Static synchronous compensator (STATCOM)

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Static synchronous compensators (STATCOMs) are power electronic converters aiming at enhancing the overall power quality and system stability in power grids, by dynamically controlling the reactive power flow and reducing the voltage and current harmonics injected into the grid. [1]

In medium voltage (MV) distribution systems, step-down transformers are commonly used in STATCOMs to reduce the voltage to levels supported by the power electronic switches [1]. Alternatively, cascaded multi-level topologies, such as the star-connected cascaded H-bridge, have been proposed to eliminate the costly and bulky transformer and thus connect the STATCOM directly to the MV grid [2].

This article presents a simple control implementation allowing the control of the reactive power flow at the point of common coupling (PCC) using the star-connected cascaded H-bridge STATCOM. The control strategy is then experimentally validated on a scaled-down prototype using the imperix MMC bundle programmed with the ACG SDK.

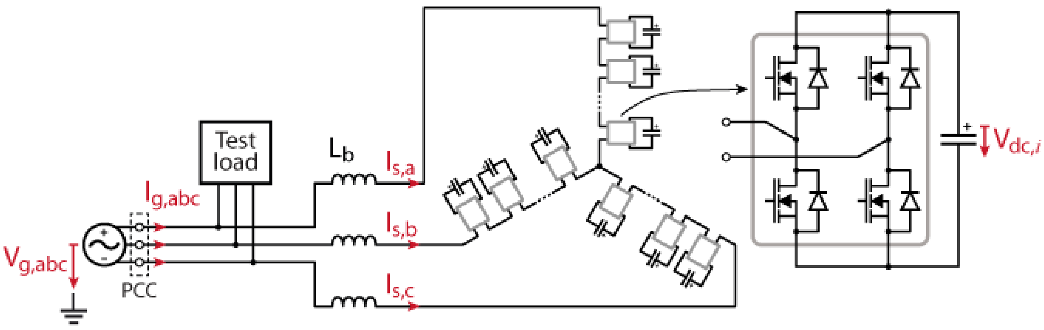

Figure 1: Topology of the star-connected cascaded H-bridge STATCOM.

Control implementation of the STATCOM

The objective of the control presented in this article is the tracking of a desired reactive power setpoint at the grid terminal (PCC) when a test load is generating or consuming reactive power. Additionally, the capacitor voltages $V_{dc,i}$ must be balanced to guarantee a safe and stable operation of the converter. The active reduction of the grid current harmonics is out of the scope of this example, and the test load is thus assumed to be a linear load.

The control of a cascaded H-bridge detailed in TN165 CHB control is used in this example, with the following adaptations:

- The grid currents $I_{g,abc}$ are measured at the PCC and additional current sensors measure the STATCOM currents $I_{s,abc}$.
- The active (d-axis) load current $I_{load,FF,d}$ is reconstructed from $I_{g,d}$ and $I_{s,d}$ and low-pass filtered to ignore possible harmonics at frequencies higher than the fundamental grid frequency.
- The output of the average DC-link voltage controller is the d-axis STATCOM current reference $I_{s,ref,d}$ instead of the d-axis grid current reference $I_{g,ref,d}$. $I_{g,ref,d}$ is then obtained after feed-forwarding the d-axis load current $I_{load,FF,d}$.
- Since the converter currents are named I_s instead of I_g, I_s is used in place of I_g in the decoupling for the dq current control and in the voltage balancing.

The overall control block diagram is depicted in Figure 2. All blocks in black color are taken directly from the example TN165 CHB control.

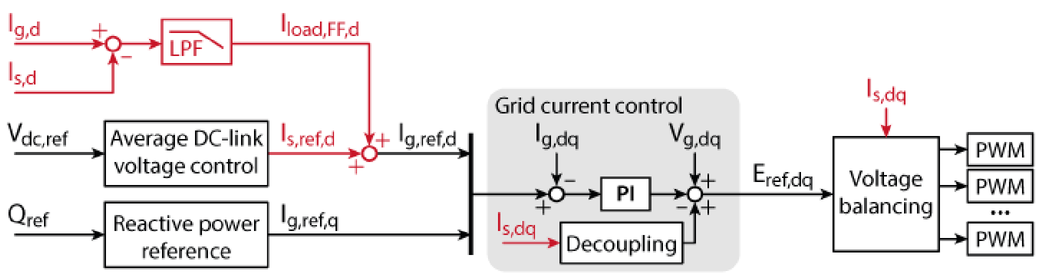

Figure 2: Control diagram of the STATCOM. Adaptations in red compared to TN165.

