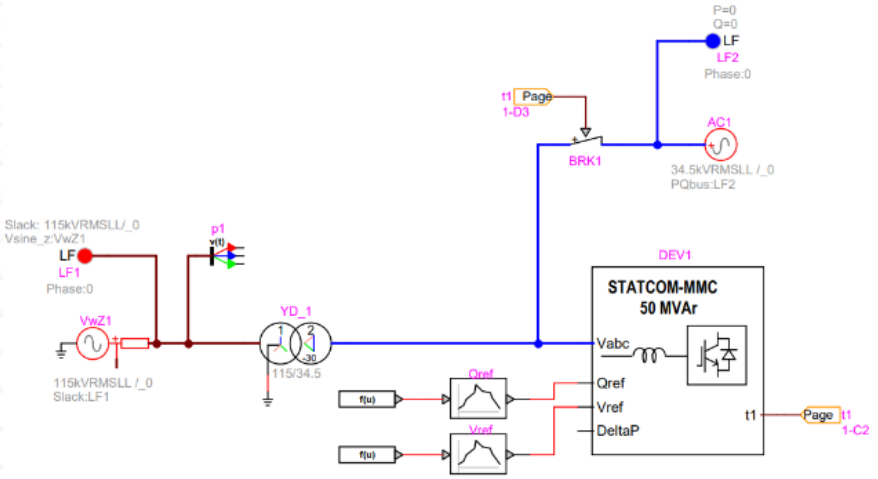
S. Ali, Z. Ling, K. Tian and Z. Huang, "Recent Advancements in Submodule Topologies and Applications of MMC," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 9, no. 3, pp. 3407-3435, June 2021, doi: 10.1109/JESTPE.2020.2990689.

