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PowerFactory 2021

Technical Reference

DC-DC Converter

ElmDcdc, ElmDcdcbi

PF2021

POWER SYSTEM SOLUTIONS

MADE IN GERMANY

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1 General Description

DC-DC converters are often used in switch-mode dc power supplies and in DC motor drive applications. There usually an unregulated DC voltage U_d is applied to the converter coming from an uncontrolled diode rectifier. The DC-DC converter then converts this non-ideal DC voltage into a controlled DC output U_o at a desired voltage level.

These converters are often used in combination with an isolation transformer, especially when set up to drive a DC machine. The converter element is only representing the ideal DC-DC converter, i.e. this isolation transformer is not included in the model.

The element *ElmDcdc* can represent two different types of DC-DC converter:

- Step-up converter or boost converter
- Step-down converter or buck converter

The circuit diagrams of both converters, in its most basic form, are shown in Figure 1.1 and in Figure 1.2.

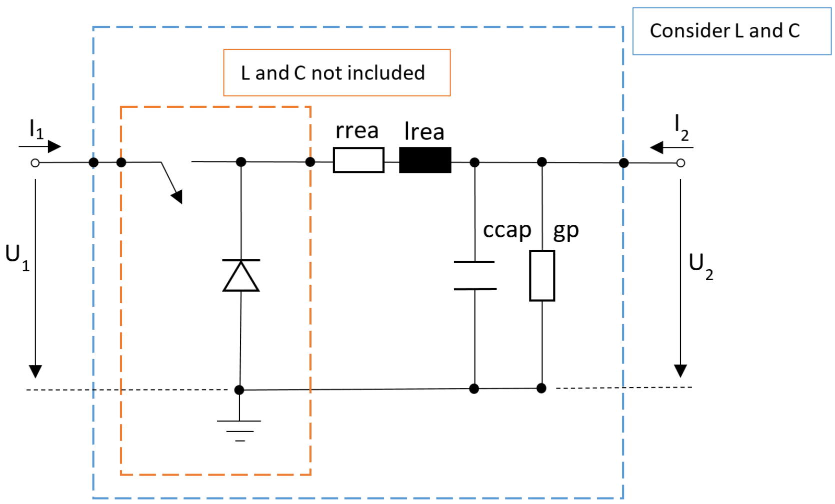

Figure 1.1: Step-Down (Buck) Converter

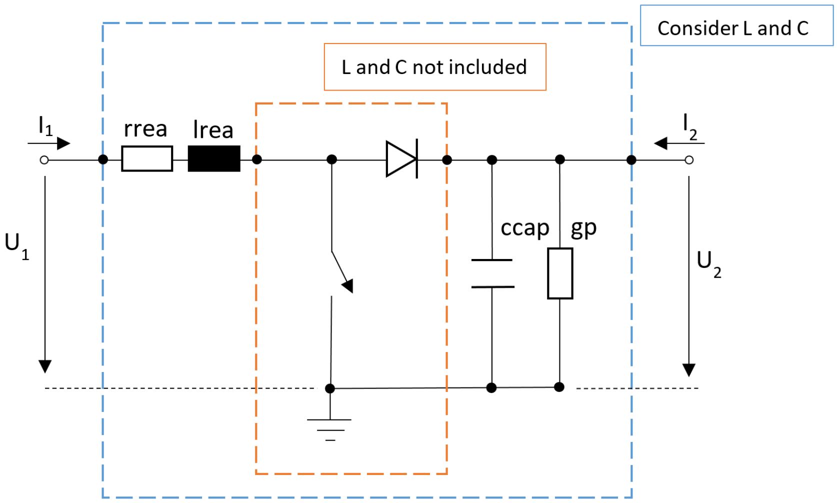

Figure 1.2: Step-up (Boost) Converter

Other types of DC-DC converters like the Ćuk converter or a step-down/step-up (buck-boost) can be modelled as combinations of this basic type of converters.

1.1 Basic Model Description

The basic model of the DC-DC converter for load-flow or RMS calculations is an ideal step-up or step-down converter. There are no losses represented in the model, i.e. the DC power flowing into the element is equal to the value flowing out of the secondary side.

The converters are controlled using the pulse-width modulation (PWM). In this method a saw-tooth voltage with a specified frequency, the 'clock' signal, is compared to a specified constant voltage, the 'alpha' signal. Using this difference the control signal for the switch is generated.

The average output voltage of the converter is controlled by the on and off durations of the switch and hence dependent on the value of alpha. If alpha becomes higher, the time the switch is in the on-state becomes larger and the average output voltage U_o increases. Figure 1.3 shows the control signals for the switch 'clock' and 'alpha', the constant primary voltage U_1 and the pulsed secondary voltage U_2, as well as the DC current and DC power flowing through the converter.

