Electric Energy Conversion

8. DC/AC converters – part 2

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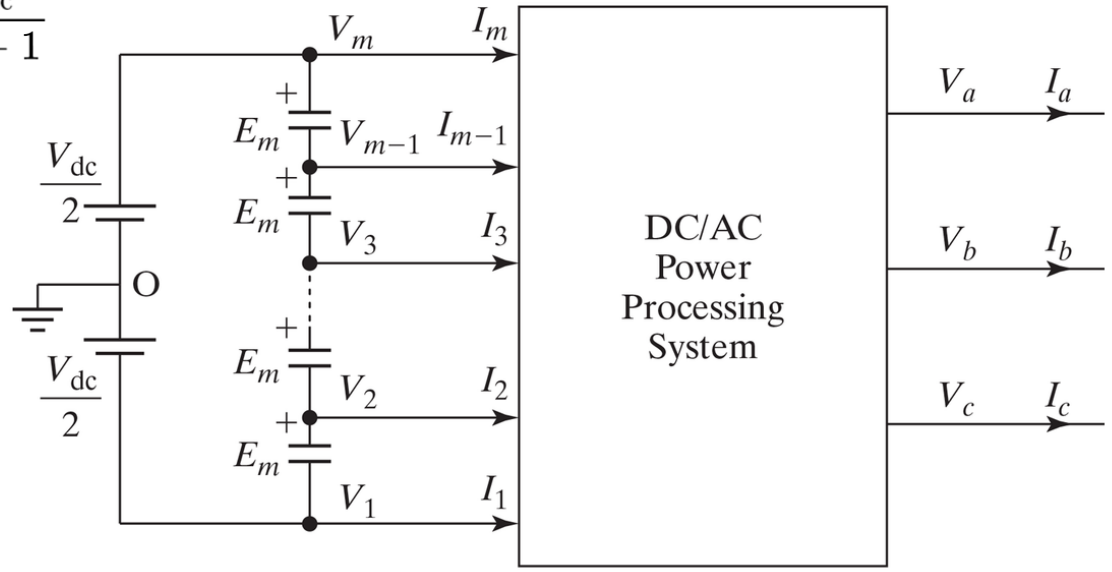
Outline

- Multilevel inverters
- Simulation

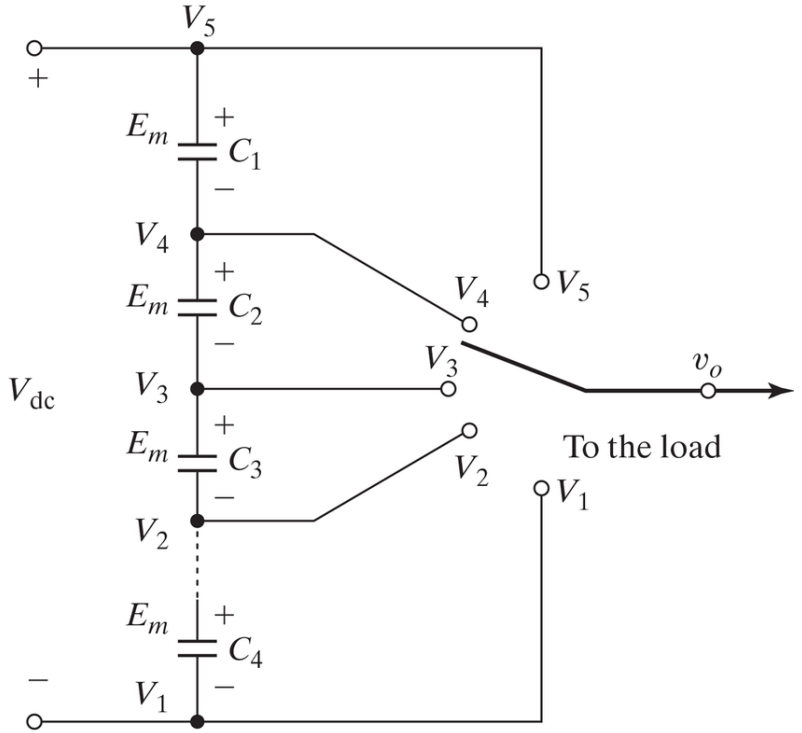
Introduction

- Multilevel inverters have drawn much interest in the power industry, transportation and renewable energy.
- With multilevel inverters, it is easier to produce high-power, high-voltage inverters due to how device voltage stresses are controlled in the structure.
- With higher voltage levels, lower switching frequencies can be used, producing higher quality waveforms.

