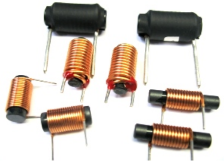
EE-465 - W1
INTRODUCTION
BOOST CONVERTER

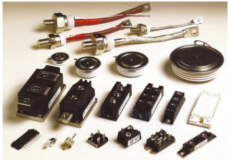
Prof. D. Dujic
École Polytechnique Fédérale de Lausanne
Power Electronics Laboratory
Switzerland

INTRODUCTION

The role of power electronics...

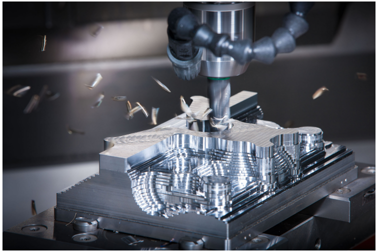
POWER ELECTRONIC DEVICES

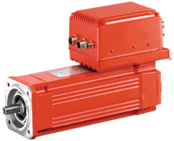




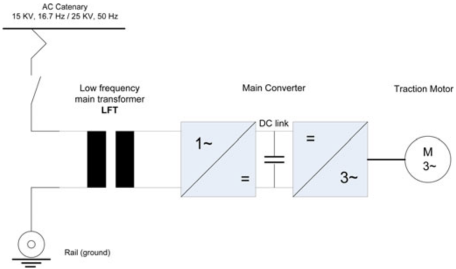
POWER ELECTRONIC APPLICATIONS – SMPS

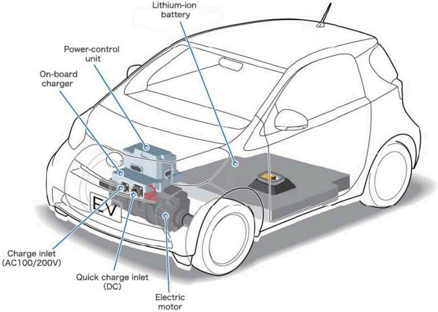
POWER ELECTRONIC APPLICATIONS – VARIABLE SPEED DRIVES

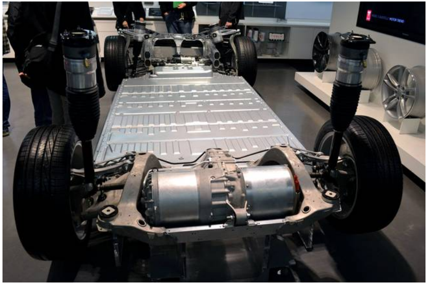




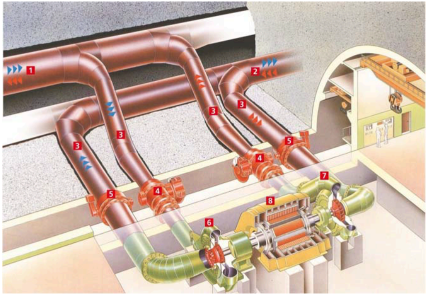
POWER ELECTRONIC APPLICATIONS – ELECTRIC TRANSPORTATION

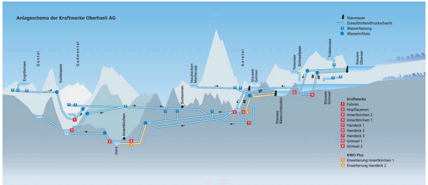


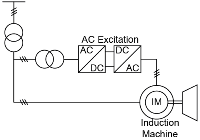


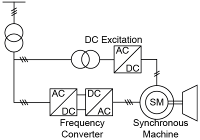


POWER ELECTRONIC APPLICATIONS – PUMPED HYDRO STORAGE PLANTS

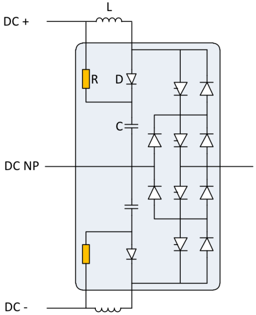


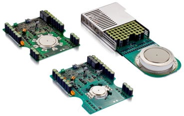


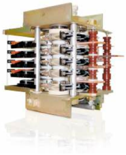


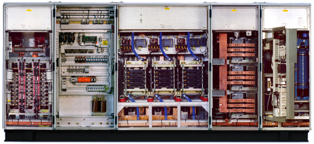


POWER ELECTRONIC APPLICATIONS – HIGH POWER DRIVES

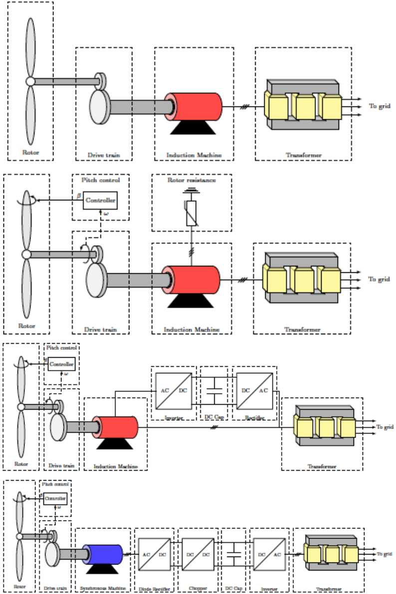




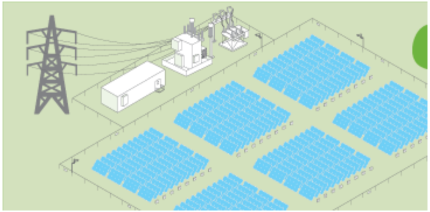


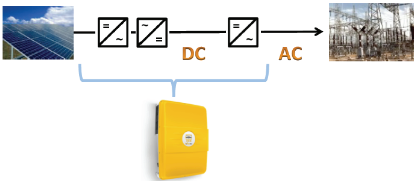


POWER ELECTRONIC APPLICATIONS – WIND POWER GENERATION



POWER ELECTRONIC APPLICATIONS – PHOTOVOLTAIC POWER GENERATION





PV PANEL CHARACTERISTICS

PV panel output characteristic is influenced with:

- Irradiation - output current increases with higher irradiation - I-V characteristic up-shift
- Temperature - open circuit voltage increases with lower temperatures - I-V characteristic right-shift

Typical PV panel shows:

- v_{OC} - open circuit voltage (the maximum panel output voltage when no power is drawn)
- i_{SC} - short circuit current (the maximum panel output current)

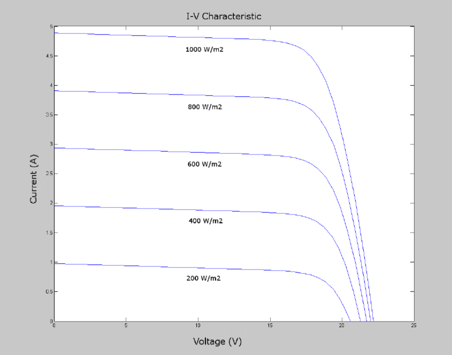


Figure 1 PV panel I-V characteristic under different irradiation.

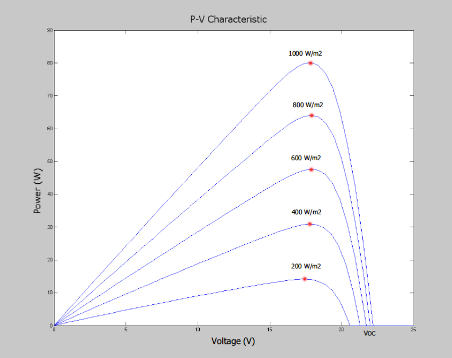


Figure 2 PV panel P-V characteristics.

MAXIMUM POWER POINT TRACKING - MPPT

MPPT algorithm tasks is:

- to determine the panel operating voltage that allows maximum power output
- this may not be always easy, especially in case of large number of PV panels connected to single MPPT controller
- we will consider simple case of a small PV panel cluster connected to our converters
- PV panel output is not constant and it depends on irradiation, temperature and load

Avoiding to use MPPT controller with PV panels, may results in:

- wasted power, since PV panels are not utilized efficiently
- costly installation, since more panels would have to be installed to get desired power out

As the PV panel output voltage is typically low, several structures are used: central inverter, string inverter, module (micro) inverter

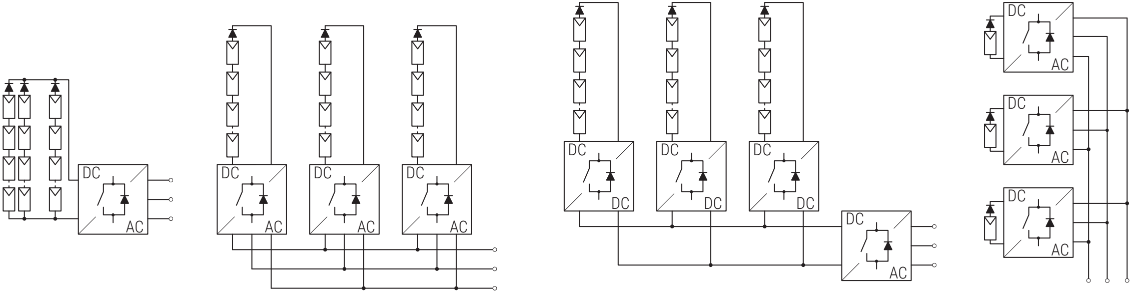


Figure 3 PV structures (from left to right): central inverter, string inverter (with AC and DC bus) and module (micro) inverter.

EE-465

Course organization and schedule

COURSE AIM

- EE-365: Power Electronics - Fundamentals and design in power electronics...
- **EE-465: Industrial Electronics I - Grid connected converters...**
- EE-490(c): Lab in Electrical Energy Systems - Project based hands-on learning
- EE-565: Industrial Electronics II - High performance drives...

