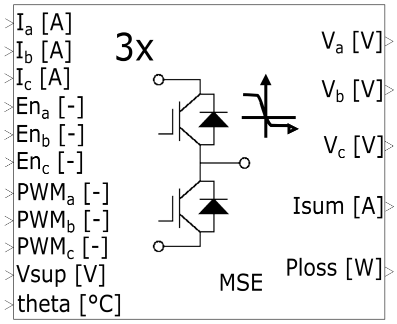
B6-Bridge (PEB601MSEREF) Documentation

September 27, 2021



Description

This is a model of a B6-bridge[1] with 6 switches, each switch consisting of a transistor parallel connected to a free-wheel diode. The 6 switches are allocated in three single power stages.

Features

- This model uses three times the Single Power Stage - PEPS101MSEREF model.
- MOSFET and IGBT transistors are supported.
- Each transistor is ideally modelled as a on resistance R_T (and a forward voltage V_T for IGBTs).
- Each free-wheel diode is ideally modelled as a on resistance R_D and a forward voltage V_D.
- The forward voltages and the on resistances are temperature dependent.
- Ohmic losses are computed.

[1] Also denoted *drive*.

- The model can handle, by approximation, the case when two transistors of one leg are open.
- With the inputs En_x and PWM_x ($x \in \{a, b, c\}$), it is not possible to generate any short-circuit between two transistors of one leg.
- For MOSFET transistors, the PWM_x input ($x \in \{a, b, c\}$) can have values in the range [0; 1] to simulate duty cycles (average PWM signals).
- To consider transistor switching dead time, it is recommended to set the En_x input ($x \in \{a, b, c\}$) of one leg temporarily to zero after the PWM_x input has switched.

Application area

The model can be used in an electric powertrain as DC/AC converter when this block is connected to a DC-voltage source resp. a DC-link and a three phase machine (e.g., Permanent Magnet Synchronous Machine or Induction Machine).

Model assumptions and limits

- A MOSFET transistor conducts current in both directions. In reverse direction, the current only circulates through the transistor [2].
- An IGBT transistor conducts current only in forward direction (in reverse direction, the current only circulates through the free-wheel diode).
- The transistors switch instantaneously (no linear switch), no oscillating behaviour considered during the switching phase due to parasitic inductive effects. No switching losses are considered.
- The diode transition between forward and reverse directions depends continuously on the current. The current is thus never exactly equal to zero in reverse direction. For more information about diode transition modelling and their possible implementations in *Simulink*, please consult the background documentation of the *MSERef_powerelectronics* library.
- Duty cycle mode (i.e., average PWM_x signals with PWM_x values in range [0; 1], $x \in \{a, b, c\}$) only possible for MOSFET transistors and for the case where, at any time, one transistor of one leg is always *ON* (ensuring thus that the current circulates only through one resistance R_T). No transistor switching dead time should thus be considered in this case.
- All temperature dependent parameters only depend on the same temperature. The temperature dependency is assumed to be linear.

[2] A warning message is displayed the first time the transistor voltage $R_T \cdot |I|$ be greater than the diode forward voltage V_D to warn about potentially unphysically results.

- The forward voltages and on resistances do not depend on further variables (like e.g., current).

Solver settings

It is recommended to use a stiff solver like e.g., *ode23tb* when this block is connected to further blocks of an electric powertrain modeled with odes[3] (e.g., a DC-voltage source, a DC-link, an electric motor) since :

- The continuous diode transition between both forward and reverse directions can be very stiff.
- The instantaneous transistor switchings introduce very high dynamic changes within very short time.

According to the investigated problem, it can be useful to set both relative and absolute solver tolerances to values in the range $[10^{-7}; 10^{-5}]$ to ensure a correct convergence regarding the computed electrical and mechanical waveforms. Moreover, the maximal solver step size should be set to a value different from *auto*.

Model equations

The equivalent circuit of a B6-bridge (e.g., with MOSFETs) is given in Figure 1.

Leg potential equations

The expression of the each leg potential V_x ($x \in \{a, b, c\}$) is documented in the Single Power Stage - PEPS101MSEREF detail documentation replacing:

- En with En_a, En_b or En_c.
- PWM with PWM_a, PWM_b or PWM_c.
- V with V_a, V_b or V_c.
- I with I_a, I_b or I_c.

