



PLECS

*DEMO MODEL*

## Flying Capacitor Single-Phase Inverter

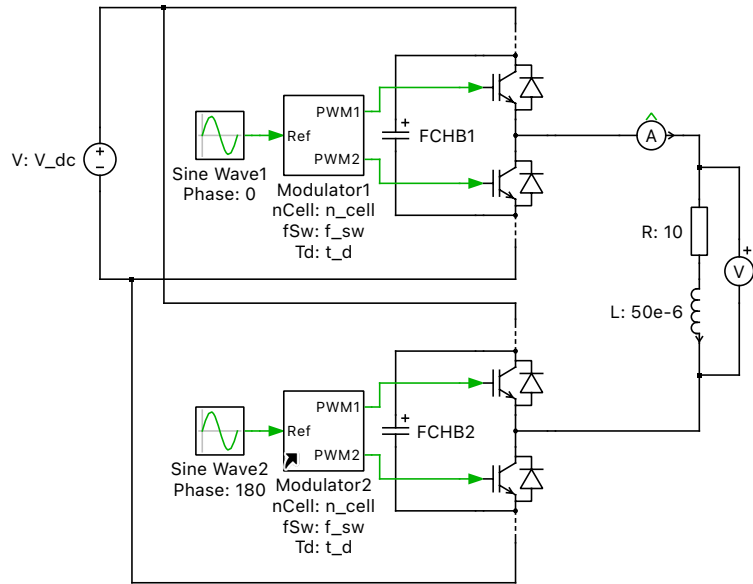
Last updated in PLECS 4.8.1

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# 1 Overview

This model shows a flying capacitor (FC) single-phase full bridge voltage source inverter (VSI). The FC VSI is a type of multilevel inverter that can produce a staircase AC waveform of magnitude  $V_{dc}/2$  by stacking switching cells to form an inverter leg. When arranged in a full bridge manner, as shown here, the inverter produces  $\pm V_{dc}$  across the RL load. This model builds off of the demo model "Flying Capacitor DC-DC Converter".



**Fig. 1: Flying capacitor single-phase inverter**

## Note

This model contains model initialization commands that are accessible from:

*PLECS Standalone:* the menu **Simulation > Simulation Parameters... > Initializations**

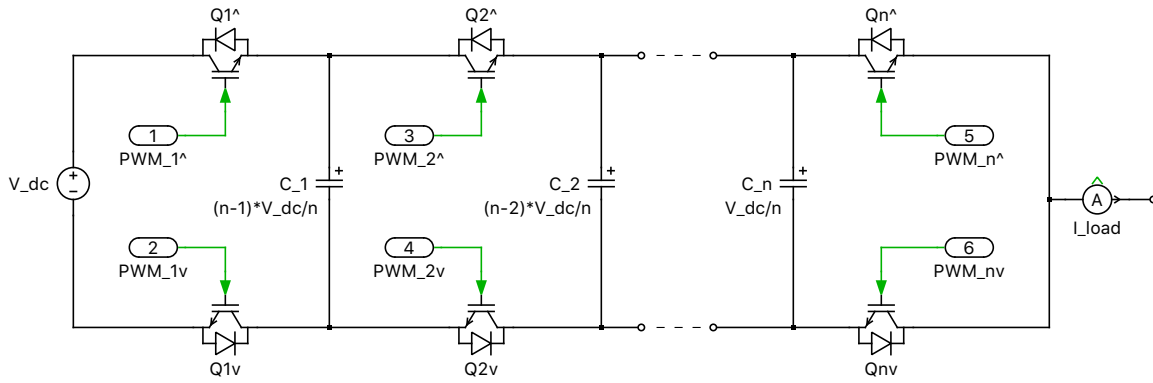
*PLECS Blockset:* right click in the **Simulink model window > Model Properties > Callbacks > InitFcn\***

# 2 Model

## 2.1 Power circuit

The circuit is modeled as a modular multilevel VSI, where the two switches in each switch pair are connected by a capacitor. The switch pair and capacitors are then connected in series to form a chopper circuit network. A DC voltage source is connected at the input, and the output of the switch capacitor network is an AC quantity. The generic configurable-length multicell network is shown in the figure below. The generic configurable-length multicell network is shown in Fig. 2.

The Flying Capacitor Half Bridge module in PLECS is implemented using a modular subsystem concept, where a dynamically-sized chain of components is connected using wires and multiplexers. This module implementation is depicted in Fig. 3 on p. 4. The input and output of the module are configured as the terminals of the flying capacitor chain. The commutation cell is repeated by means of routing its output back into its input  $n - 1$  times, for a user-specified number of cells  $n$ . As shown below, the trick to this implementation is defining one of the wires in each multiplexer to have a width of  $n - 1$ . By using a wired loop, this creates a chain with the components in between the multiplexers (a switch pair and clamping capacitor) being replicated in a series-connected fashion  $n$  times.



**Fig. 2: Configurable-length multicell network**

The capacitor connected to this module is in a vectorized fashion. The balanced chopped capacitor voltage levels are  $(n-1)V_{dc}/n, \dots, 2V_{dc}/n, V_{dc}/n$ , ordered from outer to inner level.

Since the input is 600 VDC and  $n = 5$ , the four capacitor voltage levels are 480, 360, 240, and 120 VDC. The multilevel output voltage waveform is applied to an RL load.

