DC/DC Converter: digital twin model description

DTL

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Contents

List of Figures

List of Tables

In this document we describe the Mercedes-Benz diesel engine OM471 represented in the Digital Twin Library. The model is based on the main dynamical equation of the crank-shaft and doesn't take into account the internal combustion thermodynamic. Torque curve as well as consumption contour map is taken from supplier and implemented as lookup table.

1 The DC/DC converter

The DC/DC converter is basically the interface between the fuel-cell and the battery. According to the battery management control strategy and according to the control constraints due to the fuel cell a global fuel-cell/battery control shall be designed.

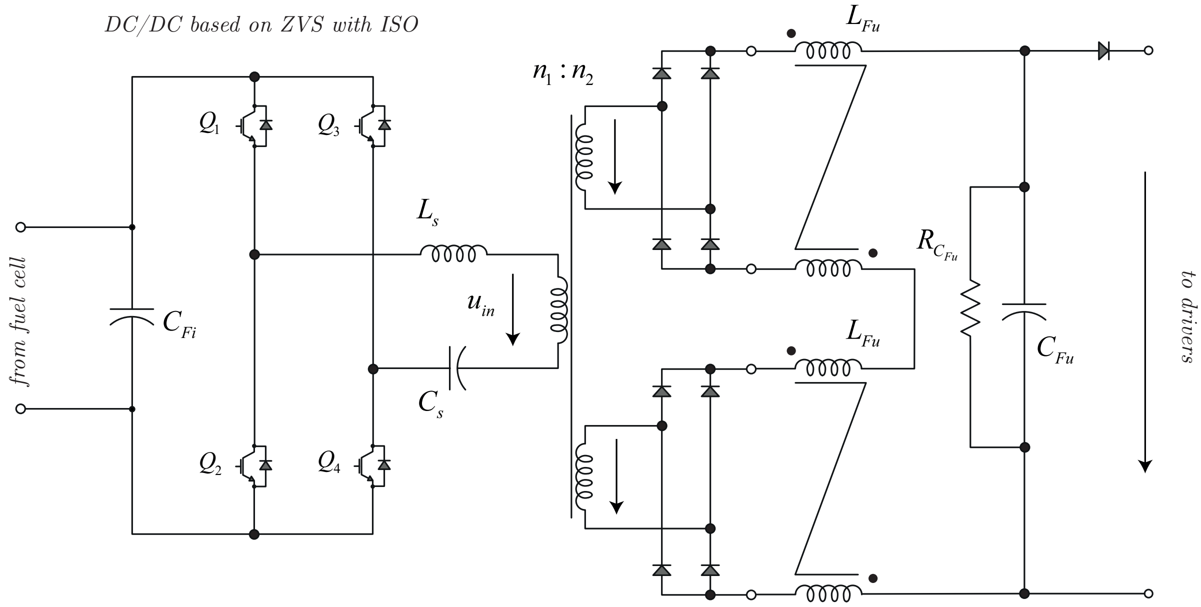

Figure 1: DC/DC converter based on galvanic insulated ZVS.

As general rule the battery charging process is performed at constant current until a certain amount to state of the charge of the battery and after that point the control of the ZVS is performed at constant voltage. According these few rules we already can understand the necessity to control the DC/DC converter in both mode: current and voltage.

The ZVS converter is a special configuration which taking advantages from the parasitic collector-emitter capacitance C_{ce} of the IGBT is able to reduce the overall switching losses (commutation occurs at low V_{ce} voltage across the IGBT) given the possibility to increase the PWM frequency and reducing the dimensioning of the transformer used to introduce a galvanic insulation between the fuel cell and the rest of the power train.