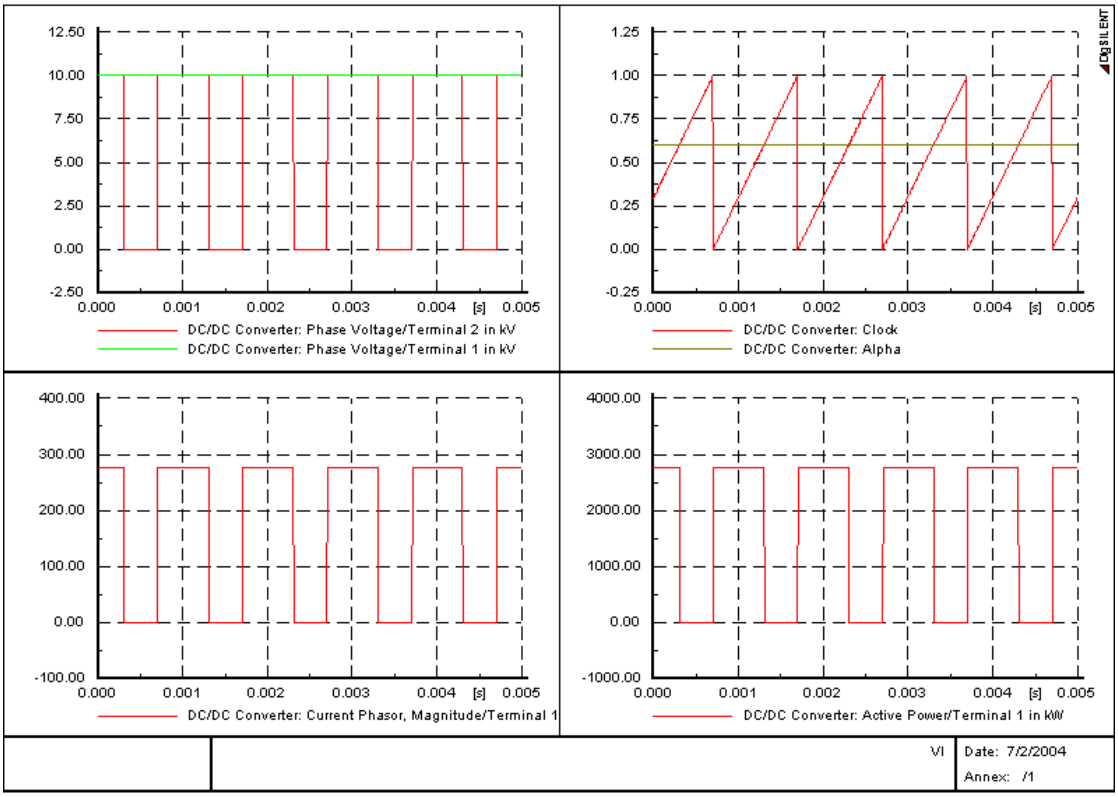

Figure 1.3: Control Signals and DC Values of a Step-Down Converter with alpha = 0.6 and a clock frequency of 1 kHz

The voltage ratio between primary and secondary side of the converter is exactly as specified in the basic data page of the element.

1.2 Basic Data

In the basic data page of the element of the DC-DC converter element, the main parameters for the converter layout are to be entered. The main parameter characterizing the element is the rated current Ir of the converter. As you can see in Figure 1.3, the currents coming in and going out of the element are identical.

The *Converter Type* option allows the user to use the model of a step-down/step-up, only step down, or only step-up converter. The option step-down/step-up is useful when the control mode in the load flow page is active power (see section 2.1.2).

The *Direction* parameter has two options:

- *Unidirectional*: the current is allowed to have a positive flow from Terminal 1 to Terminal 2, but is blocked when it tries to go in the opposite direction. This allows only positive active power flow from Terminal 1 to Terminal 2.
- *Bidirectional*: The current, and therefore the active power flow, are never blocked, so that they can flow in any direction at Terminal 1.

The option *DC Neutral connection* allows the element to have a neutral connection, which can be graphically connected to a neutral busbar. For the specific model details, see sections 3 and 5.

2 2-Terminals DC-DC Converter

2.1 Load Flow

See figures 1.2 and 1.1 representing the 2-terminals DC/DC Converter.

The load flow page has two different control modes:

- Voltage Ratio
- Active Power

2.1.1 Voltage Ratio Control Mode

The ratio of the voltages on the primary side U_1 and on the secondary side U_2 is defined by the parameter alpha (α), which is defined by

$$\alpha = \frac{U_2}{U_1} \qquad with \qquad 0 < \alpha < 1 \quad , \quad 1 < \alpha < 2 \tag{1}$$

α can be specified in the range between 0 and 2, with exception of selecting the value 1, which would represent neither a step-up nor a step-down converter.

- if $< \alpha < 1$, the DC-DC converter operates as a step-down converter, where the secondary voltage is smaller than the primary voltage
- if $< \alpha < 2$, the DC-DC converter operates as a step-up converter, where the secondary voltage is larger than the primary voltage

2.1.2 Active Power Control Mode

In this control mode, an active power setpoint is specified (*psetp*), so that the corresponding α is calculated to achieve this active power flow at Terminal 1.

The success of finding the corresponding value of α depends on the *Converter Type* selected. When the option is *Step-down/Step-up*, the α value will be searched in the ranges $0 < \alpha < 1$ and $1 < \alpha < 2$. However, when the converter type is either step-down or step-up, the value for α will be limited to the corresponding converter range, thus limiting the possibilities of achieving the specified active power.