Control system development

- Schematic

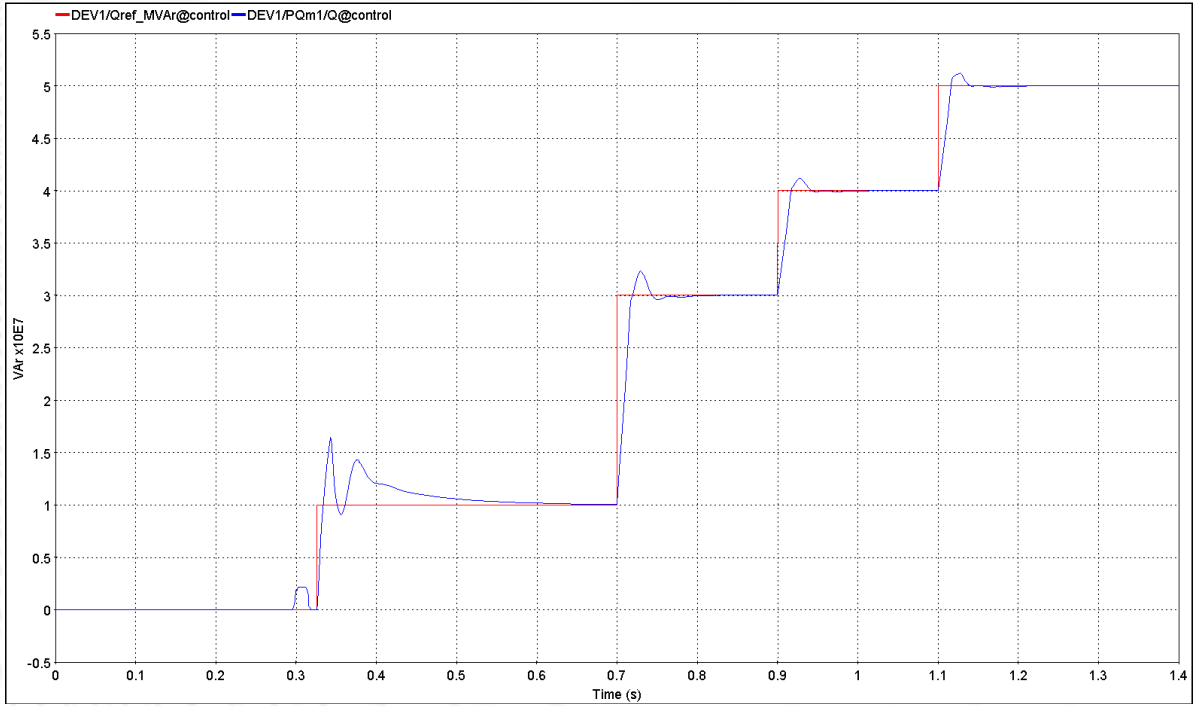


- EMTP implementation



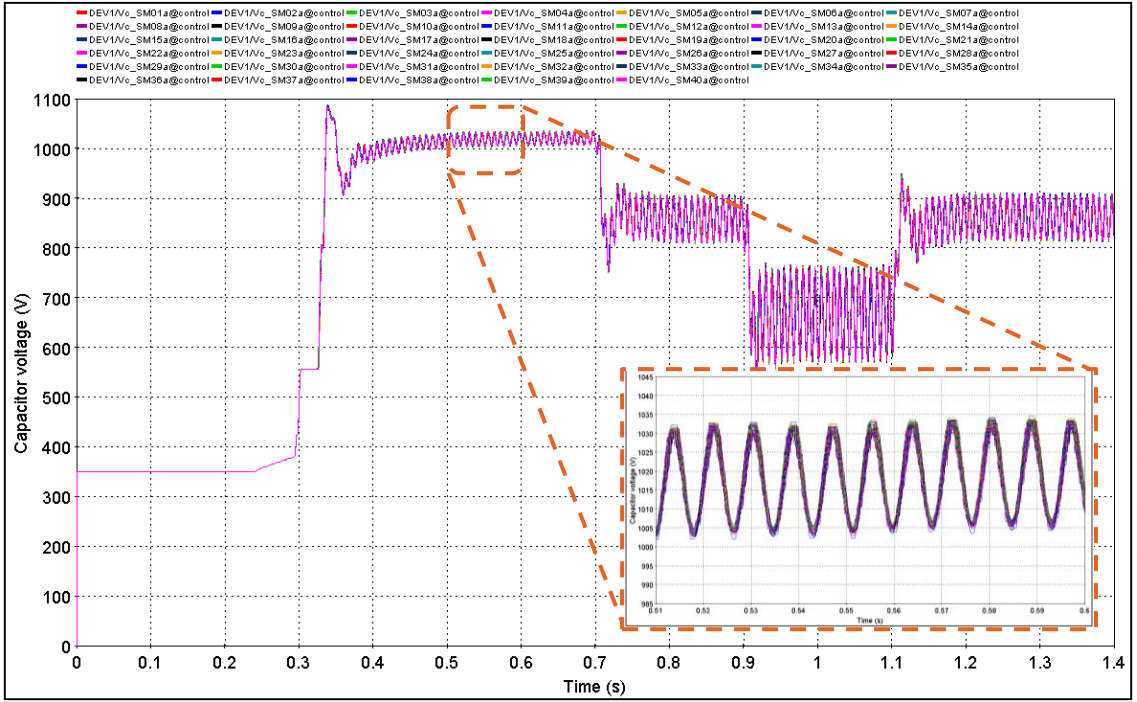
Simulation results

- Reactive power regulation at different operating steps



Simulation results

- Balancing of individual DC bus voltages

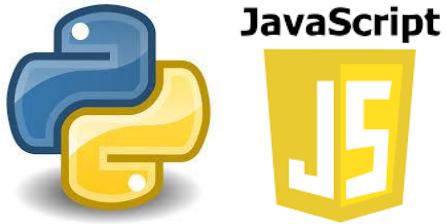


Accelerating MMC Submodule Integration

Developing modulation and control schemes for our MMC-based STATCOM involved the complex task of instantiating and connecting numerous submodules in each upper and lower arm across all three phases.

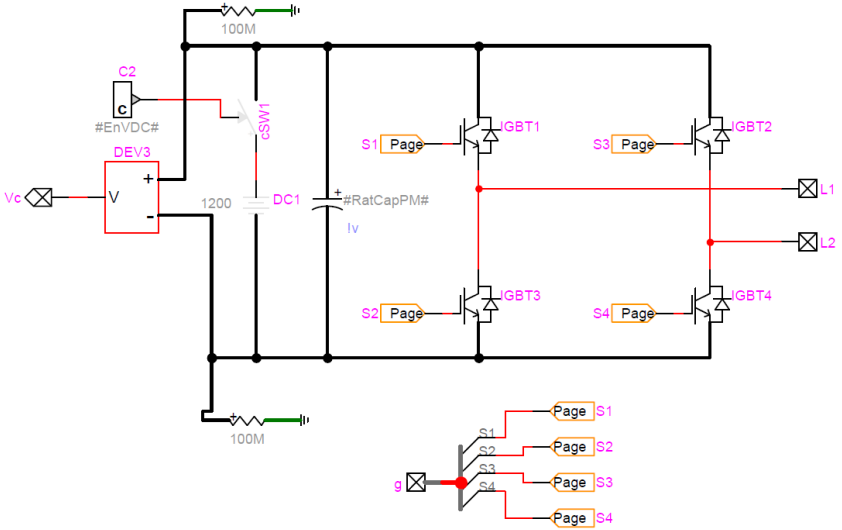
To address this, we implemented a Python/JavaScript-based automation tool that:

- **Generates submodule instances** based on configurable parameters (e.g., number of levels, arm type).
- **Connects submodules** in series within each arm and phase.
- **Assigns identifiers and circuit references** to ensure EMTP model consistency.
- **Validates topology** structure before simulation.