Some topics are adapted from the books:

- *Fundamentals of Power Electronics* by Robert W. Erickson and Dragan Maksimovic, ISBN 978-0-306-48048-5, KAP
- *Grid Converters for Photovoltaic and Wind Power Systems* by Remus Teodorescu, Marco Liserre, Pedro Rodríguez, ISBN: 978-0-470-05751-3, Wiley
- *Grid-Side Converters Control and Design* by Slobodan Vukosavic, ISBN: 978-3-319-73278-7, Springer

We will deal with topics:

- Converter topologies and operating principles
- Pulse Width Modulation techniques
- Modeling and control of converters
- PI and PR type of regulators
- Cascaded control loops: power, voltage and current
- Digital control implementation
- Grid monitoring and synchronization (PLL)
- Grid filter design (L and LCL)

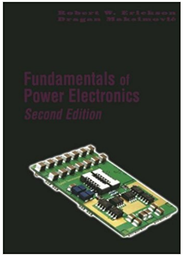


Figure 4 Fundamentals of Power Electronics.

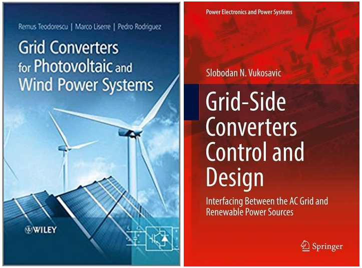


Figure 5 Grid connected converters...

COURSE LOGISTICS

Lectures:

- ELD-020
- Every Monday, 08:15 - 10:00
- Slides provided on Moodle in advance
- PLECS, MATLAB examples

Laboratory exercises:

- ELD-020
- Every Thursday, 08:15 - 10:00
- PLECS
- Skeleton models will be provided (on Moodle)

Teaching Assistants:

- Ms. Celia Hermoso Diaz
- Mr. Amin Darvishzadeh

Exam and final grade is composed of two parts:

- 40% of the final grade - 4 project reports based on exercises
- 60% of the final grade - Oral exam (open book, 20 min. + 20 min.)

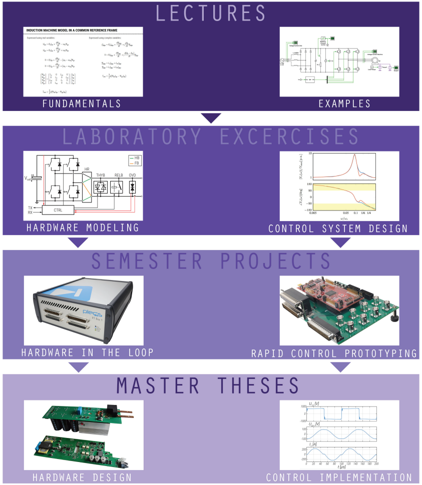


Figure 6 Different kinds of teaching at PEL

COURSE SCHEDULE

Lectures:

- 08.09. - W1: Intro, Applications, Boost converter
- 15.09. - W2: Boost converter modeling, PI reg., tuning
- 22.09. - W3: **Holiday**
- 29.09. - W4: PWM, carrier-based, SVPWM
- 06.10. - W5: Modeling AC systems, coordinate transformation
- 13.10. - W6: 3-phase VSI control, PR reg., discretization
- 20.10. - W7: **Break**
- 27.10. - W8: 3-phase PLL
- 03.11. - W9: 3-phase VSI control with L filter, I and V loops
- 10.11. - W10: Boost + VSI + MPPT
- 17.11. - W11: 3-phase VSI control with LCL filter
- 24.11. - W12: Active and passive damping
- 01.12. - W13: Unbalanced grid conditions, advanced PLL
- 08.12. - W14: Overall control in different reference frames
- 15.12. - W15: Reserve

Exercises:

- 11.09. - W1: PLECS Boost conv. vs Average Boost conv.
- 18.09. - W2: PLECS Boost conv. vs Average Boost conv.
- 25.09. - W3: Closed loop Boost converter (s-domain) + PI
- 02.10. - W4: Closed loop Boost converter (z-domain) + PI + AW
- 09.10. - W5: 3-phase VSI PWM: carrier-based PWM, SVPWM
- 16.10. - W6: 3-phase VSI modeling, reference frames
- 23.10. - W7: **Break**
- 30.10. - W8: Output current control: PI vs PR - z-domain
- 06.11. - W9: PLL implementation
- 13.11. - W10: Cascaded closed loop VSI control with L filter
- 20.11. - W11: Control of Boost + VSI
- 27.11. - W12: Control of Boost + VSI + MPPT
- 04.12. - W13: VSI grid current control with LCL
- 11.12. - W14: LCL filter passive and active damping
- 18.12. - W15: Reserve

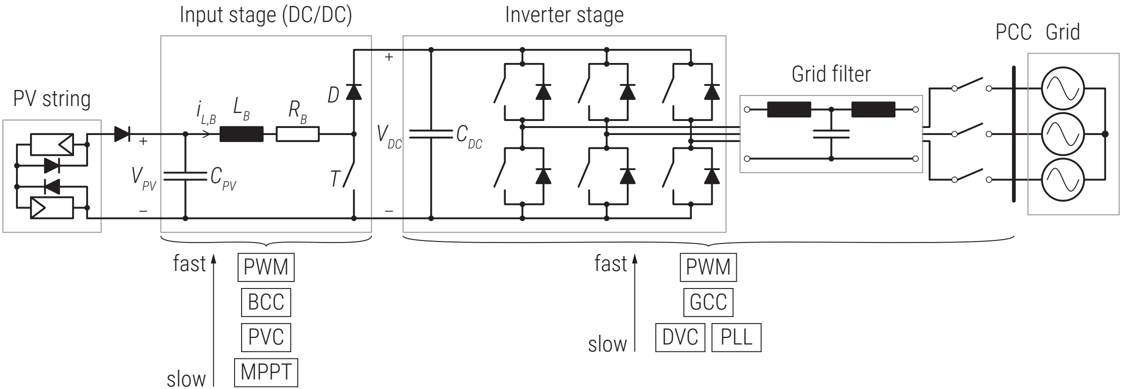


Figure 7 Overall system: Double stage photovoltaic inverter

Lectures:

- Application specific requirements
- Power electronics topologies
- Digital control in power electronics
- Grid related considerations

Exercises:

- Modeling of power electronic systems
- Implementation and verification of theoretical concepts
- Performance verification
- Comprehensive and practical learning

COURSE PROGRAM: W1

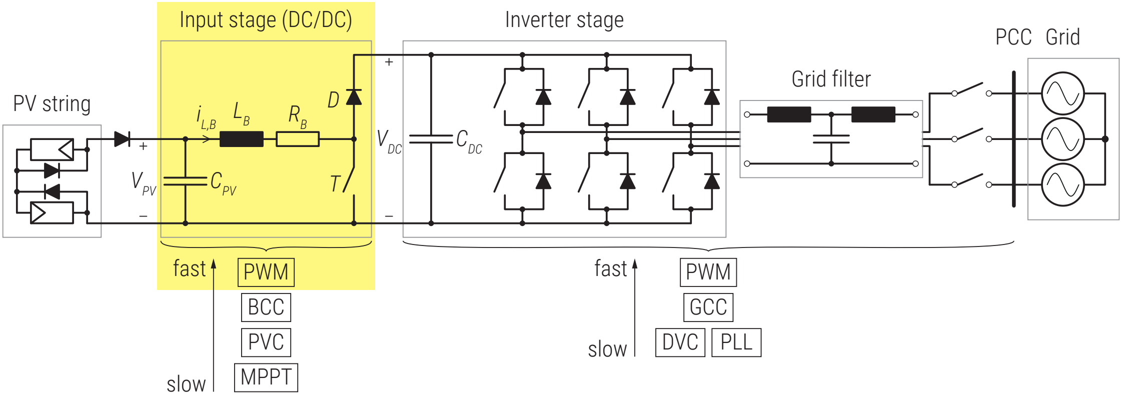


Figure 8 Overall system: Double stage photovoltaic inverter

Lectures:

- Course introduction
- Applications and motivation
- Boost converter operating principles
- Boost converter modeling

Exercises:

- Boost converter modeling and sizing
- Pulse Width Modulation
- PLECS switched model simulations
- PLECS average model simulations

COURSE PROGRAM: W2 AND W3

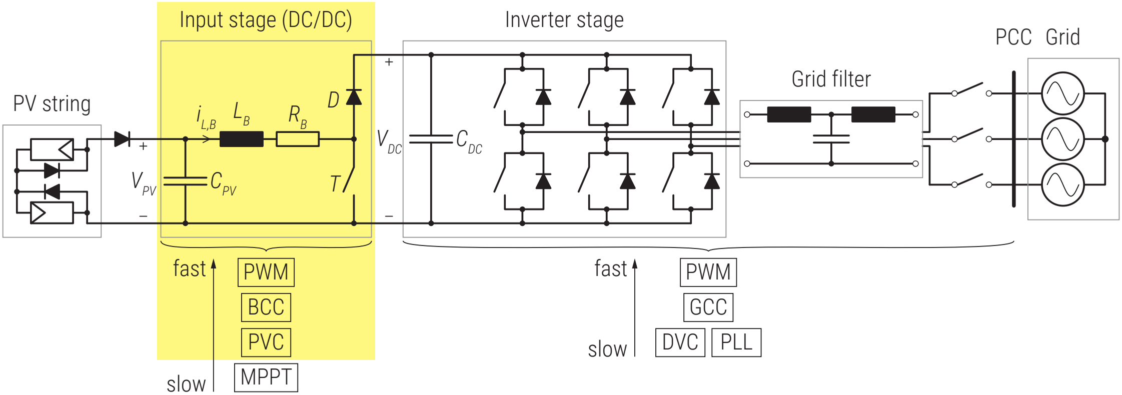


Figure 9 Overall system: Double stage photovoltaic inverter

Lectures:

- Boost converter modeling - plant identification
- PI regulators tuning: Magnitude and Symmetrical Optimum
- Cascaded closed loop control
- Discretization (from s-domain to z-domain)

Exercises:

- Current control of a Boost converter - s-domain
- Closed loop control of a Boost converter - s-domain
- Closed loop control of a Boost converter - z-domain
- Performance verification