2.1.3 Calculation Quantities

Loading

The loading of the DC-DC converter is calculated as follows:

$$loading = \frac{max(I_{bus1}, I_{bus2})}{I_{nom}} \cdot 100 \qquad in\ \%$$

- $loading$: Loading in %
- I_{nom} : Nominal current $= I_r$ of the DC-DC converter in kA
- I_{bus1} : Magnitude of the current at terminal i
- I_{bus2} : Magnitude of the current at terminal j

Losses

The losses are calculated as follows:

Table 2.1: Losses Quantities, AC-model

Quantity	Unit	Description	Value
$Ploss$	MW	Losses (total)	$=0$
$Qloss$	$Mvar$	Reactive-Losses (total)	$=0$
$Plossld$	MW	Losses (load)	$=0$
$Qlossld$	$Mvar$	Reactive-Losses (load)	$=0$
$Plossnld$	MW	Losses (no load)	$=0$
$Qlossnld$	$Mvar$	Reactive-Losses (no load)	$=0$

2.2 RMS Simulation

The RMS simulation (balanced and unbalanced) use the same equations as load flow:

$$\alpha = \frac{U_2}{U_1} \qquad with \qquad 0 < \alpha < 1 \ \ , \ \ 1 < \alpha < 2$$

2.3 EMT Simulation

$$\alpha = \begin{cases} \dfrac{U_2}{U_1} = \dfrac{t_{on}}{T_s}, & 0 < \alpha < 1 \\ \\ \dfrac{U_2}{U_1} = \dfrac{T_s}{T_s - t_{on}}, & 1 < \alpha < 2 \end{cases} \tag{2}$$

$$T_s = t_{on} + t_{off} \tag{3}$$

For the electro-magnetic transient simulation the DC-DC converter element is modelled as an ideal step-up or step-down converter. This means that the valve and the diode are represented as ideal switches neglecting the on- and off-resistances of the switches (R_{on}, G_{off}). Thus the losses are neglected in this model.

Nevertheless the control signals of the system have to be represented in detail. The pulse-width modulation including the sawtooth voltage and the control voltage is modelled. In the simulation these signals can be displayed and the conducting time of the valve T_{on} can be shown. The signals are shown in Figure 1.3.

In the EMT-simulation page of the element the frequency of the sawtooth voltage and thus the constant switching frequency of the converter can be specified.

Additionally, the built-in inductance and capacitance can be specified. If this option is not selected, then the user must model this elements externally.

2.3.1 Step-down (Buck) Converter

The current at Terminal 2 for the converter depicted in Figure 1.1 is shown in Figure 2.1. Here it can be observed that during the t_{on}, the valve is closed and the diode is blocked, so that the current starts to increase. When the valve is open, the voltage source is removed from the circuit, and the current starts decreasing.

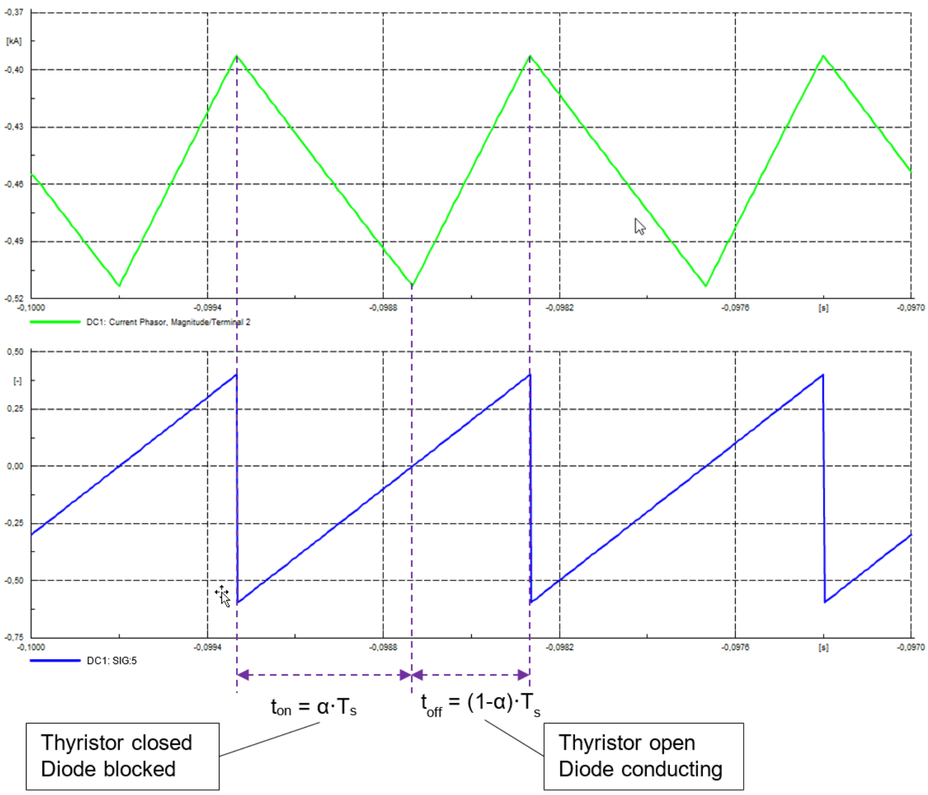

Figure 2.1: Step-down (Buck) Converter: Current at Terminal 2 and Clock signal

2.3.2 Step-up (Boost) Converter

The current at Terminal 1 for the converter depicted in Figure 1.2 is shown in Figure 2.2. Here it can be observed that during the t_{on}, the valve is closed and the diode is blocked, so that the increasing current flows through the inductor. When the valve is open, the current starts decreasing as the impedance is higher.