Experimental validation of the STATCOM controller

Test setup

The control algorithm presented in the previous section is validated on a scaled-down prototype shown in Figure 3. The STATCOM is implemented using a slightly modified MMC bundle with 8 H-bridge modules (PEH2015) per phase and extended with 3 optical expansion boards to obtain 16 PWM signal pairs per phase. The grid is taken from the standard 230/400V 50Hz mains and the average DC-link voltage setpoint is chosen as 50V.

The test load is emulated using a programmable inverter (TPI8032), controlled as a grid-following inverter (see TN167 for an implementation example). This allows a freely selectable amount of reactive power to be generated or consumed.

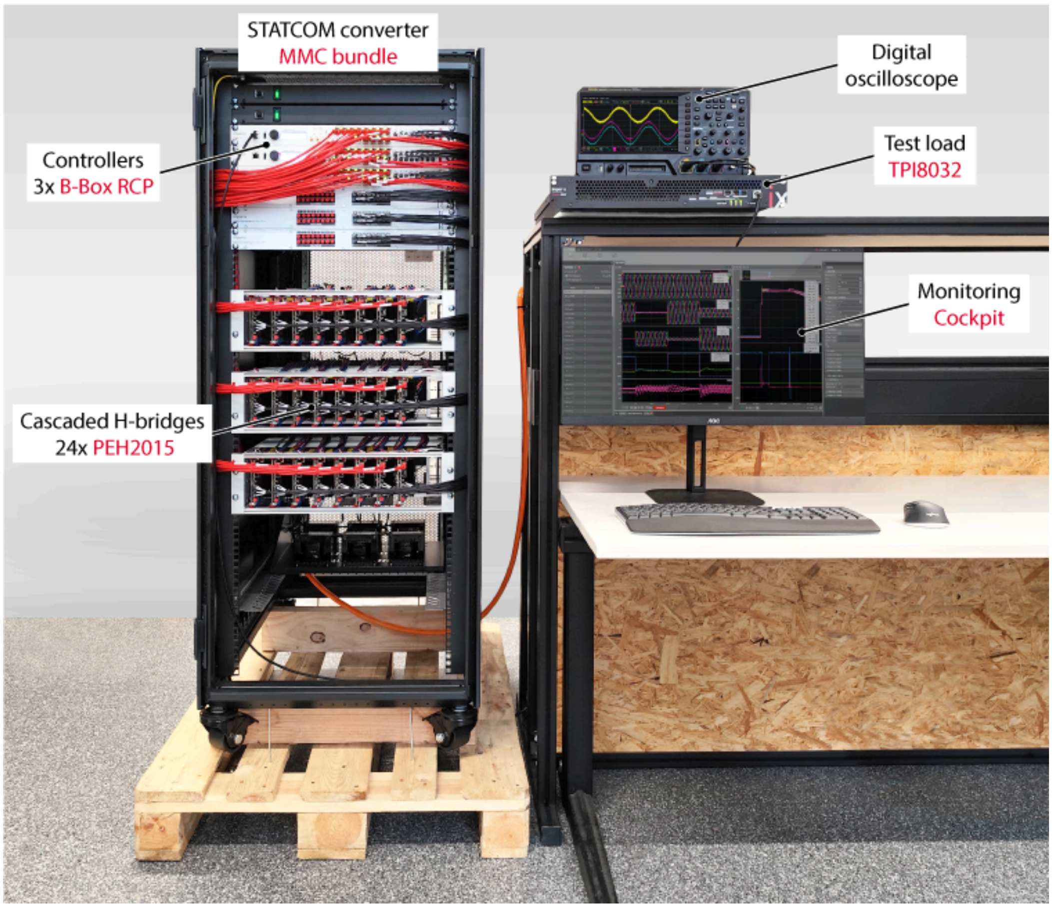

Figure 3: Picture of the test setup including the STATCOM prototype, the test load, an oscilloscope, and a desktop computer running Cockpit.