## 2.2 Control

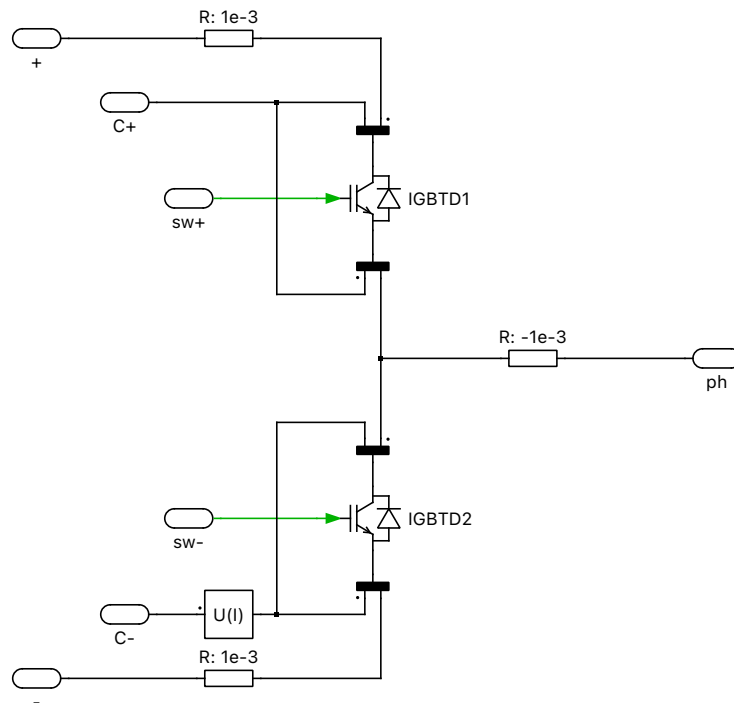
The modulation scheme is a phase-shifted carrier pulse-width modulation (PSCPWM) technique consisting of  $n$  triangular carriers, each shifted from the previous one by  $2\pi/n$ . Sinusoidal reference waveforms are fed into the two modulators, where the reference for the second phase leg has a  $180^\circ$  phase shift compared to the first. The controller provides two pulse-width modulated signals that gate the upper and lower IGBTs with the same duty cycle in a complementary fashion. A dead time is included to delay the turn-on between switch commutation for each switch pair. The converter doesn't require closed-loop control because the capacitors themselves will self-balance as each commutation cell has equal duty cycles and  $2\pi/n$  phase shifts, as discussed in [1] and [2]. Any changes to the DC input will produce a transient, but the system will settle to a well-defined steady-state operating point without feedback regulation.

## 3 Simulation

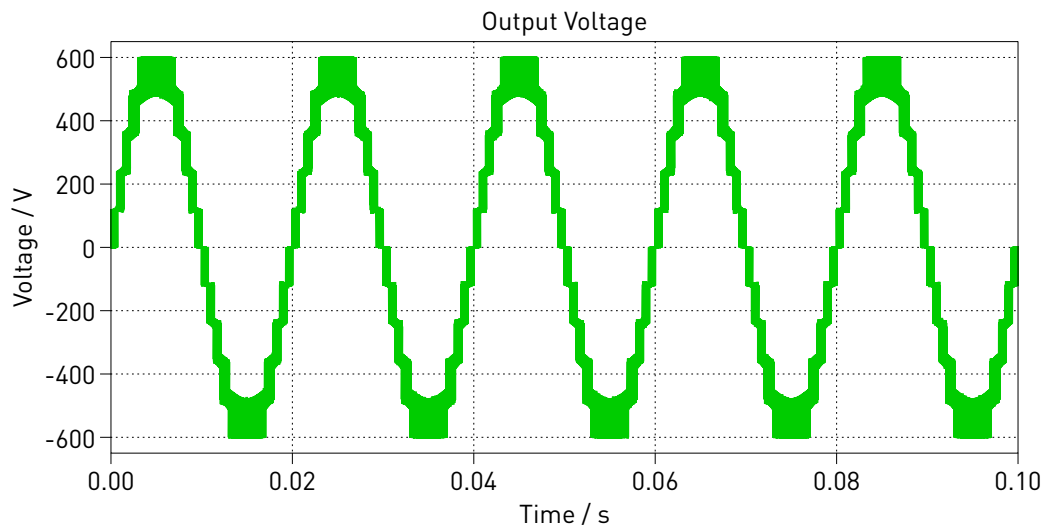
Run the simulation with the model as provided to view the signals and verify that the load voltage is a stepped waveform of  $\pm 600$  VAC. The result is depicted in Fig. 4. Observe that the capacitor voltages are stacked DC levels of  $V_{dc}/n$ . Changing the initial capacitor voltages and rerunning the simulation will show the self-balancing nature of the topology and the capacitor voltages will migrate to their balanced state. Also, the number of cells in the network can be changed in the model initialization commands.

## 4 Bibliography

- [1] T. A. Meynard, H. Foch, P. Thomas, et al, "Multicell converters: Basic concepts and industry applications", *IEEE Transactions on Industrial Electronics*, vol. 49, no. 5, pp. 955-964, Oct. 2002.
- [2] R. H. Wilkinson, T. A. Meynard, and H. du T. Mouton, "Natural balance of multicell converters: The general case", *IEEE Transactions on Power Electronics*, vol. 21, pp. 1658-1666, Nov. 2006.



**Fig. 3: Cell implementation of flying capacitor single-phase inverter**



**Fig. 4: Simulation result of load voltage**

## Revision History:

PLECS 4.3.1	First release
PLECS 4.8.1	Use the Flying Capacitor Half Bridge power module from the library

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