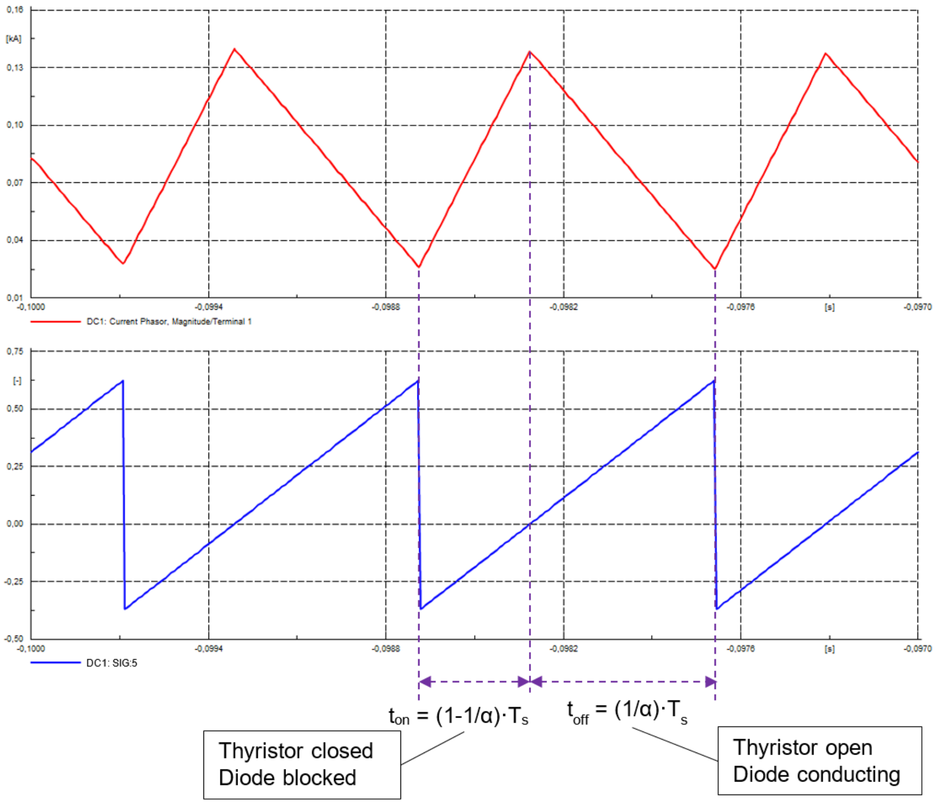

Figure 2.2: Step-up (Boost) Converter: Current at Terminal 1 and Clock signal

2.3.3 Bidirectional Converter

When the option *Bidirectional* converter is used, and the conditions in the system allow it, it is possible to simulate the change of positive to negative active power flow. For both types, step-down and step-up, the logic is the same.

In order to change the direction of the converter, provided that the conditions in the system allow for that, it is necessary to apply a Parameter Event with the parameter *dTrans* set to 1. This will start the process of transition to the opposite direction. The second time that the parameter event *dTrans* is set to 1, the process of transition will finish.

In the Figure 2.3, we can see a birectional step-down (buck) converter. The event parameter *dTrans=1* is applied at 0.001 s. The DC-DC converter waits until the valve is open and the diode is closed to change the configuration, by exchanging the diode and the valve positions. Thus, the new diode is blocked and the new valve closed, until the parameter event *dTrans=1* is applied again, at 0.003 s, and the clock switches to the t_{off} to finalize the transition. After that, the inverted step-up (boost) converter logic is applied.