The following components data can be taken into account (considering a PWM switching frequency of $f_{PWM} = 20\,\text{kHz}$)

$C_{Fi} = 240\,\mu\text{F}$	$u_{tr}^{1nom} = 400\,\text{V}$	$u_{tr}^{2nom} = 438\,\text{V}$	$u_{tr}^{3nom} = 438\,\text{V}$
$n1 = 23$	$n2 = 21$	$n3 = 21$	$C_s = 180\,\mu\text{F}$
$L_{Fu} = 500\,\mu\text{H}$	$C_{Fu} = 3.3\,\text{mF}$	$R_{CFu} = 2\,\text{k}\Omega$	$L_s = 11.7\,\mu\text{H}$

Table 1: Components data of the ZVS dc/dc converter.

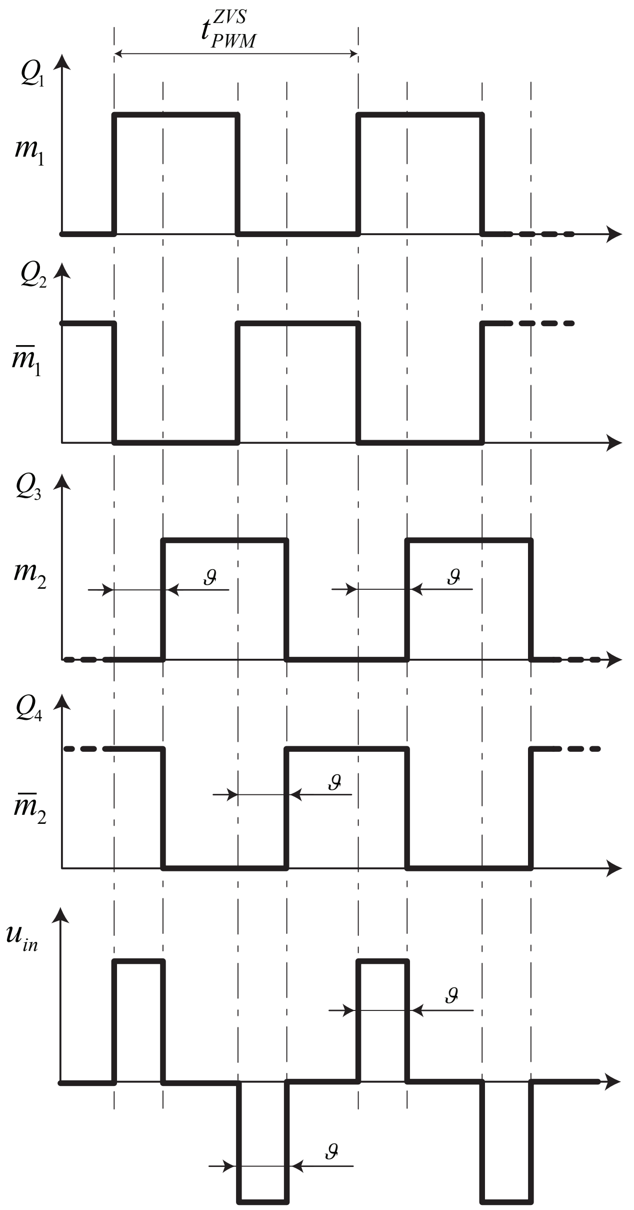

Figure 2: ZVS modulation strategy based on phase shift ϑ of the leg Q_3Q_4 respect to the leg Q_1Q_2.

Figure 2 shows the modulation strategy used at the H-bridge. Each leg of the H-bridge is commanded with a 50% duty cycle PWM, where we can call m_1 and m_2. When the phase-displacement ϑ between m_1 and m_2 the output voltage u_{in} is zero. As soon as the the phase-displacement ϑ become different from zero the output voltage u_{in} according to Figure 2. When the phase-displacement ϑ reach the value of π the output voltage u_{in} reach its maximum value. From this short description of the working principle of the ZVS converter we can see the ZVS works like a *buck-converter*. As shown in Figure 1 the output voltage u_{in} passes through a transformer (in this case as step-up) in order to introduce a galvanic insulation and to adapt, the rectified voltage, to the constraints of the battery. The L_sC_s group is used to limit the current ripple and to remove any DC-voltage component which could saturate the transformer. In particular the resonance frequency $f_0 = 1/(2\pi\sqrt{(L_sC_s)})$ of the LC group is kept 5 time slower than the PWM frequency of the H-bridge. At the output of the rectifier an LRC filter is placed. The aim of the LRC is to limit the voltage ripple creates a stable DC-voltage source for the inverter which are here connected. During the inverter operating most of the switching current is fed by the DClink capacitor and not by the battery. The battery should deliver the only DC components.