[3] Ordinary Differential Equations.

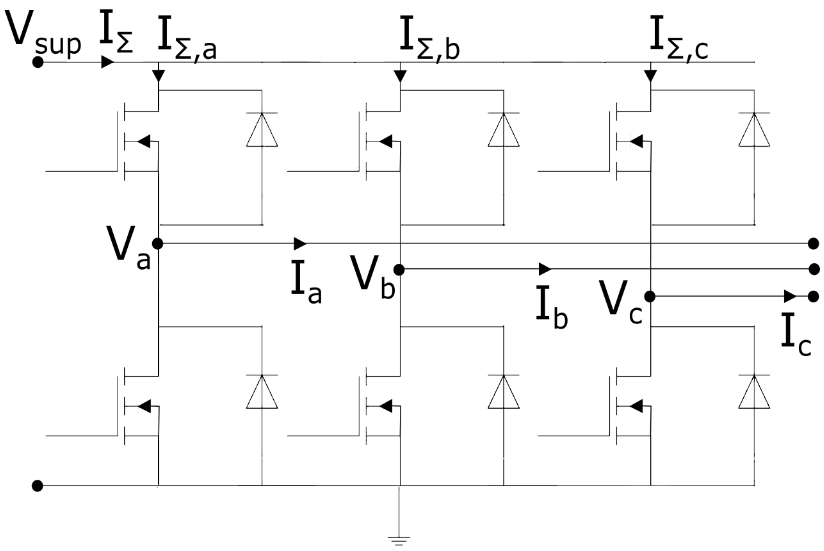


Figure 1: B6-bridge equivalent circuit (here with MOSFETs).

Supply current equation

The expression of the each current entering in one leg $I_{\Sigma,x}$ ($x \in \{a, b, c\}$) is documented in the Single Power Stage - PEPS101MSEREF detail documentation replacing I_Σ with $I_{\Sigma,a}$, $I_{\Sigma,b}$ or $I_{\Sigma,c}$.

The expression of the resulting supply current I_Σ is given by equation (1).

$$\boxed{I_\Sigma = I_{\Sigma,a} + I_{\Sigma,b} + I_{\Sigma,c}} \tag{1}$$

Electrical power loss equations

The power losses P_D are due to ohmic effects. The expression of each conducting loss $P_{D,x}$ ($x \in \{a, b, c\}$) generated by one leg is documented in the Single Power Stage - PEPS101MSEREF detail documentation replacing P_D with $P_{D,a}$, $P_{D,b}$ or $P_{D,c}$.

The expression of the resulting conducting power losses P_D is given by equation (2).

$$\boxed{P_D = P_{D,a} + P_{D,b} + P_{D,c}} \tag{2}$$

Model validation

This model has been validated in combination with further blocks that model an electric powertrain (e.g., a voltage source, a DC-link and an electric machine, mostly a PMSM[4]).

Several motor topologies have been investigated like e.g., wye or delta winding connection, surface mounted or embedded magnets, several operation modes have been considered like e.g., motoring or generatoring on a steady state with or without fault case, both usual *sine* and *squarewave* commands have been also considered.

Please consult the *Validation* section in the overview documentation of the MSERef emachines library for more information.

Code Generation

To inquire if it is principally possible to generate code from this block, please consult the related *Code generation* section in the overview documentation.

Parameters

- The parameter *Transistor forward voltage at* 20^oC is not displayed in the block mask if $En_{IGBT} = false$.