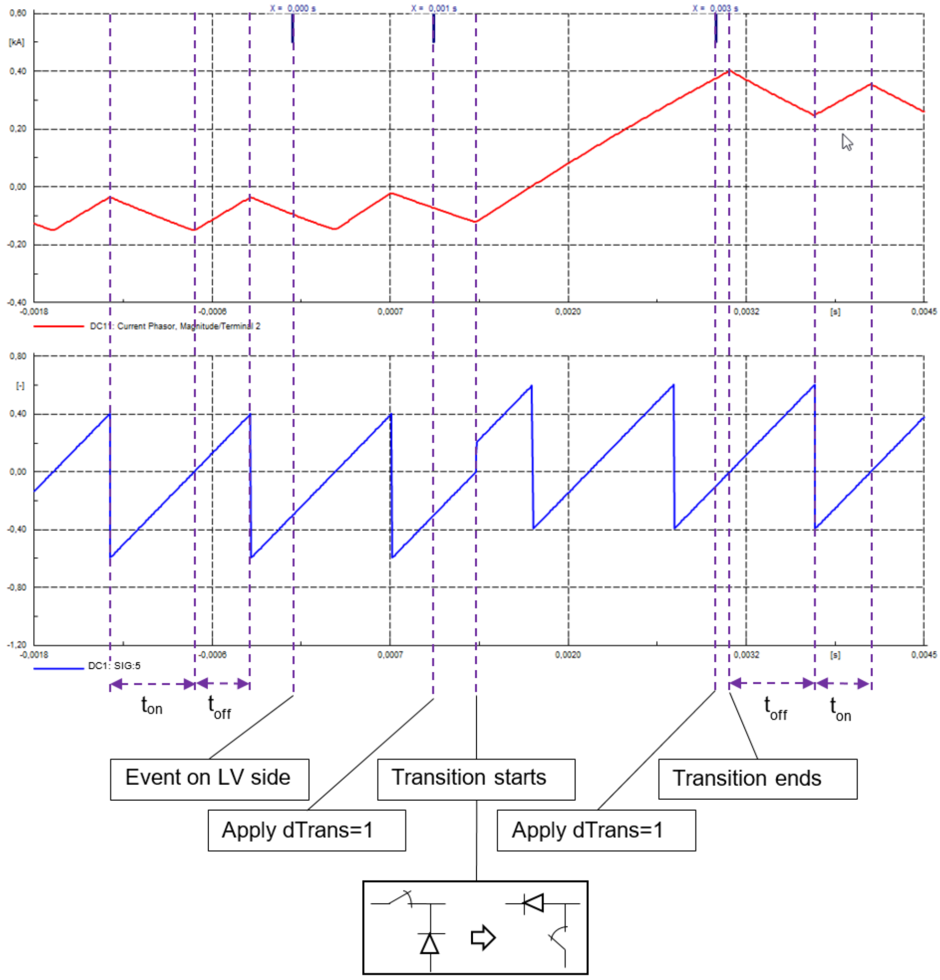

Figure 2.3: Bidirectional Step-up (Buck) Converter: Current at Terminal 2 and Clock signal

3 2-Terminals DC-DC Converter with Neutral Connection

Figures 3.2 and 3.1 represent the corresponding schemes of the 2-Terminals DC/DC converter with a neutral connection.

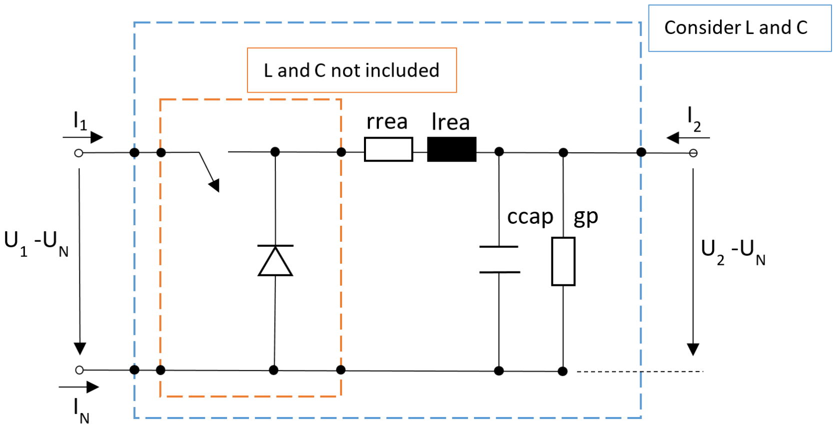

Figure 3.1: Step-Down (Buck) Converter with a neutral connection

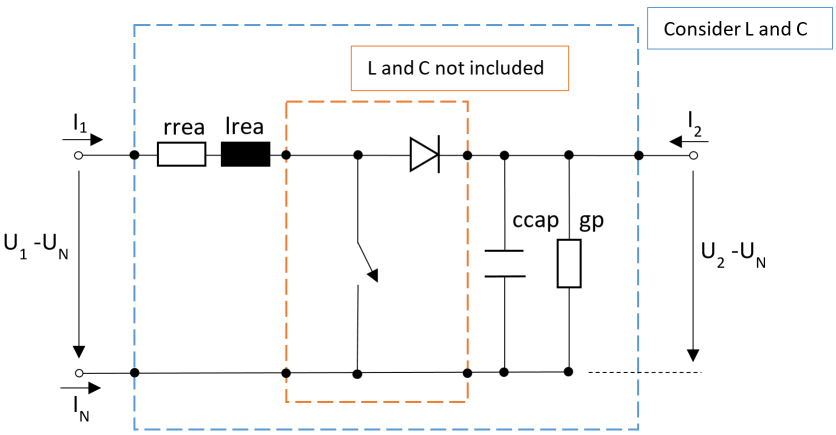

Figure 3.2: Step-up (Boost) Converter with a neutral connection

3.1 Load Flow

The options and the functionality described in Section 2.1 are also valid for this model. However, the voltages are with reference to the neutral, and one additional equation for the current in the neutral connection is introduced.