Test results

To validate the implemented control, the code generated by the ACG SDK is loaded onto the master B-Box RCP. The linear load emulated by the TPI using the control in TN167 is set to 4kVar (inductive behavior). In Cockpit, the following test sequence is initiated and a scope module monitors the relevant signals (Figure 4):

- t < 1 s: The STATCOM is inactive and the 4kVar generated by the load (TPI8032) flow into the grid.
- t = 1 s: The STATCOM is activated with a reference reactive power at the PCC of 0Var. This efficiently suppresses the grid currents $I_{g,a}$, $I_{g,b}$ and $I_{g,c}$.
- t = 1.1 s: The reactive power reference at the PCC steps to 5kVar (inductive)
- t = 1.2 s: The reactive power reference at the PCC steps to -2kVar (capacitive).

During the whole test sequence, it can be seen that the 24 capacitor voltages $V_{dc,A0}$ to $V_{dc,C7}$ remain balanced despite unavoidable transient perturbations at the reactive power steps. The maximum transient imbalance does not exceed the amplitude of the voltage pulsation, which can be considered satisfactory.

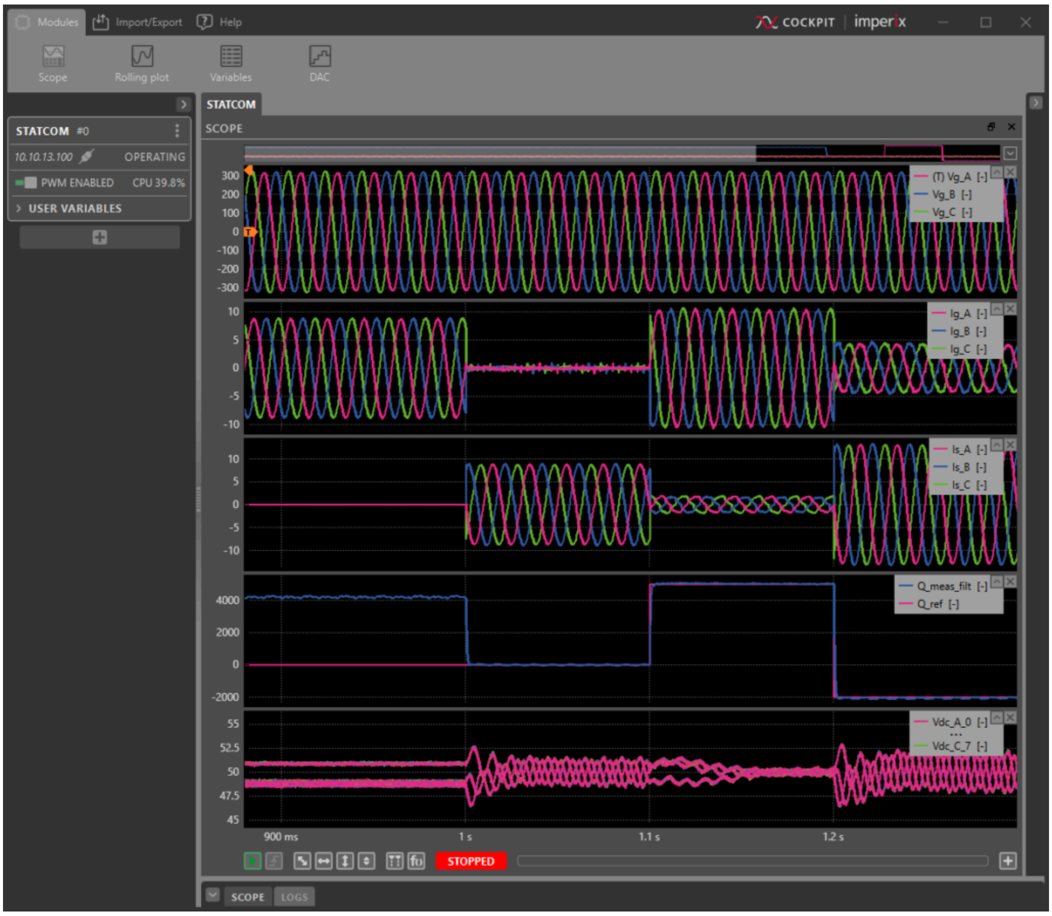

Figure 4: Test sequence of the STATCOM initiated and monitored with the Cockpit software.