Type[5]	Name	Description	Symbol	Unit	Default	Values
Basic parameters						
D	`RT20`	Transistor on resistance at 20^oC	$R_{T,20}$	Ω	10^{-3}	$[0, 10^3]$
D	`RD20`	Diode on resistance at 20^oC	$R_{D,20}$	Ω	10^{-3}	$[0, 10^3]$
D	`VT20`	Transistor forward voltage at 20^oC	$V_{T,20}$	V	0	$[0, 10^3]$
D	`VD20`	Diode forward voltage at 20^oC	$V_{D,20}$	V	0.7	$[0, 10^3]$
B	`IGBT`	Enable IGBT	En_{IGBT}	-	false	true, false
Advanced parameters						
D	`Ieps`	Numerical parameter for diode treatment	I_ϵ	A	10^{-3}	$[10^{-11}, 10^6]$
D	`alphaRT`	Thermal coefficient of transistor on resistance	α_{R_T}	1/K	0	$[-10^9, 10^9]$
D	`alphaRD`	Thermal coefficient of diode on resistance	α_{R_D}	1/K	0	$[-10^9, 10^9]$
D	`alphaVT`	Thermal coefficient of transistor forward voltage	α_{V_T}	1/K	0	$[-10^9, 10^9]$
D	`alphaVD`	Thermal coefficient of diode forward voltage	α_{V_D}	1/K	0	$[-10^9, 10^9]$

[4] Permanent Magnet Synchronous Machine
[5] B: Boolean parameter, D: Double parameter

Ports

- An error message is returned if PWM_a, PWM_b or PWM_c is not in the range $[0;1]$.

Inputs

Direction	Type	Name	Symbol	Description	Unit
input	Double	`Ia`	I_a	Leg a current	A
input	Double	`Ib`	I_b	Leg b current	A
input	Double	`Ic`	I_c	Leg c current	A
input	Double	`Ena`	En_a	Leg a enable transistor control	-
input	Double	`Enb`	En_b	Leg b enable transistor control	-
input	Double	`Enc`	En_c	Leg c enable transistor control	-
input	Double	`PWMa`	PWM_a	Leg a PWM signal	-
input	Double	`PWMb`	PWM_b	Leg b PWM signal	-
input	Double	`PWMc`	PWM_c	Leg c PWM signal	-
input	Double	`Vsup`	V_{sup}	Supply voltage	V
input	Double	`theta`	ϑ	Temperature	°C

Outputs

Direction	Type	Name	Symbol	Description	Unit
output	Double	`Va`	V_a	Leg a potential	V
output	Double	`Vb`	V_b	Leg b potential	V
output	Double	`Vc`	V_c	Leg c potential	V
output	Double	`Isum`	I_Σ	Supply current	A
output	Double	`Ploss`	P_D	Conducting power losses	W

Implementation-specific Aspects

Implementation as block diagram

The equations of this model are implemented as block diagram using three times the Single Power Stage - PEPS101MSEREF block as given given in Figure 2.

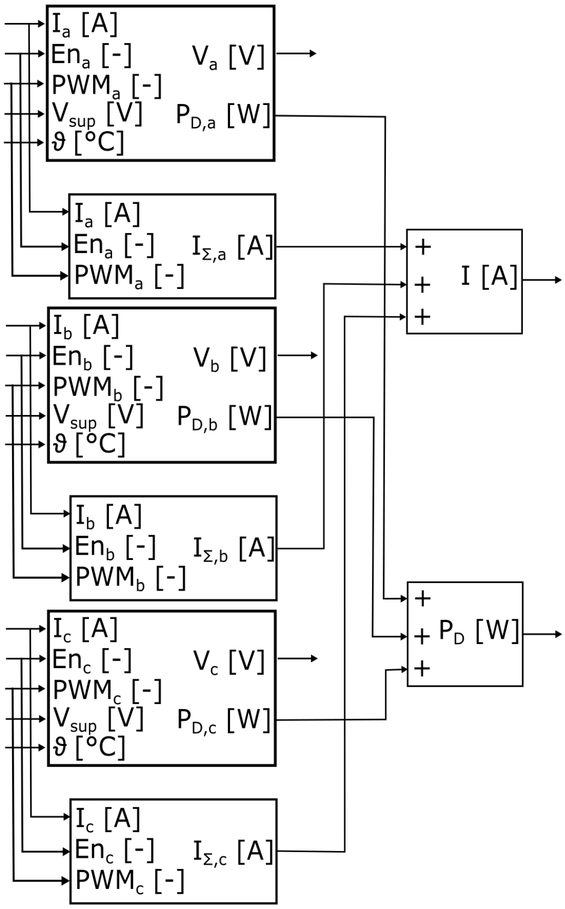


Figure 2: B6-bridge block diagram implementation.