$$\alpha = \frac{U_2 - U_N}{U_1 - U_N} \qquad with \qquad 0 < \alpha < 1 \quad , \quad 1 < \alpha < 2 \tag{4}$$

$$I_N = 0 \tag{5}$$

3.2 RMS Simulation

The options and functionality described in Section 2.2 are also valid for this model. However, the equations also consider the neutral:

$$\alpha = \frac{U_2 - U_N}{U_1 - U_N} \qquad with \qquad 0 < \alpha < 1 \quad , \quad 1 < \alpha < 2$$
$$I_N = 0$$

3.3 EMT Simulation

The options and functionality described in Section 2.3 are also valid for this model. However, the equations also consider the neutral:

$$\alpha = \begin{cases} \dfrac{U_2 - U_N}{U_1 - U_N} = \dfrac{t_{on}}{T_s}, & 0 < \alpha < 1 \\ \\ \dfrac{U_2 - U_N}{U_1 - U_N} = \dfrac{T_s}{T_s - t_{on}}, & 1 < \alpha < 2 \end{cases} \tag{6}$$
$$T_s = t_{on} + t_{off}$$

4 4-Terminals DC-DC Converter

Figures 4.2 and 4.1 represent the corresponding schemes of the DC/DC converter with four terminals (positive and negative ports).

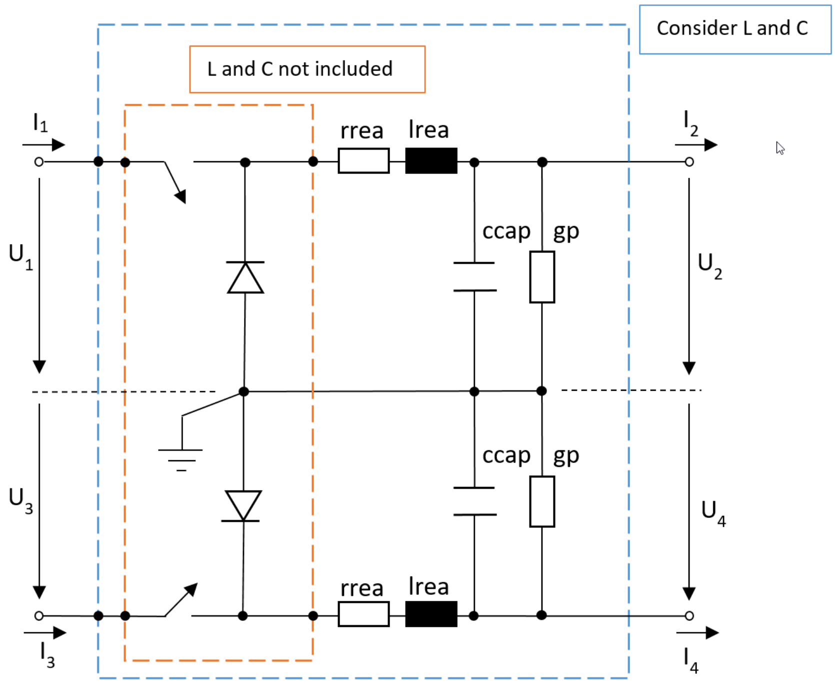

Figure 4.1: Step-Down (Buck) Converter with four terminals

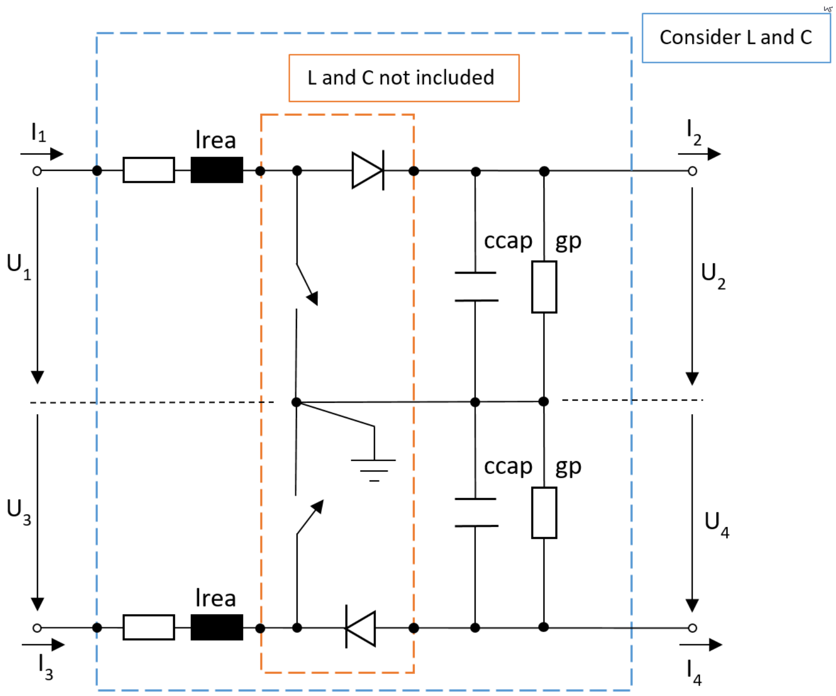

Figure 4.2: Step-up (Boost) Converter with four terminals

4.1 Load Flow

The options and the functionality described in Section 2.1 are also valid for this model. However, there are now two ports:

$$\alpha = \frac{U_2}{U_1} = \frac{U_4}{U_3} \qquad with \qquad 0 < \alpha < 1 \quad , \quad 1 < \alpha < 2 \tag{7}$$