$$E_m = \frac{V_{\text{dc}}}{m-1}$$



(a) Three-phase multilevel power processing system

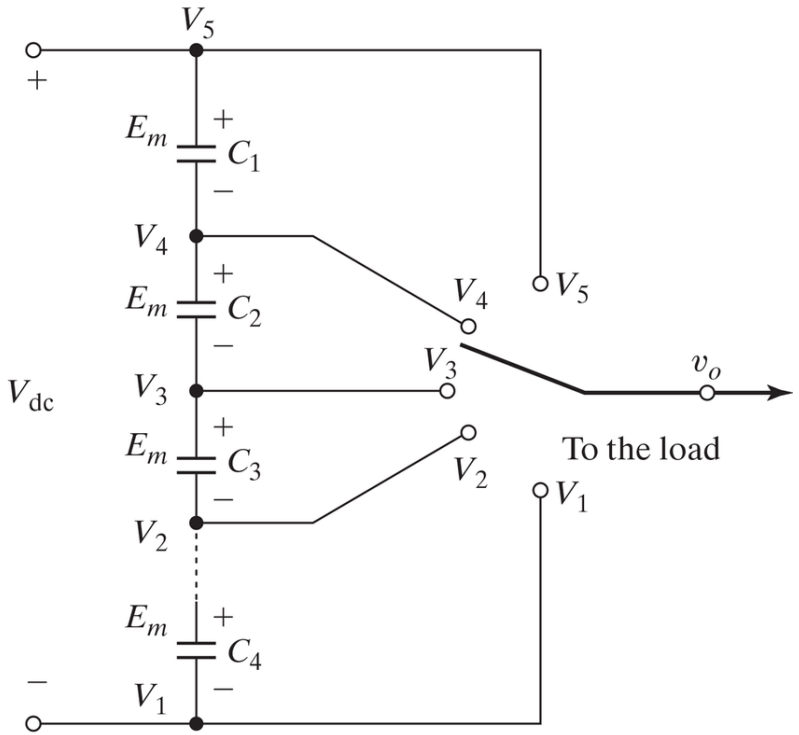


(b) Schematic of single pole of multilevel inverter

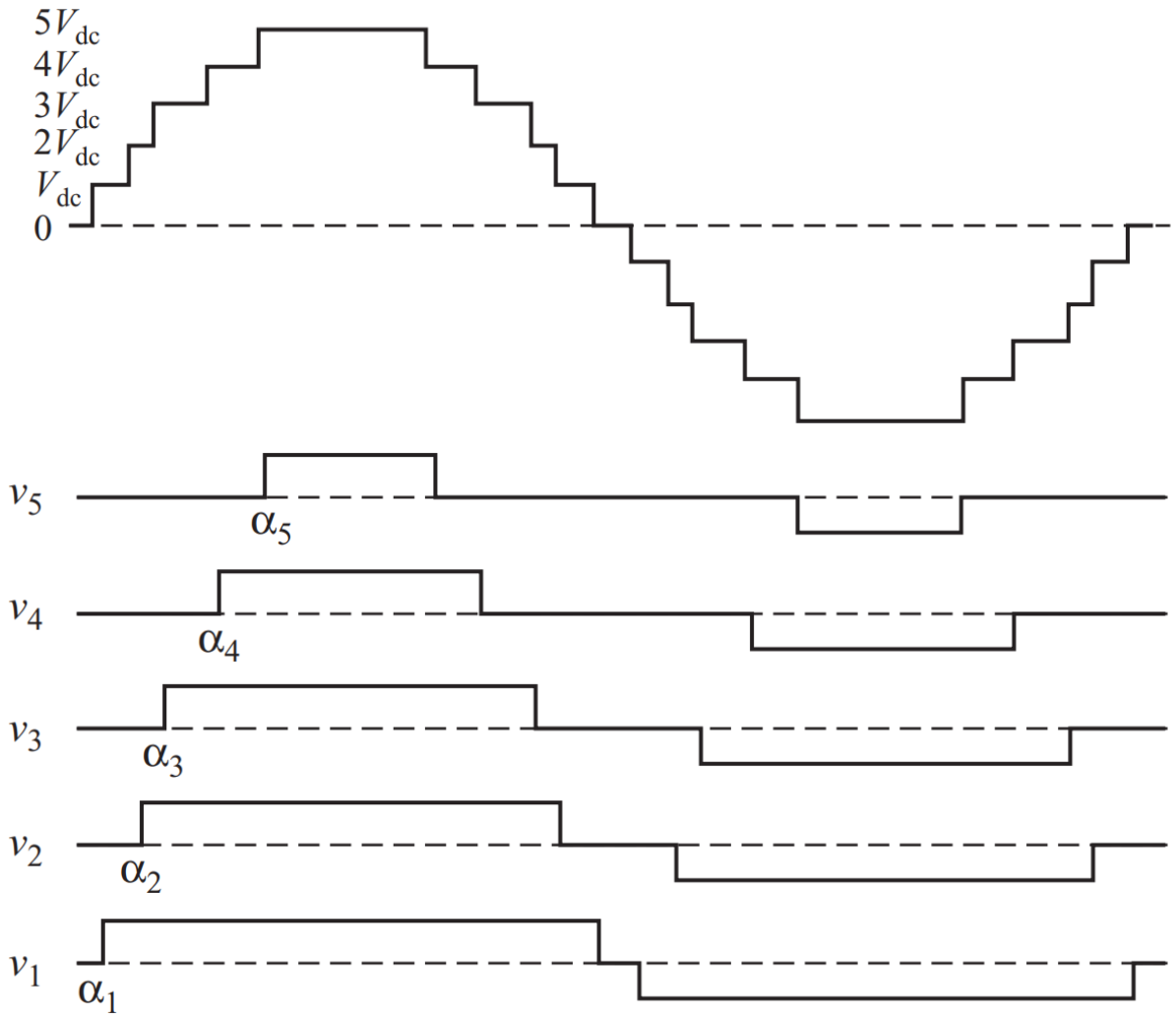
Principle of operation – half-bridge

- The AC waveform is generated from the series connection of charged capacitors.

$$E_m = \frac{V_{dc}}{m-1}$$



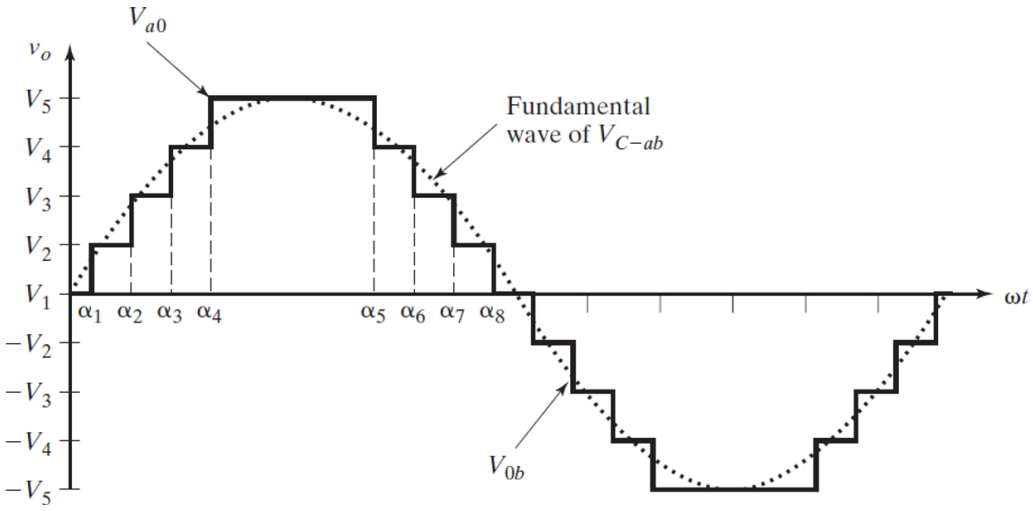
(b) Schematic of single pole of multilevel inverter