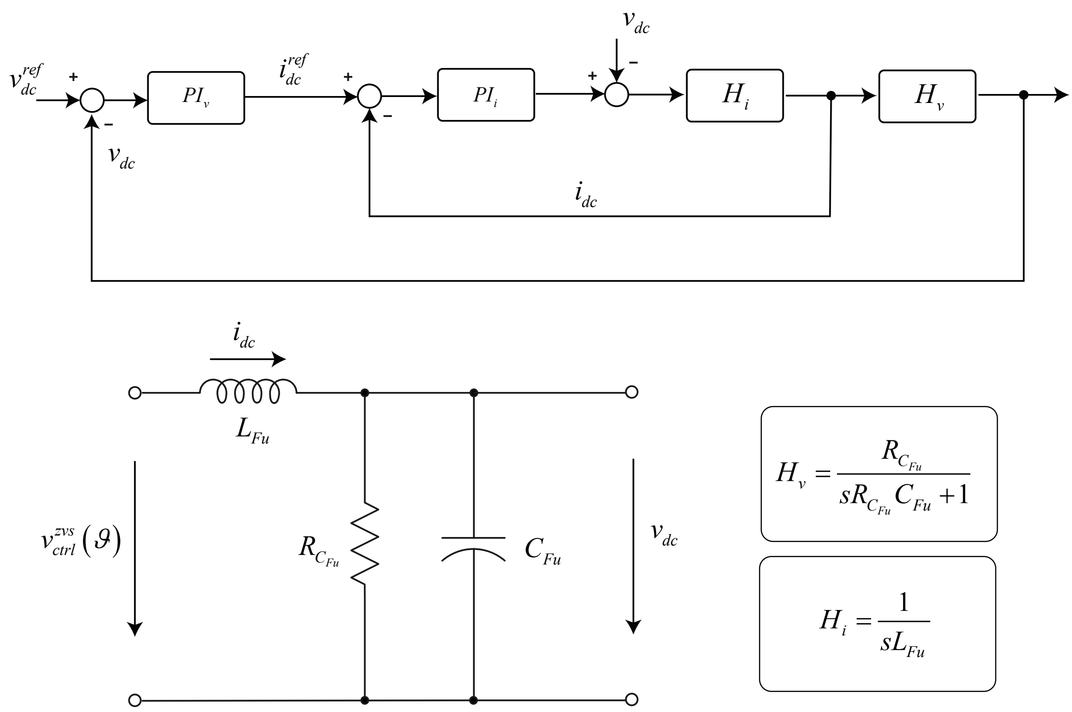

Figure 3: ZVS control architecture and equivalent control model.

1.1 The DC/DC converter and its control

The equivalent plant model seen by the ZVS converter is shown in Figure 3, where the voltage plant can be defined as follows

$$H_v(s) = \frac{V_{dc}(s)}{I_{dc}(s)} = \frac{R_{C_{Fu}}}{sR_{C_{Fu}}C_{Fu} + 1} \tag{1.1}$$

and the current plant as follows

$$H_i(s) = \frac{I_{dc}(s)}{V_{ctrl}^{zvs}(s) - V_{dc}(s)} = \frac{1}{sL_{Fu}} \tag{1.2}$$

where $v_{ctrl}^{zvs}(\vartheta(t))$ is the rectified voltage and is controlled by the phase-displacement ϑ. Overall control can be implemented by a cascade PI control with a voltage outer loop and a inner current loop control as shown in Figure 3.