4.2 RMS Simulation

The options and functionality described in Section 2.2 are also valid for this model. However, the equations also consider the two ports:

$$\alpha = \frac{U_2}{U_1} = \frac{U_4}{U_3} \qquad with \qquad 0 < \alpha < 1 \quad , \quad 1 < \alpha < 2$$

4.3 EMT Simulation

The options and functionality described in Section 2.3 are also valid for this model. However, the equations also consider the two ports:

$$\alpha = \begin{cases} \frac{U_2}{U_1} = \frac{U_4}{U_3} = \frac{t_{on}}{T_s}, & 0 < \alpha < 1 \\ \\ \frac{U_2}{U_1} = \frac{U_4}{U_3} = \frac{T_s}{T_s - t_{on}}, & 1 < \alpha < 2 \end{cases} \tag{8}$$
$$T_s = t_{on} + t_{off}$$

5 4-Terminals DC-DC Converter with Neutral Connection

Figures 5.2 and 5.1 represent the corresponding schemes of the DC/DC converter with four terminals (positive and negative ports) and a neutral connection.

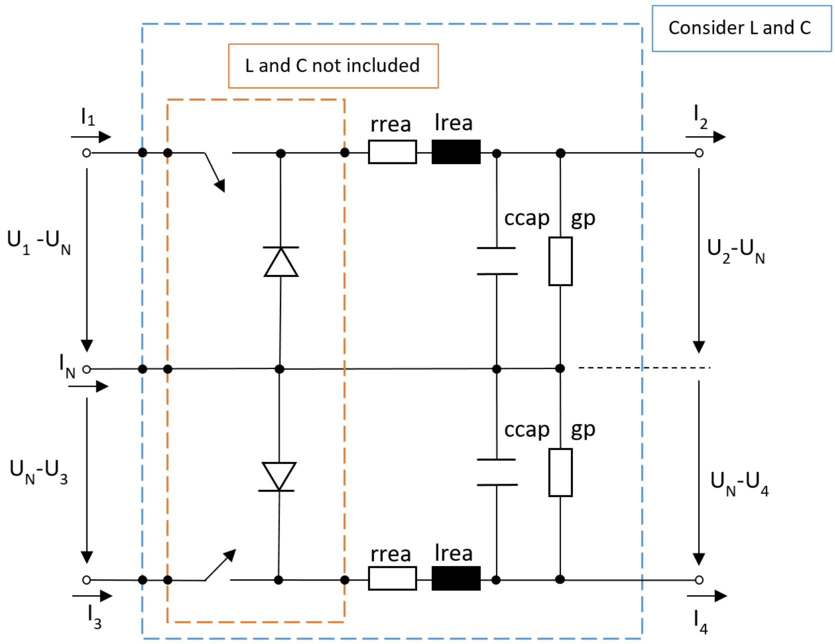

Figure 5.1: Step-Down (Buck) Converter with four terminals and a neutral connection

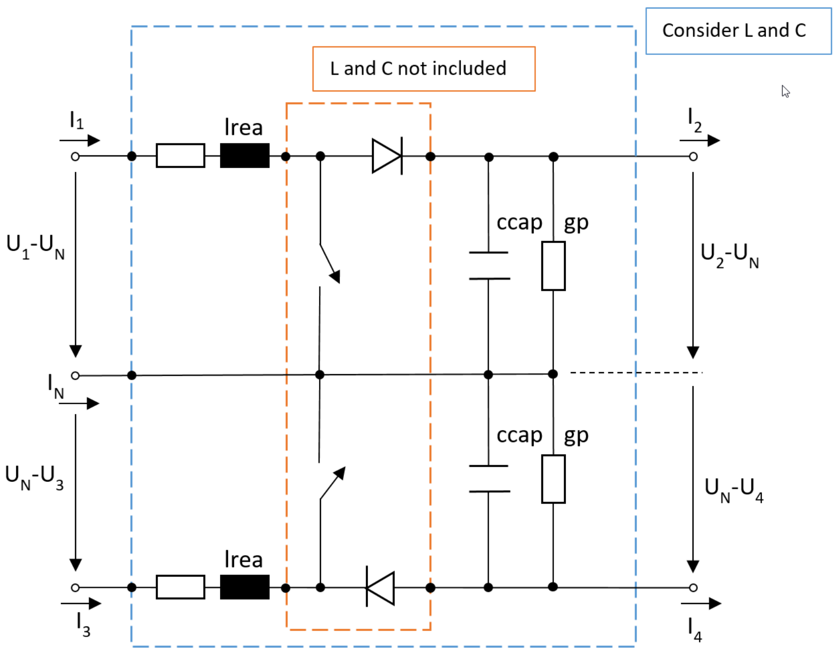

Figure 5.2: Step-up (Boost) Converter with four terminals and a neutral connection