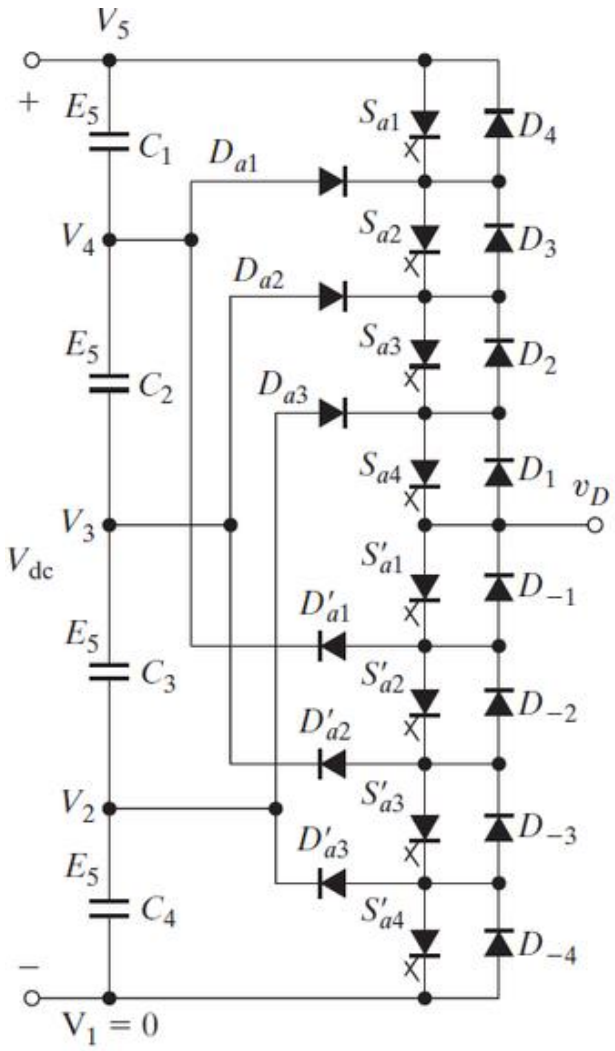


Diode-clamped multilevel inverter

- The diode-clamped topology typically consists of (m-1) capacitors on the DC bus and produces m voltage levels. The switches are turned ON in the staircase.
- Although each switch is required to a block a voltage level of $V_{dc}/(m-1)$, the campled diodes need to have different reverse voltage blocking ratings.
- Excessive number of campling diodes are required when the number of levels is high.
- Improved topologies were proposed.

	Switch State							
Output v_{a0}	S_{a1}	S_{a2}	S_{a3}	S_{a4}	S'_{a1}	S'_{a2}	S'_{a3}	S'_{a4}
$V_5 = V_{dc}$	1	1	1	1	0	0	0	0
$V_4 = 3V_{dc}/4$	0	1	1	1	1	0	0	0
$V_3 = V_{dc}/2$	0	0	1	1	1	1	0	0
$V_2 = V_{dc}/4$	0	0	0	1	1	1	1	0
$V_1 = 0$	0	0	0	0	1	1	1	1





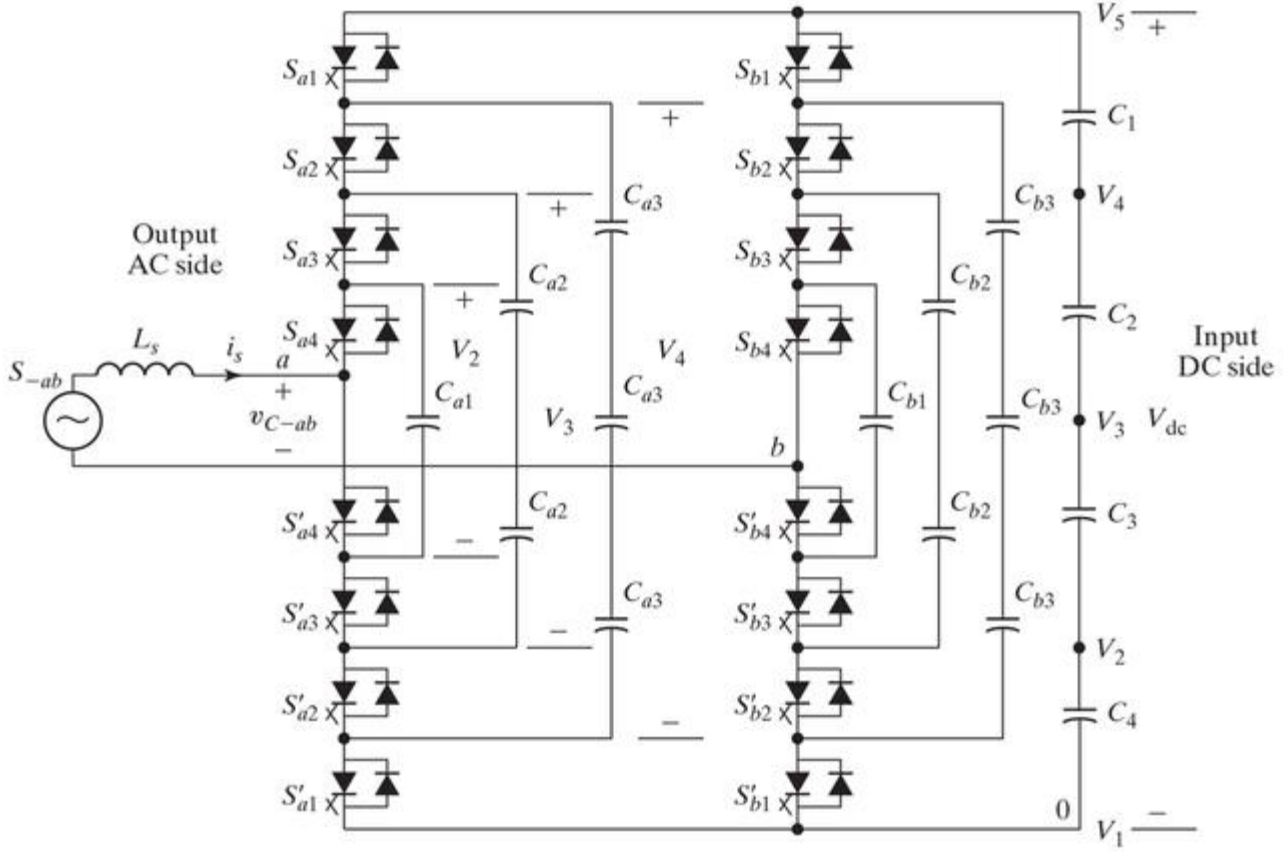
(a) One leg of a bridge

Flying-Capacitors Multilevel Inverter

- The flying-capacitors topology consists on an inner loop of balancing capacitors to provide the required voltage steps.
- This topology requires (m-1)x(m-2)/2 capacitors, more than other topologies

