IGBT Control

Jochen Krause, Günter Schmitt
Bergische Universitaet Wuppertal
Electrical Machines and Drives
Advantages of an Active Gate Voltage Control:

- adjustable $du/dt$
- reduction of travelling waves in motor cables
- reduction of EMI (*Electromagnetic Influence*)
- limitation of overvoltage at IGBT collector
Basic Structure

- Voltage feedback
- Controlled system
- Reference value
- Controller
- Amplifier
- $U_{CE}$
- $U_{DC}$
- $V_f$
- $I_{Last}$
- $L_{Last}$
- $R_{Last}$
Design and Equivalent Circuit of an IGBT
Equivalent Circuit of an IGBT

**Miller-Transformation**

\[ C_{M1} = C_{GD} \times (1 - V_U) \]

\( C_{M2} \) negligible

**Capacitance of Depletion Zone and Oxide Layer**
Switching-On Behaviour of an IGBT – Inductive Load
Switching-On Behaviour of an IGBT – Inductive Load

switching-on: +15V to the gate
Switching-On Behaviour of an IGBT – Inductive Load

charging of input capacitance
charge carrier accumulation at the gate
Switching-On Behaviour of an IGBT – Inductive Load
Switching-On Behaviour of an IGBT – Inductive Load

\[-U_o = L_o \frac{dl}{dt}\]
Switching-On Behaviour of an IGBT – Inductive Load
Switching-On Behaviour of an IGBT – Inductive Load
Switching-On Behaviour of an IGBT – Inductive Load

Miller capacitance increases saturated voltage reached
Switching-On Behaviour of an IGBT – Inductive Load

Miller capacitance is re-charged
Switching-On Behaviour of an IGBT – Inductive Load

Miller capacitance is re-charged
switching-on finished
Switching-Off Behaviour of an IGBT – Inductive Load

activating of 0 V
Switching-Off Behaviour of an IGBT – Inductive Load
Switching-Off Behaviour of an IGBT – Inductive Load

- $U_{CE}$
- $I_C$
- $U_{GE}$
- $I_G$

until MOS channel starts blocking
plateau phase
Switching-Off Behaviour of an IGBT – Inductive Load

$U_{ce}$ increases slowly, as many charge carriers have to be extracted from the basis area.
Switching-Off Behaviour of an IGBT – Inductive Load
Switching-Off Behaviour of an IGBT – Inductive Load

dl/dt causes overvoltage in $U_{ce}$
Switching-Off Behaviour of an IGBT – Inductive Load
Switching-Off Behaviour of an IGBT – Inductive Load
• Control of IGBTs in Active Operation Area

• Discharging of Internal Capacitances (Plataeu Phase) before Control can be Activated

Idea: Pre-Processing in Reference Generator
Reference Curve

pre-step for switch-off

pre-definition of the voltage gradient

pre-step for switch-on

$u^*$

$u_{Soli}[V]$
Reference Generator

- Pre-step period
- Pre-step amplitude
- Delay
- Voltage gradient

Amplitude Preamplifier

"offset"
Circuit Design

- L
- V_f
- I_Last
- R_Last
- L_o
- U_σ
- U_DC
- U_CE
- R_g
- reference value
- controller
- amplifier
- voltage feedback

controlled system
IGBT in active operation

with pre-steps
Definition of Transfer Funktion:

- ... by step signal on IGBT in active operation
- ... by calculation (equivalent circuit - e.g.: Hefner, Saber)

problem: manufacturers do not provide all product informationen doping depth and area of semiconductor levels missing
Investigating the Transfer Function by Step Function (Simulation):

- using simulation program PSpice
- in PSpice there are complete models of IGBTs (Saber)
- results: PT1 – behaviour with small dead time
Control of a $\text{PT}_1$ System with Dead Time

- possible by PI or PID controller
- with respect to dead time an analytical optimization is not possible
- evaluating control parameters by PSpice
- PI controller, because it can be adjusted more easily
Simplified Control Circuit
Control Circuit
Measurements at IGBT with Active Voltage Control

Switch-on

Switch-Off
Switch-on – Different Voltage Gradients

\[ \frac{du}{dt} = 360 \text{ V/µs} \]

\[ \frac{du}{dt} = 900 \text{ V/µs} \]
Switch-off – Different Voltage Gradients

\( \frac{du}{dt} = 360 \text{ V/µs} \)

\( \frac{du}{dt} = 900 \text{ V/µs} \)
Comparison of Driver Circuits – Switch-on

Driver with $U_{CE}$ Control (10Ω)

Conventional Driver (120Ω)

Max. $du/dt = 900 \text{ V/μs}$

$7 \text{mJ} \xrightarrow{8,32 \text{mJ}} 15,9\%$

less switching losses with active control
Comparison of Driver Circuits – Switch-off

Driver with $U_{CE}$ Control (10Ω) vs. Conventional Driver (120Ω)

Max. $du/dt = 900$ V/µs

- 7.98 mJ
- 9.6 mJ

16.9% less switching losses with active control.
Variation of Switching Losses under different Voltage Gradients

\[ 1 - \left( \frac{E_{\text{aktiv}}}{E_{\text{konv.}}} \right) \% \]

- 15% at 900 V/µs

\[ \frac{du}{dt} \ [V/\mu s] \]
Summary/Results

• du/dt is adjustable
  (between „slew rate“ of OPs and any integrator capacitance)

• limitation of IGBT collector-emitter-voltage
  (as long as IGBT is in the SOA)

• switching power loss ca. 15 % lower (at 900 V/µs)
  than a conventional driver circuit providing the same max. du/dt