Additionally, the voltage generated by the STATCOM converter in phase A is measured using a differential voltage probe and an oscilloscope (CH1, yellow). It can be verified in Figure 5 that the voltage has a staircase shape with 2*N+1 = 17 levels. The screenshot in Figure 5 is taken at t = 1.05 s, when the STATCOM current (phase A, CH2, cyan) matches the purely reactive load current (phase A, CH3, magenta). This means that the grid current (difference between load current and STATCOM current) vanishes and the reactive power of the load is compensated by the STATCOM.

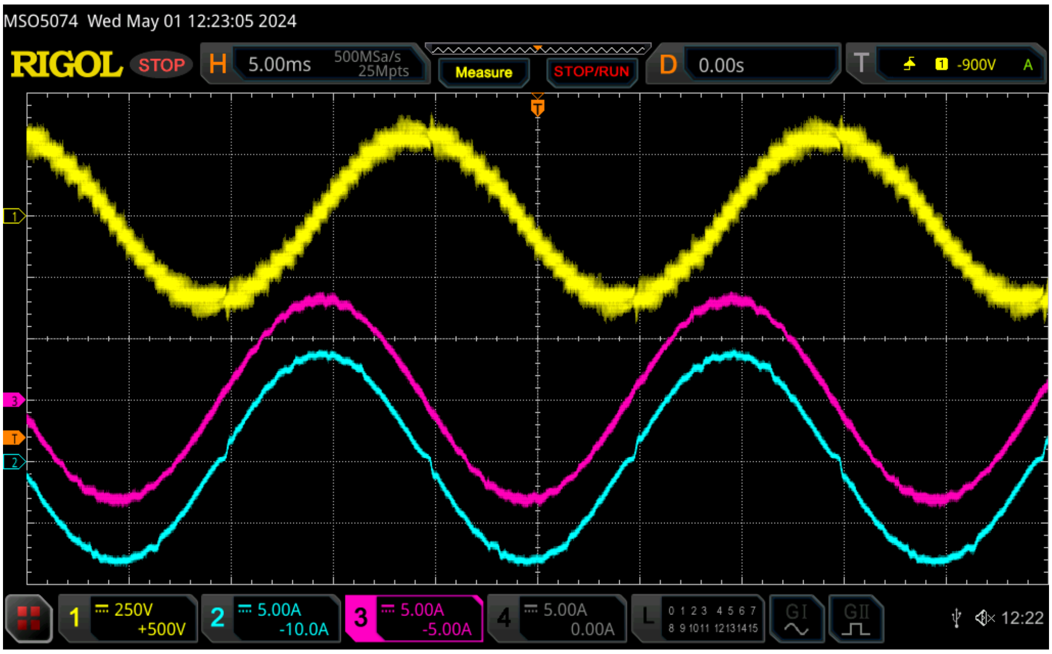

Figure 5: CH1 (yellow) generated converter voltage in phase A, CH2 (cyan) STATCOM converter current in phase A (Is,a), CH3 (magenta) load current in phase A. Taken at 1.05 s in Figure 4.

Downloads

Two sets of files are proposed, suitable for implementing the STATCOM control and simulating its behavior in MATLAB Simulink or Plexim PLECS environment.

Simulink model

Download **AN013_STATCOM_Simulink.zip**

PLECS model

Download **AN015_STATCOM_PLECS.zip**

Minimum requirements:

- Imperix ACG SDK 2024.1.1 or newer.
- For control code development and simulation in Simulink:
  - MATLAB Simulink R2016a or newer

- For control code development and simulation in PLECS:
    - Plexim PLECS 4.5 or newer.

To go further

Another possible application of the cascaded H-bridge control (TN165) used in this example with reactive power control is the MV-LV solid-state transformer (AN015).

In some applications, the reactive power flow at the PCC is used to stabilize the grid voltage. There, the reactive power setpoint is dynamically adjusted by a higher-level controller. This concept is for instance used in Proportional droop control (TN169), Virtual synchronous generator for droop control (TN170) and Virtual impedance for droop control (TN171).

Academic references

[1] Y. Liang, C. O. Nwankpa, “A New Type of STATCOM Based on Cascading Voltage-Source Inverters with Phase Shifted Unipolar SPWM,” in IEEE Transactions on Industry Applications, vol. 35, no. 5, September/October 1999.

[2] H. Akagi, S. Inoue, T. Yoshii, “Control and Performance of a Transformerless Cascade PWM STATCOM With Star Configuration,” in IEEE Transactions on Industry Applications, vol. 43, no. 4, July/August 2007.