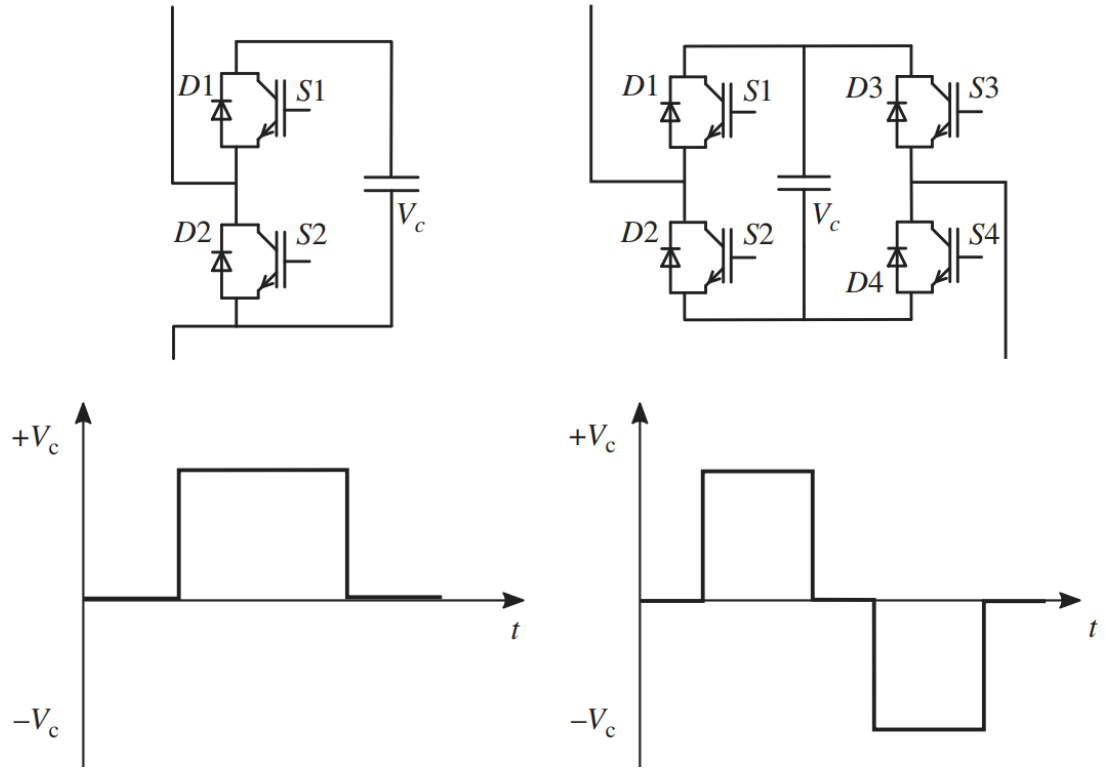
	Switch State							
Output v_{a0}	S_{a1}	S_{a2}	S_{a3}	S_{a4}	S'_{a4}	S'_{a3}	S'_{a2}	S'_{a1}
$V_5 = V_{dc}$	1	1	1	1	0	0	0	0
$V_4 = 3V_{dc}/4$	1	1	1	0	1	0	0	0
$V_3 = V_{dc}/2$	1	1	0	0	1	1	0	0
$V_2 = V_{dc}/4$	1	0	0	0	1	1	1	0
$V_1 = 0$	0	0	0	0	1	1	1	1

Single-phase example



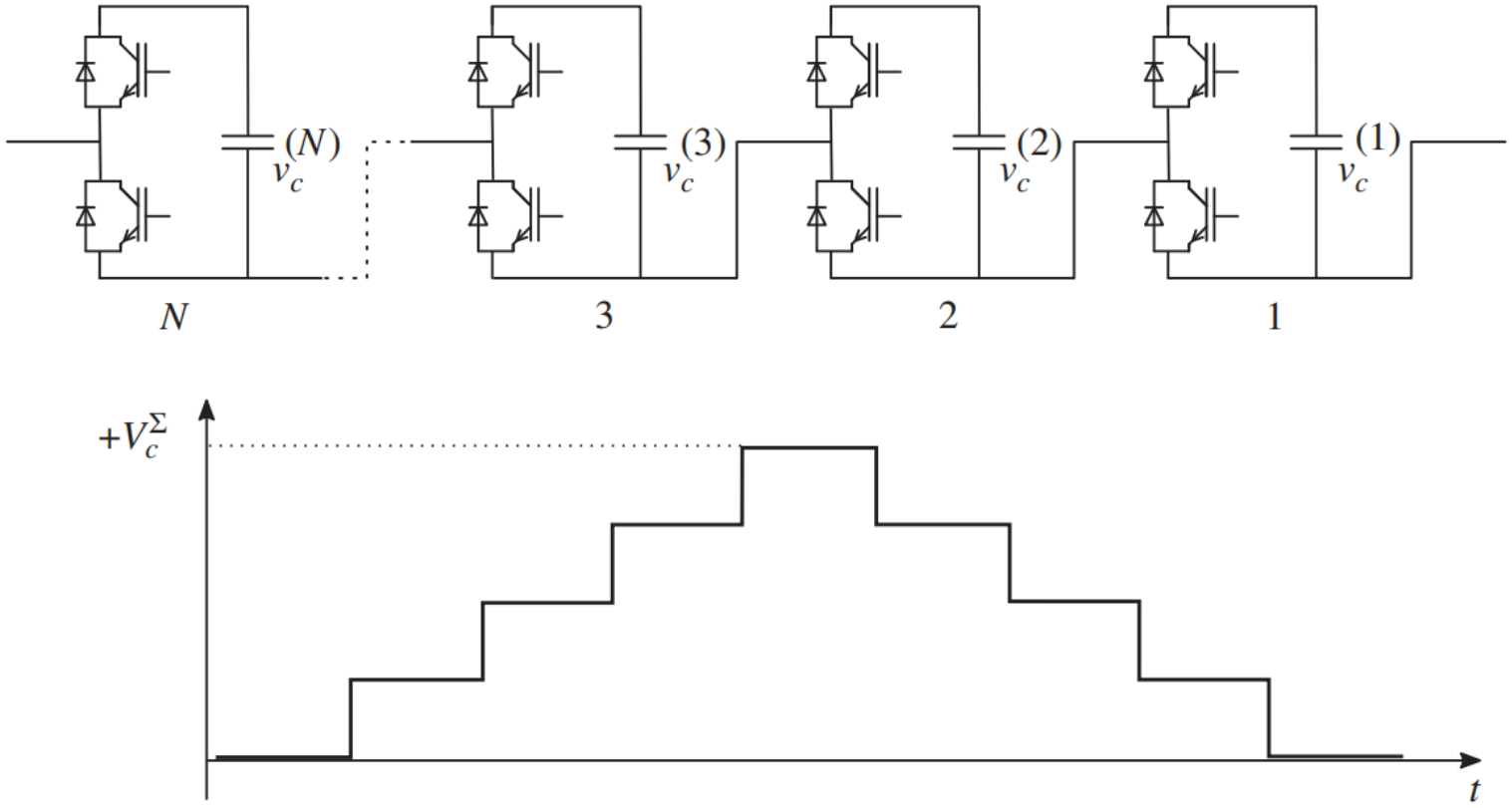
Cascaded Multilevel Inverter

- The building blocks of cascaded multilevel converters are the switching submodules (also called cells).
- The submodules can be half-bridge or full-bridge. The half-bridge can generate 0 or $+V_c$ and the full bridge can generate three voltage levels: 0, $+V_c$, $-V_c$. When the switching function is 0 the submodule is bypassed. When it is 1 the submodule is inserted. The full bridge has two switching functions.