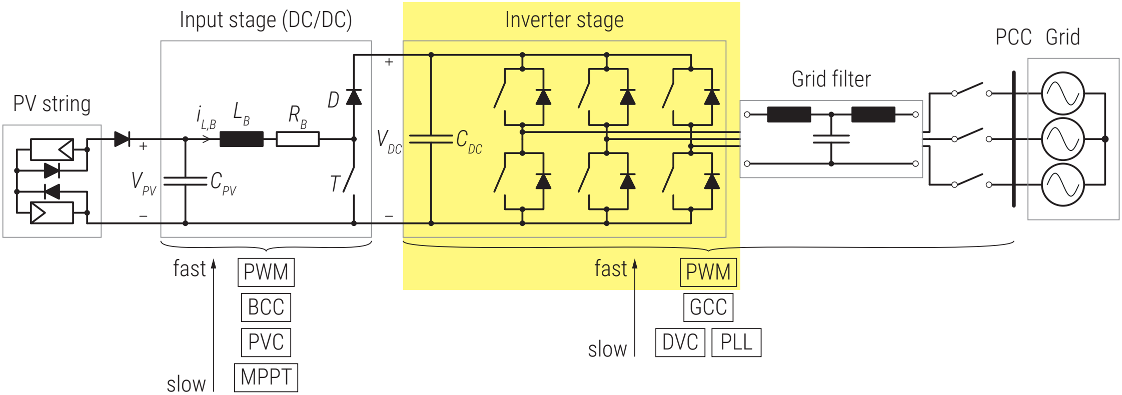


Figure 10 Overall system: Double stage photovoltaic inverter

Lectures:

- 3-phase Voltage Source Inverter (VSI)
- Pulse Width Modulation: Carrier-based and SVPWM
- Coordinate frame transformations $\alpha - \beta, d - q$
- Modeling of AC systems

Exercises:

- 3-phase VSI open loop control
- Carrier based PWM vs SVPWM
- 3-phase VSI modeling
- PLECS switched vs average model simulations

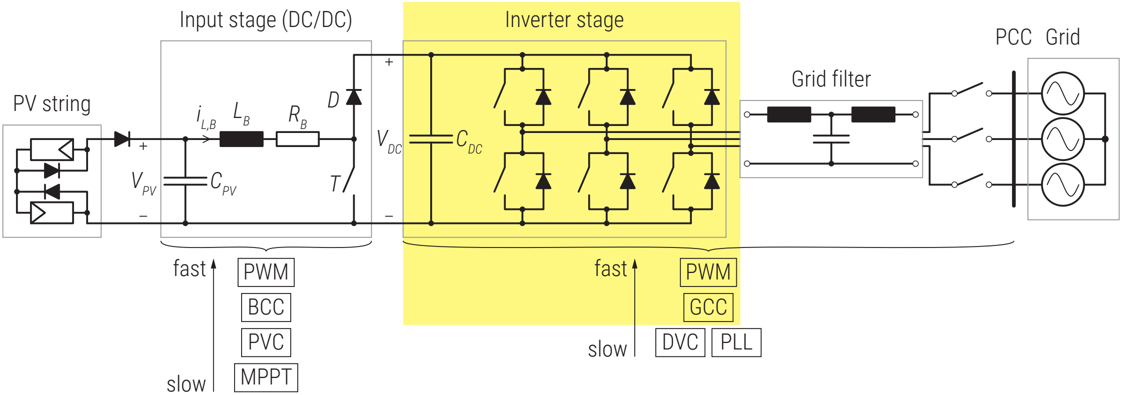


Figure 11 Overall system: Double stage photovoltaic inverter

Lectures:

- Limits of PI regulators in AC system
- PR regulators for AC systems
- Tuning and performances
- Discretization

Exercises:

- PR regulator implementation
- PI vs PR regulator comparison
- Grid current control in different reference frames
- Hysteresis regular

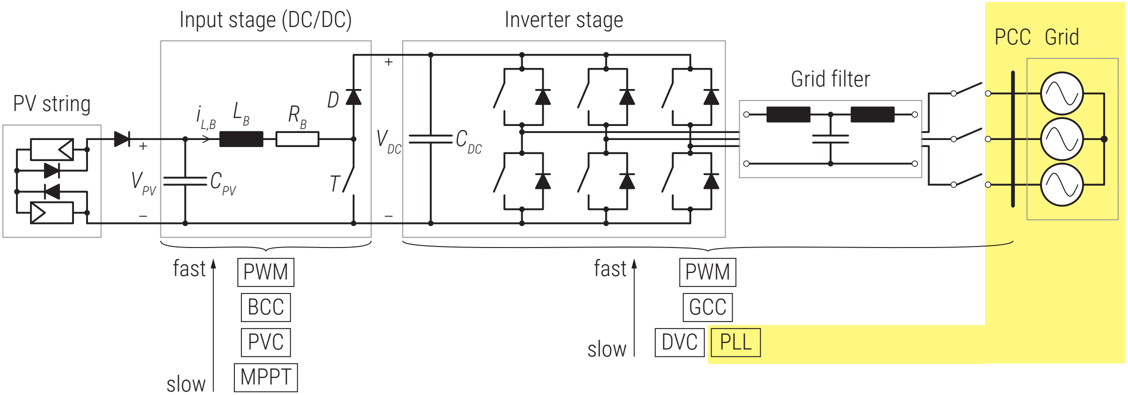


Figure 12 Overall system: Double stage photovoltaic inverter

Lectures:

- Grid monitoring and synchronization
- Sequence decomposition
- Phase Locked Loops
- Variations and implementations

Exercises:

- Grid modeling
- PLL implementation
- Alternative PLLs
- Performance verification