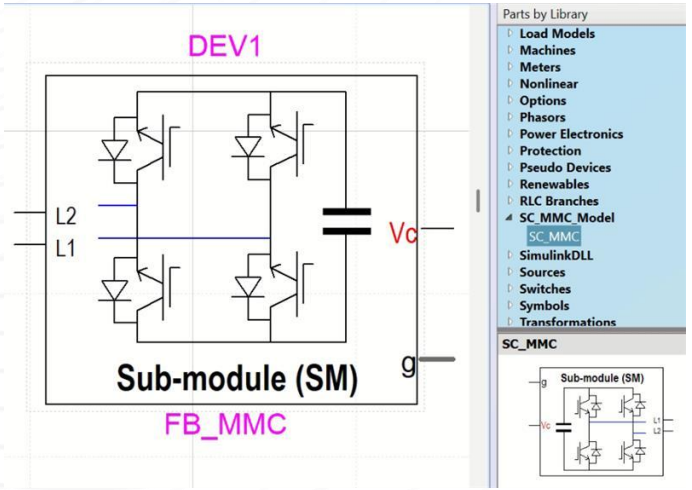


Submodule generation

- Full bridge Submodule



- Subcircuit added to Library



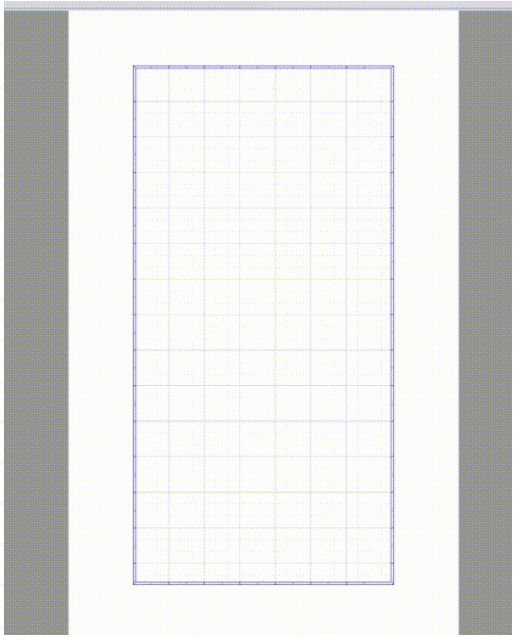
Python implementation

- Python code

EKEME.py

```
63  def placeSubCct(glob, cct):
69      num_x = 3
70      num_y = 10
71      sep_x = 2000
72      sep_y = 2000
73      start_x = 0
74      start_y = 0
75      for i in range(0,num_x, 1):
76          posY = start_y
77          for y in range(0, num_y, 1):
78              renewDev = cct.addDevice("SC_MMC_Model","SC_MMC", start_x, posY)
79              posY += sep_y
80          start_x+= sep_x
81
```

- Subcircuit automatic creation



Conclusions

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Conclusions and open questions (Section 2)

- It is possible to approximate the system dynamics using real data measurements.
- It was determined that the root cause of the disturbance was an external event.
- The reactive power performance obtained from the simulations differs from those obtained in the measurements.
- A correct operation of the wind farm control system allows to mitigate the voltage oscillations on the grid through the reactive power management.
- In contrast, an improper operation of the control system can contribute to the disturbance exacerbation.
- There is non-compliance of the Grid Code.

Open questions:

- Is the voltage and reactive power regulation issue due to an incorrect tuning of the control system?
- Or is it a technological limitation of the control system of the wind farm or wind turbines?

Conclusions and open questions (Section 3)

- It is possible to implement MMC-based STATCOMs in detail in EMTP.
- It is possible to implement a complex modulation schemes in EMTP, thus allowing the correct operation of STATCOMS for reactive power regulation.
- The STATCOM operation was validated at different reactive power values. In addition, compliance with Mexican regulations was verified [16].

References

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Thank you!

Questions?

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