Cascaded Multilevel Inverter

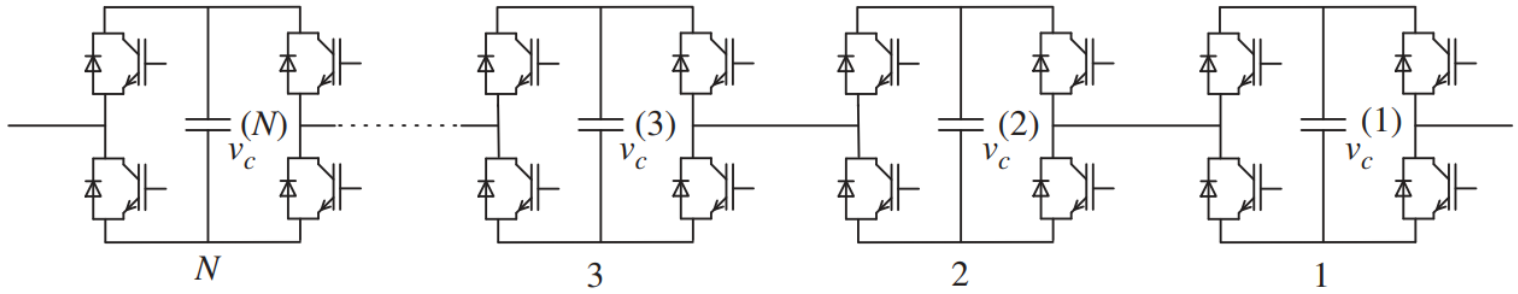
- Example with cascaded half-bridges

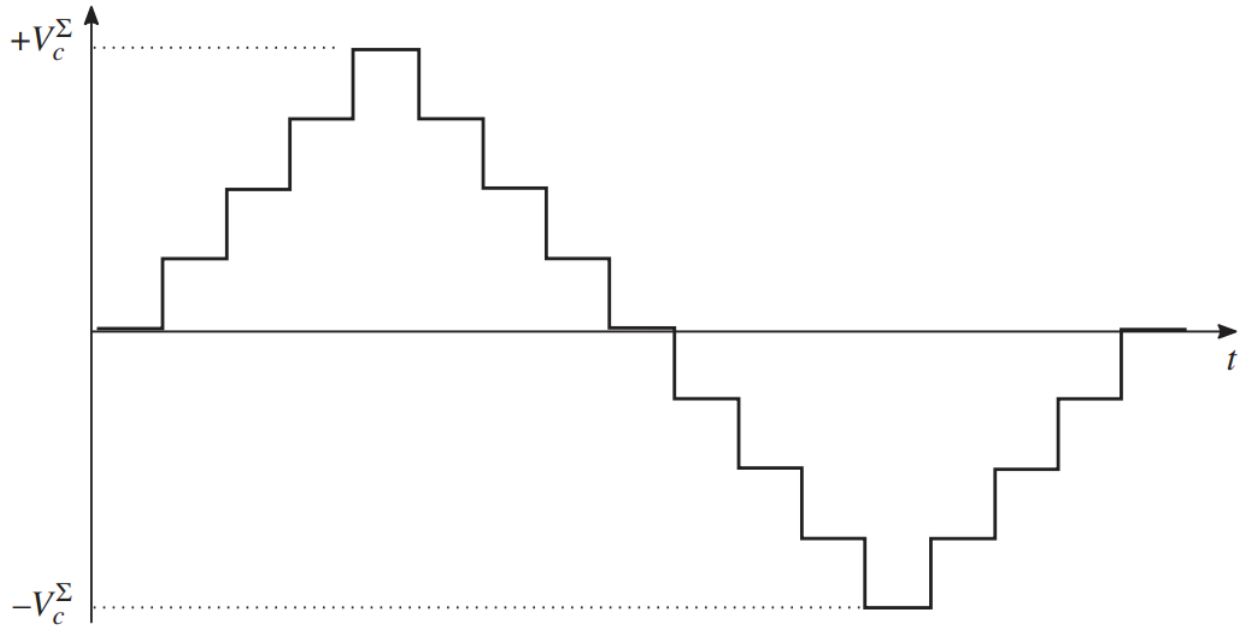


Half-bridge string and possible voltage levels

Cascaded Multilevel Inverter

- Example with cascaded full-bridges

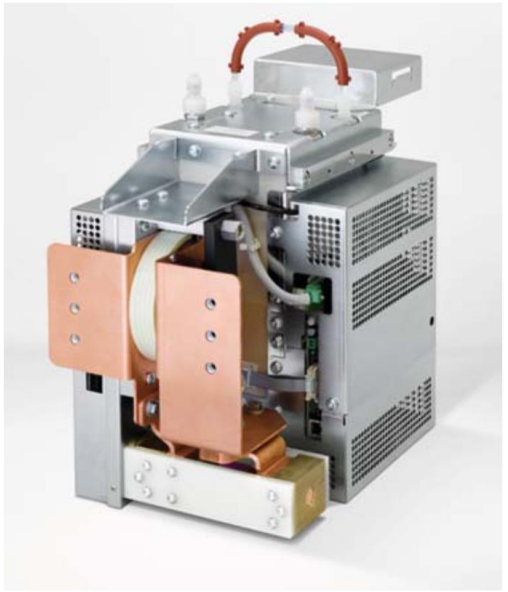


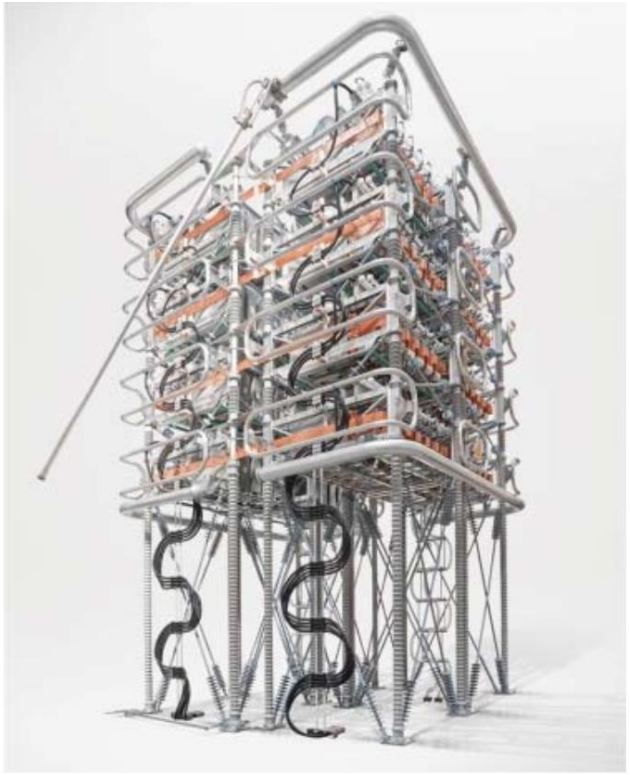


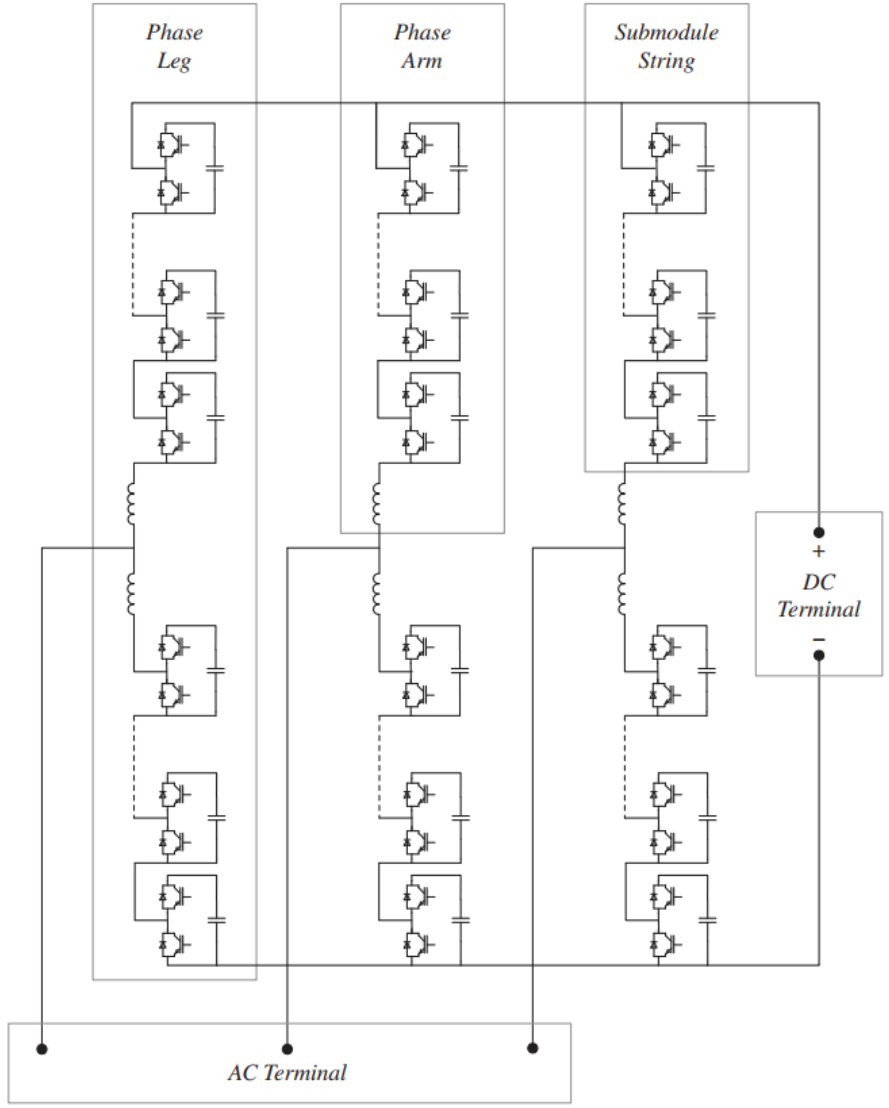
Full-bridge string and possible voltage levels

Modular Multilevel Converter