5.1 Load Flow

The options and the functionality described in Section 2.1 are also valid for this model. However, the voltages are with reference to the neutral, and one additional equation for the current in the neutral connection is introduced.

$$\alpha = \frac{U_2 - U_N}{U_1 - U_N} = \frac{U_N - U_4}{U_N - U_3} \qquad with \qquad 0 < \alpha < 1 \quad , \quad 1 < \alpha < 2 \tag{9}$$

$$I_N = 0 \tag{10}$$

5.2 RMS Simulation

The options and functionality described in Section 2.2 are also valid for this model. However, the equations also consider the neutral:

$$\alpha = \frac{U_2 - U_N}{U_1 - U_N} = \frac{U_N - U_4}{U_N - U_3} \qquad with \qquad 0 < \alpha < 1 \quad , \quad 1 < \alpha < 2$$

$$I_N = 0$$

5.3 EMT Simulation

The options and functionality described in Section 2.3 are also valid for this model. However, the equations also consider the neutral:

$$\alpha = \begin{cases} \dfrac{U_2 - U_N}{U_1 - U_N} = \dfrac{U_4 - U_N}{U_3 - U_N} = \dfrac{t_{on}}{T_s}, & 0 < \alpha < 1 \\ \\ \dfrac{U_2 - U_N}{U_1 - U_N} = \dfrac{U_4 - U_N}{U_3 - U_N} = \dfrac{T_s}{T_s - t_{on}}, & 1 < \alpha < 2 \end{cases} \tag{11}$$

$$T_s = t_{on} + t_{off}$$

6 Input/Output Definition of Dynamic Models

6.1 EMT-Model

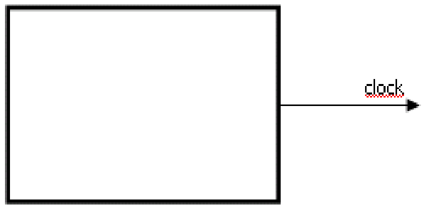

Figure 6.1: Input/Output Definition of the DC-DC converter model EMT-simulation

Table 6.1: Output Definition of the EMT-Model

Parameter	Description	Unit
clock	Clock signal	p.u.
dTrans	Transition	

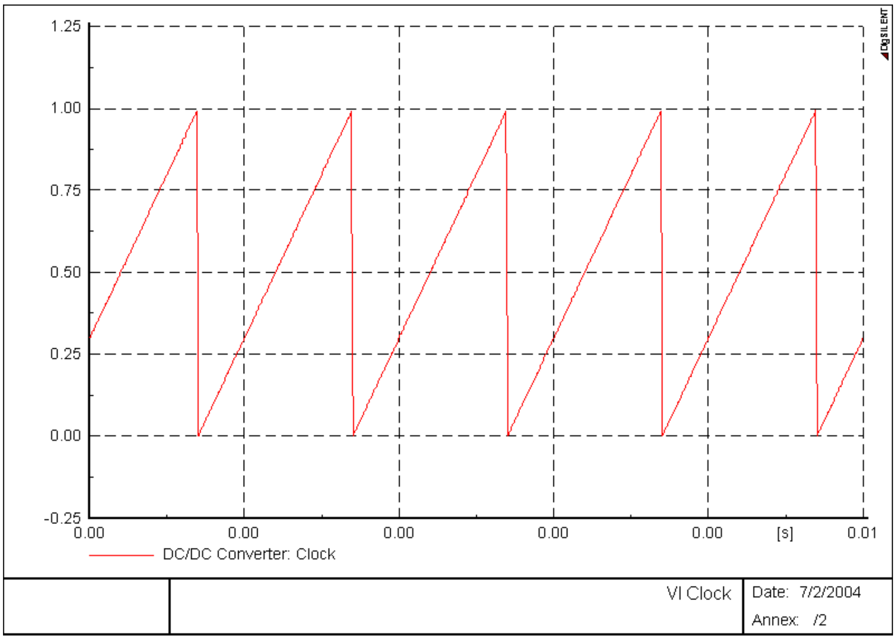

Figure 6.2: Clock Signal Output of the DC-DC Converter

7 Input Parameter Definitions

7.1 *.ElmDcdc

Table 7.1: Input Parameter Definitions of the DC-DC Converter Element

Parameter	Description	Unit
loc_name	Name	
bus1	Terminal AC (StaCubic)	
bus1_bar	Terminal AC	
bus2	Terminal DC (StaCubic)	
bus2_bar	Terminal DC	
outserv	Out of Service	
Curn	Rated Current	A
alpha	Alpha U2/U1	
i_ctrl	Control mode	
psetp	P setpoint	kW
i_ctype	Converter Type	
i_cdir	Direction	
LCbuiltin	Built-in LC	
Rrea	Resistance	Ω
Lrea	Inductance	mH
Ccap	Capacitance	μF
Gp	Parallel Conductance	S
fclock	Clock Rate	kHz

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