- An AC voltage waveform can be produced either with half-bridges or full-bridges.
- In the star configuration the submodules are connected such that the midpoint of the string is connected to the grid,

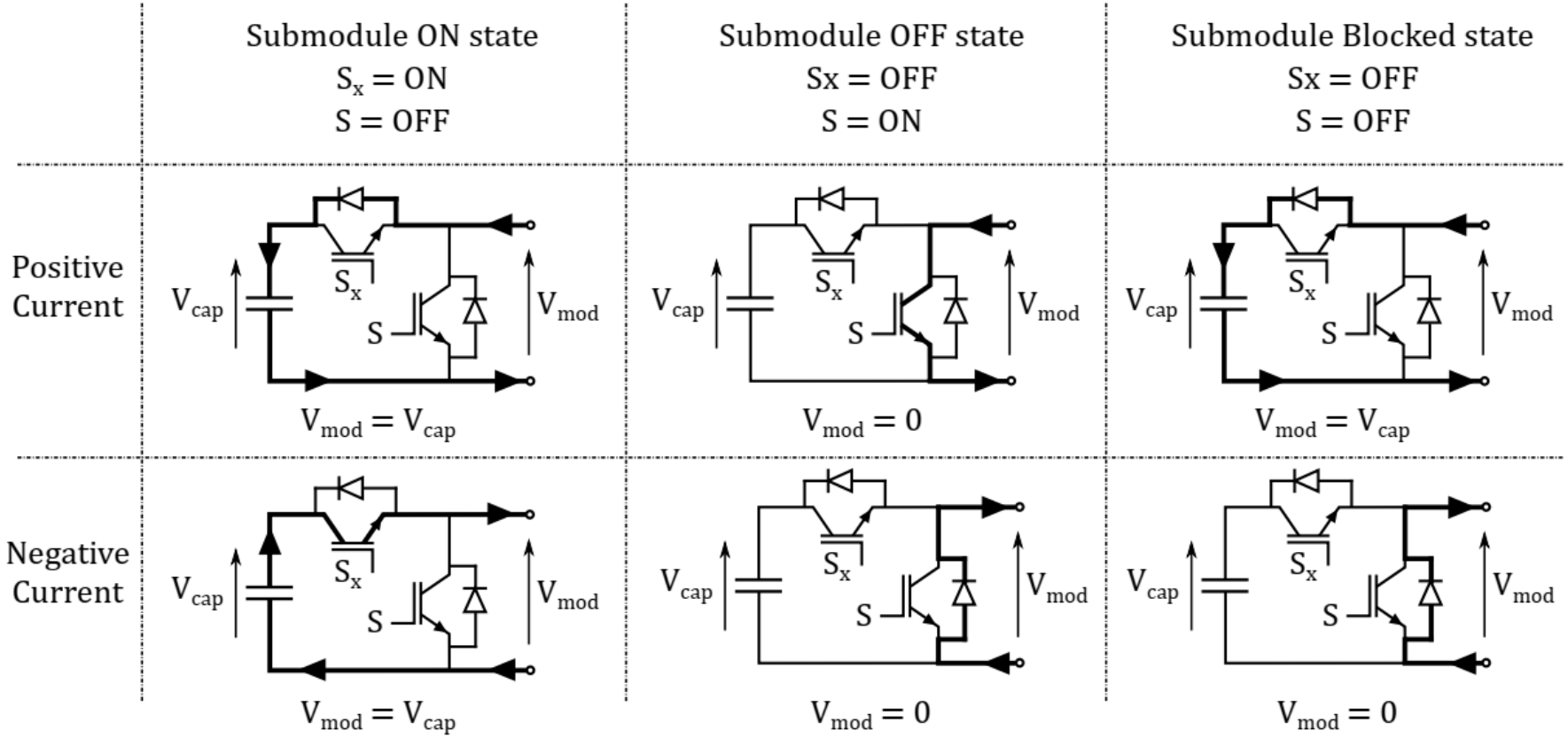






Modular Multilevel Converter

- Depending on the sign of the current, the capacitors can charge or discharge. As a consequence, the energy across capacitors is not balanced. Thus, an energy balance algorithm is used to keep the capacitors evenly charged.

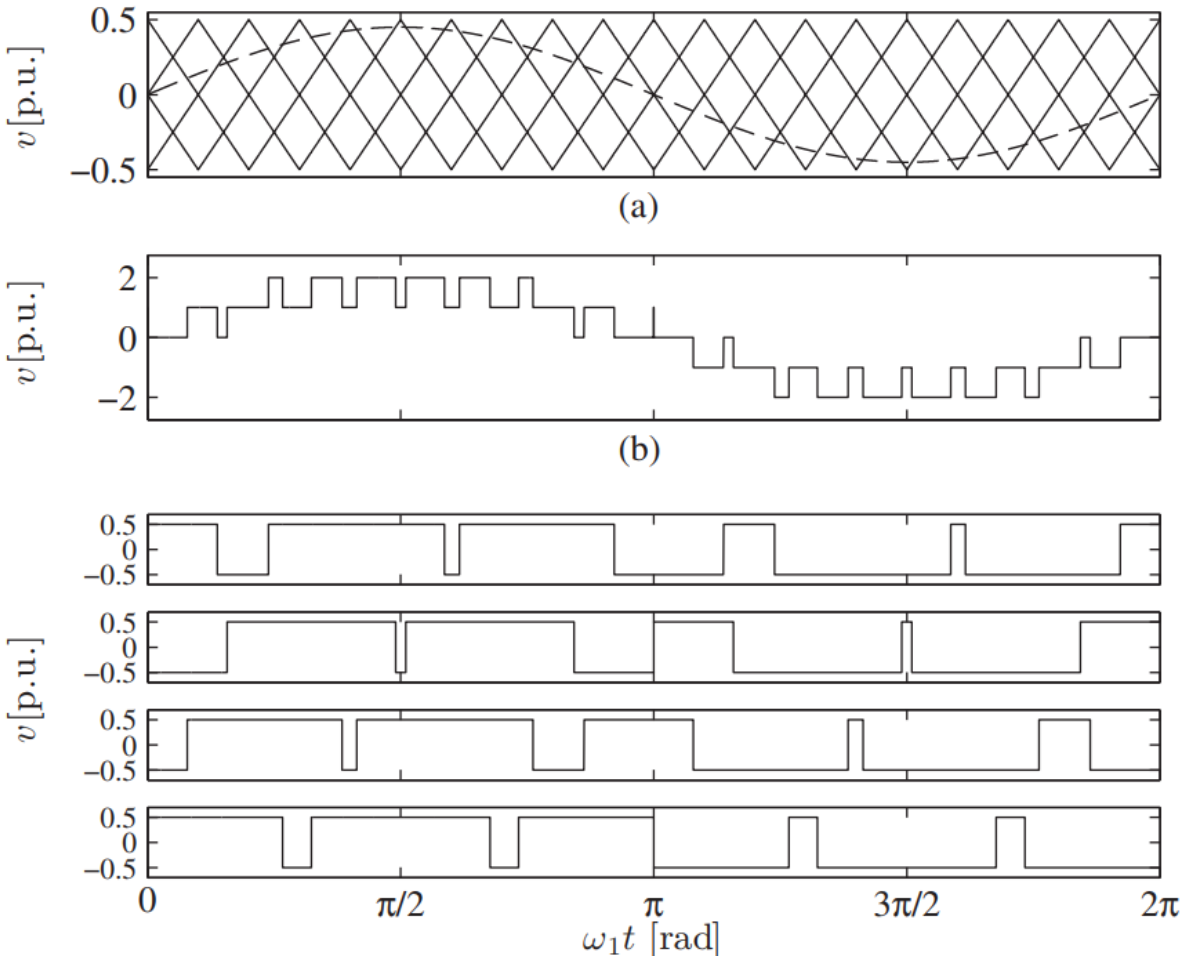


Source: CIGRE Working Group B4-57. Technical Brochure 604: Guide for the Development of Models for HVDC Converters in a HVDC Grid

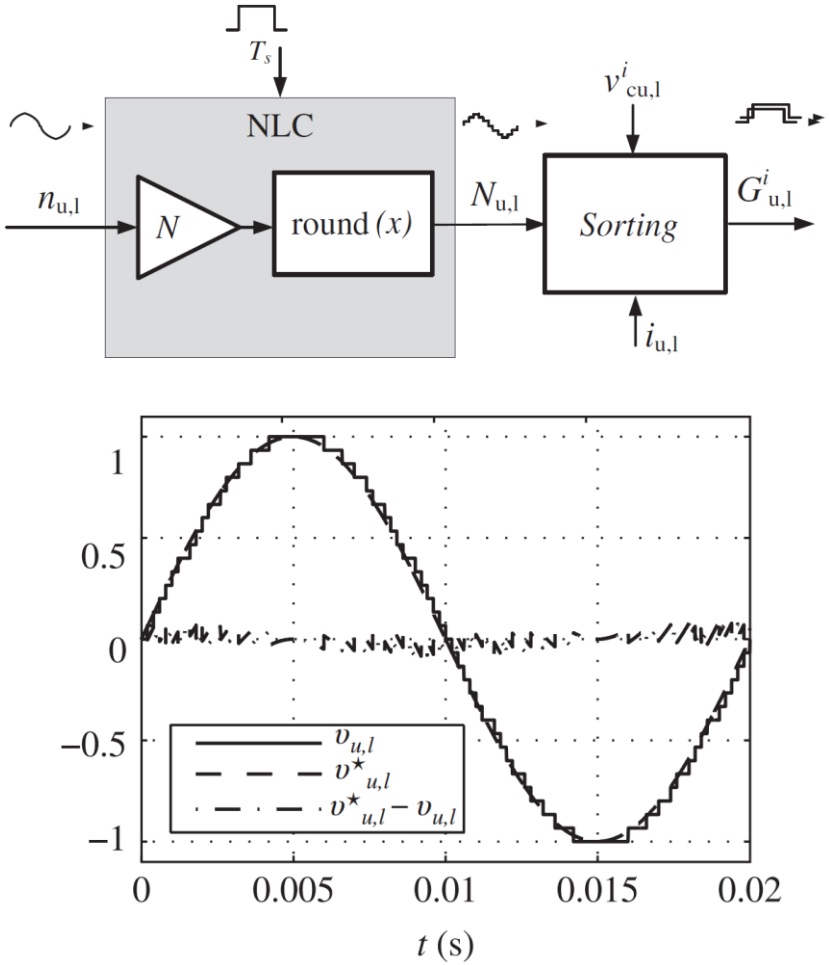
Modular Multilevel Converter

- There are two main types of modulation for MMCs:

Multilevel PWM



Nearest-level modulation

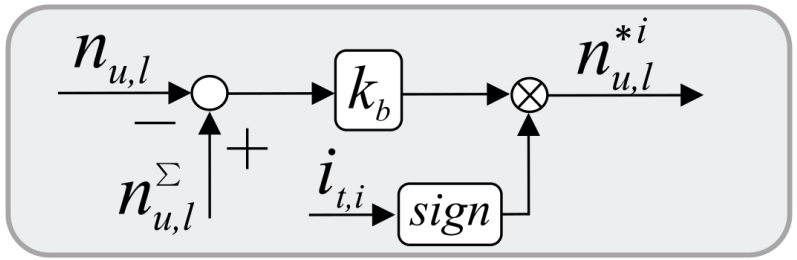


Source: Sharifabadi, K., Harnefors, L., Nee, H. P., Norrga, S., & Teodorescu, R. (2016). Design, control, and application of modular multilevel converters for HVDC transmission systems. John Wiley & Sons.

Modular Multilevel Converter

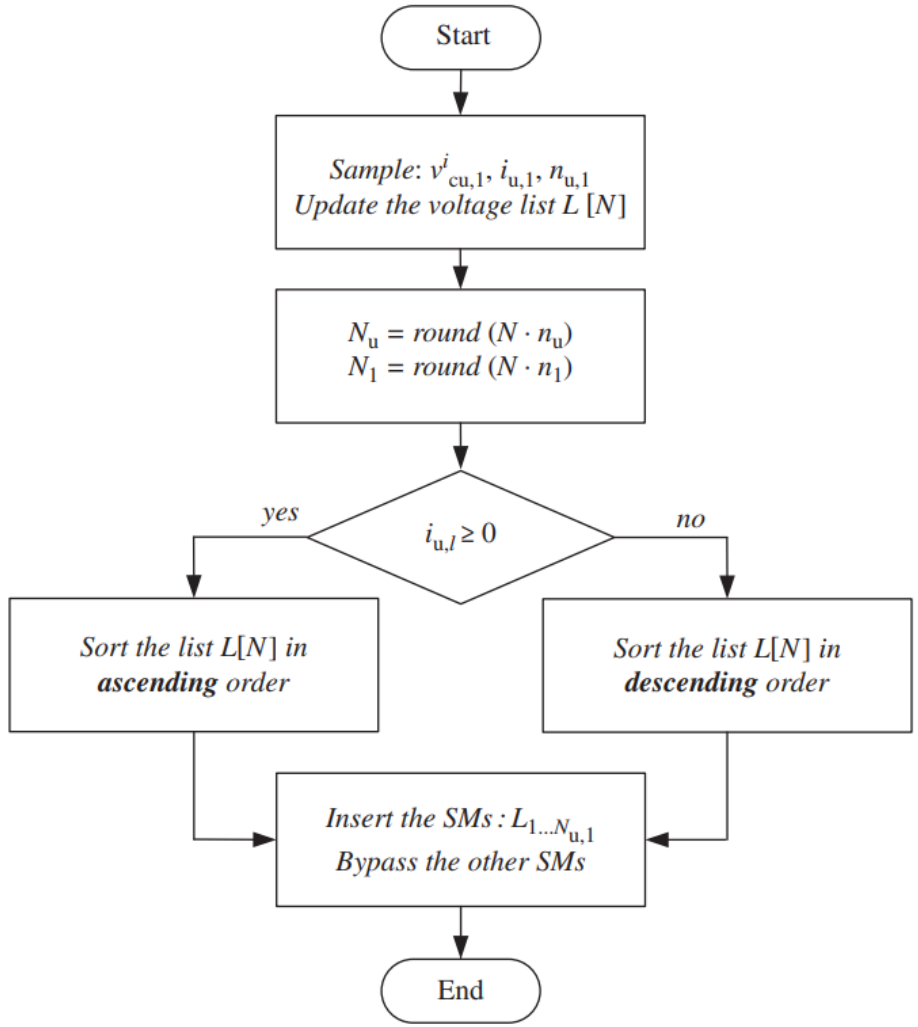
- Energy balance

Multilevel PWM



- The modulation index of each cell is modified by a factor that depends on the difference between the voltage of one capacitor with respect to the average voltage of the arm.
- If the current is positive, the modulation index is reduced. If the current is negative, the modulation index is increased.

Nearest-level modulation



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Outline

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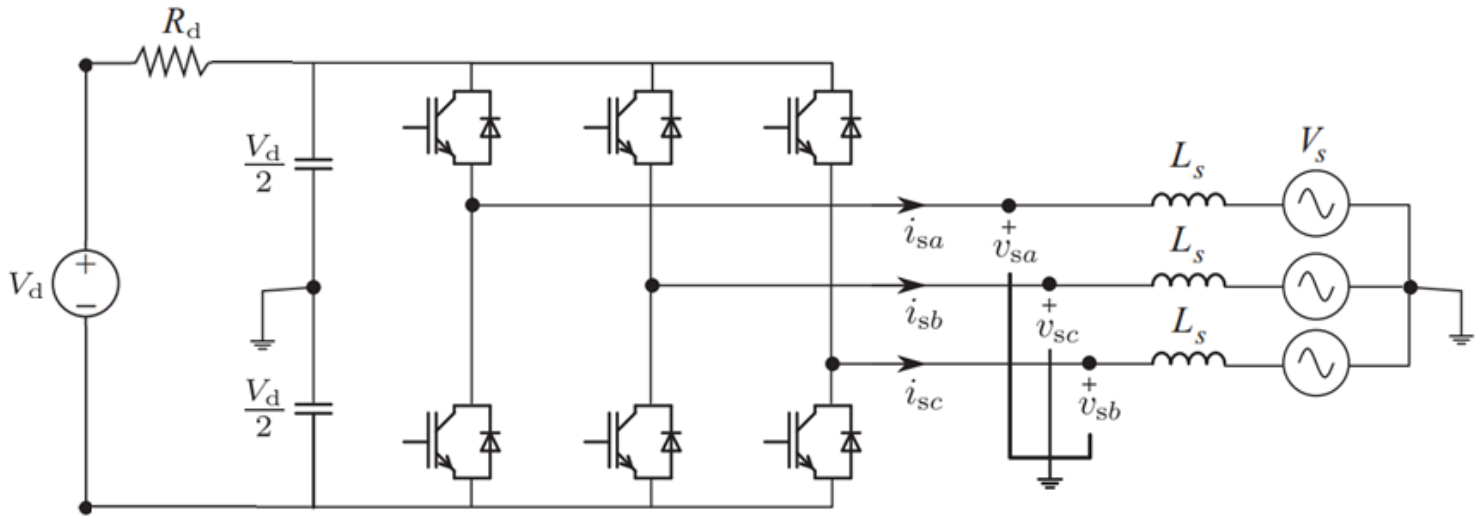
- Simulation

Simulation

- Simulate a three-phase DC/AC converter.

Data:

- L_s = 10 mH (R=X/40)
- R_d = 0.1 Ohm
- V_s = 1200 V peak phase-to-ground
- C = 1 mF
- Carrier freq = 33*50 Hz



a) Build the circuit

b) Calculate V_{dc} such that the output voltage at M = 0.8 is equal to Vgrid.

c) Define the reference amplitude to generate 900 V in the output

d) Define the angle to export 200 kW to the grid

e) Define the voltage magnitude to import 100 kVAr from the grid

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