COURSE PROGRAM: W8

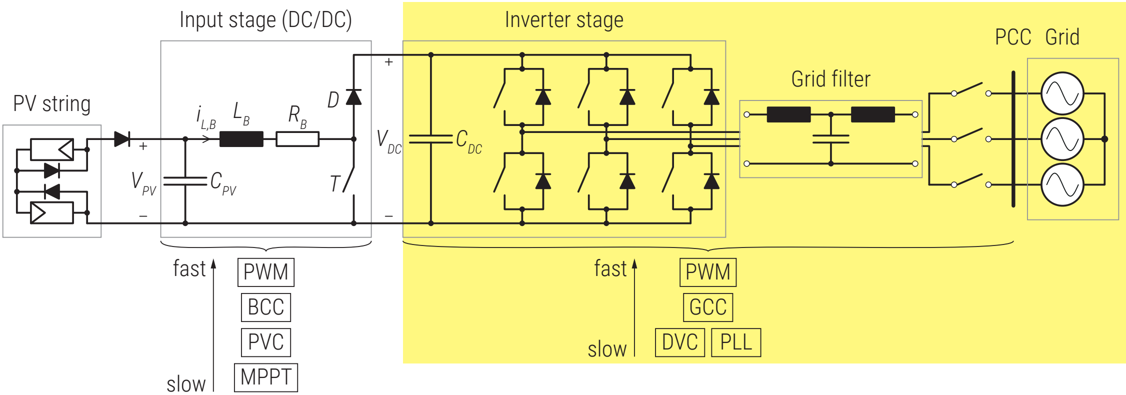


Figure 13 Overall system: Double stage photovoltaic inverter

Lectures:

- 3-phase VSI control with L filter
- DC link voltage control
- Grid current control
- Implementation in different reference frames

Exercises:

- Grid synchronization
- Grid current control in abc $\alpha - \beta$, and $d - q$ frame
- DC link voltage control
- Performance verification

COURSE PROGRAM: W9

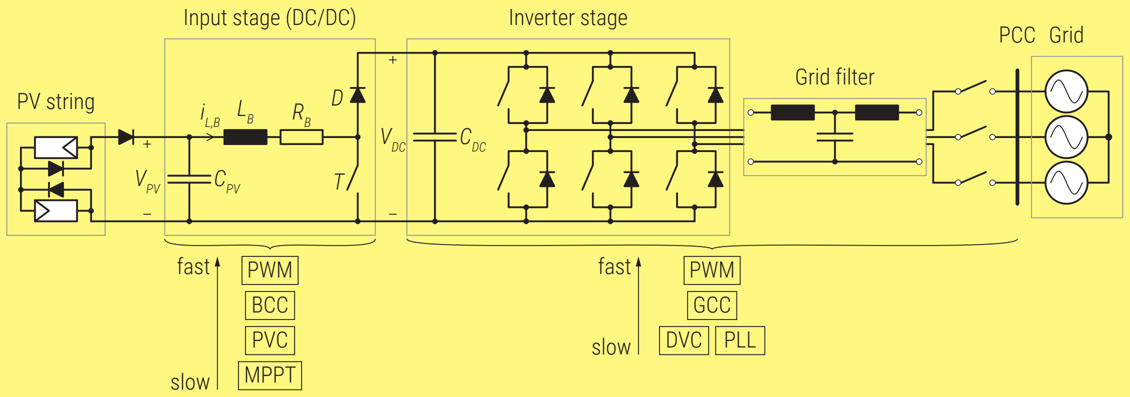


Figure 14 Overall system: Double stage photovoltaic inverter

Lectures:

- Photovoltaic Inverter overall structure
- Maximum Power Point Tracking (MPPT)
- Cascaded control loops with L filter
- Sampling and bandwidths

Exercises:

- Boost converter + 3-phase VSI
- Control loops coordination
- Overall control tuning
- Performance verification

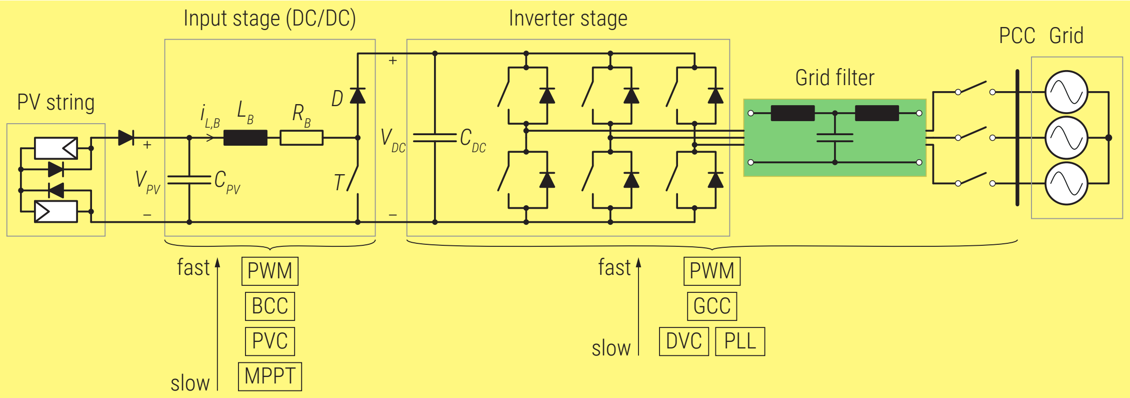


Figure 15 Overall system: Double stage photovoltaic inverter

Lectures:

- LCL filter versus L filter
- Sizing and design
- Implications on the control
- Active and passive damping

Exercises:

- LCL filter modeling
- MPPT implementation
- Overall control tuning
- Performance verification

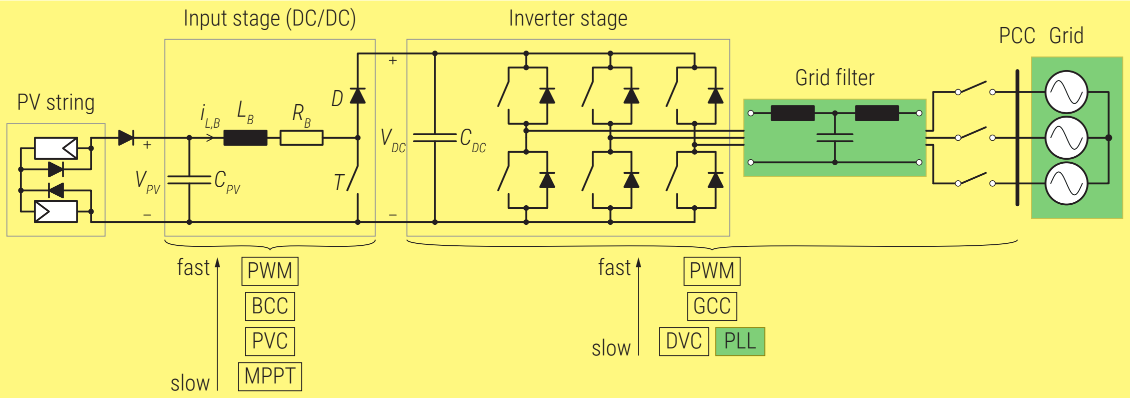


Figure 16 Overall system: Double stage photovoltaic inverter

Lectures:

- Unbalanced grid conditions
- Grid disturbances and power quality
- Grid voltage sequences
- Advanced PLL implementations

Exercises:

- Performance comparison in different reference frames
- LCL filter performance verification
- Passive damping implementation
- Active damping implementation

COURSE PROGRAM: W13 AND W14

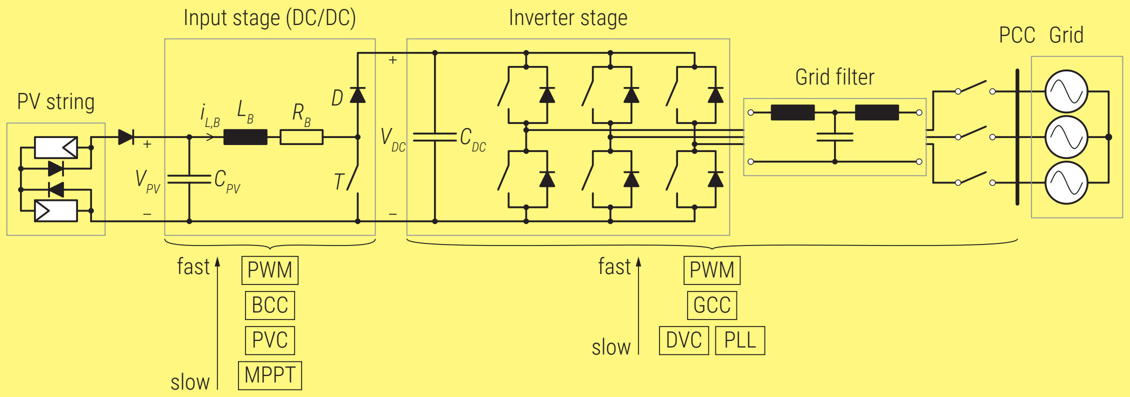


Figure 17 Overall system: Double stage photovoltaic inverter

Lectures:

- Alternative implementations
- Reference frames
- Discussions
- Course wrap-up

Exercises:

- Reserve
- Reserve
- Reserve
- Reserve

REPORTING

Reporting:

- Latex report templates will be provided
- Reports should not be longer than 10 page each
- It is technical report, not an essay
- Be precise, clear, punctual, keep it simple
- Use graphics to convey your message better
- Number equations, figures, use captions
- Acknowledge sources and reference
- **Submission deadlines are fixed**

Grading:

- Maximum number of points per report is 150
- 4 Reports x 150 = 600 points in total
- Point scored / 100 = Your grade
- Report grade = 40% of the final grade

Report submission on Moodle:

- Upload your report in pdf
- Upload your PLECS model for that report

Exercises → 4 Reports

- 11.09 - W1: PLECS Boost converter vs Average Boost converter
- 18.09 - W3: Closed loop Boost converter (s-domain) + PI
- 02.10 - W4: Closed loop Boost converter (z-domain) + PI + AW
- **REPORT 1 Deadline 09.10.2025**
- 09.10 - W5: 3-phase VSI PWM: carrier-based PWM, SVPWM
- 16.10 - W6: 3-phase VSI modeling, reference frames
- 30.10 - W8: Output current control: PI vs PR - z-domain
- 07.11 - W9: PLL implementation
- **REPORT 2 Deadline 13.11.2025**
- 13.11 - W10: Cascaded closed loop VSI control with L filter
- 20.11 - W11: Control of Boost + VSI
- 27.11 - W12: Control of Boost + VSI + MPPT
- **REPORT 3 Deadline 04.12.2025**
- 04.12 - W13: VSI grid current control with LCL
- 11.12 - W14: LCL filter passive and active damping
- 18.12 - W15: Reserve
- **REPORT 4 Deadline 25.12.2025**

BOOST CONVERTER

Non isolated, step-up DC-DC converter

BOOST CONVERTER - STEP-UP CONVERTER

By reorganizing the three basic elements (S, D, L), we can implement step-up converter

- Boost converter output is greater than its input voltage
- it is widely used for different applications
- it is also used to realize power factor correction (PFC) circuits

During the t_{on}

- Switch is ON and Diode is OFF (reverse biased)
- input voltage source V_d provides the energy to the inductor
- output capacitor is supplying the load

During the t_{off}

- Switch is OFF and Diode is ON
- output stage receives the energy from inductor and the source V_d
- inductor is releasing some of its stored energy to the load

The average inductor current is equal to the average input current $I_i = I_L$

We need to recall that for the steady state:

- the average voltage across the inductor is zero
- the average current through the capacitor is zero

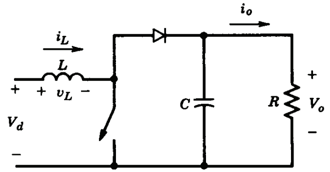


Figure 18 Boost Converter.

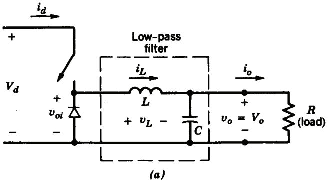


Figure 19 Buck Converter.

BOOST CONVERTER - CCM

During the CCM:

- inductor current i_L is flowing continuously (it never reaches zero value)
- the average inductor current is equal to the average input current i_d

For the Boost converter we have:

$$v_L = L\frac{di_L}{dt}, \quad i_C = C\frac{dV_o}{dt} \quad i_L(t_{on}) = i_d, \quad i_L(t_{off}) = i_C + i_o = C\frac{dV_o}{dt} + \frac{V_o}{R}$$

During the t_{on} - Switch is ON and Diode is OFF

$$v_L = V_d, \quad i_L = i_d, \quad i_C = C\frac{dV_o}{dt} = -i_o = -\frac{V_o}{R}$$

During the t_{off} - Switch is OFF and Diode is ON

$$v_L = V_d - V_o, \quad i_L = i_d = i_C + i_o = C\frac{dV_o}{dt} + \frac{V_o}{R}$$

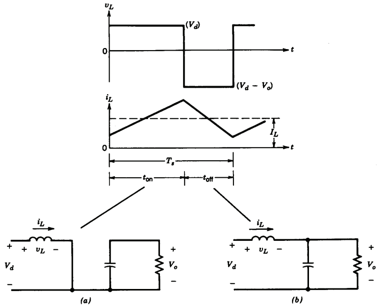


Figure 20 Boost Converter during CCM.

Considering the steady state, the average voltage across the inductor is zero

$$\int_0^{T_s} v_L dt = 0 \quad \Rightarrow \quad \int_0^{t_{on}} v_L dt + \int_{t_{on}}^{T_s} v_L dt = 0 \quad \Rightarrow \quad V_d t_{on} + (V_d - V_o)t_{off} = 0$$

Neglecting the power losses:

$$P_d = P_o \Rightarrow V_d I_d = V_o I_o$$

Finally, input-output voltage relation (transfer function) of a Boost converter is:

$$\frac{V_o}{V_d} = \frac{T_s}{t_{off}} = \frac{1}{1-D}$$

$$\frac{I_o}{I_d} = \frac{V_d}{V_o} = 1 - D$$

BOOST CONVERTER - BOUNDARY BETWEEN CCM AND DCM

Similar to Buck converter, Boost converter also can operate in:

- CCM: the inductor current i_L is flowing continuously (it never reaches zero value)
- DCM: the inductor current i_L is zero for a certain period of time

At the boundary condition, the average inductor current is (note that $I_o = (1-D)I_d = (1-D)I_L$):

$$I_{LB} = \frac{1}{2} i_{L,peak} = \frac{V_d}{2L} t_{on} = \frac{T_s V_o}{2L} D(1-D) \quad \Rightarrow \quad I_{oB} = \frac{T_s V_o}{2L} D(1-D)^2$$

With constant V_o, I_{oB} can be plotted as function of duty cycle D, and we can calculate:

$$I_{LB,max}(D=0.5) = \frac{T_s V_o}{8L} \Rightarrow I_{LB} = 4D(1-D) I_{LB,max}, \qquad I_{oB,max}(D=1/3) = \frac{2}{27} \frac{T_s V_o}{L} \Rightarrow I_{oB} = \frac{27}{4} D(1-D)^2 I_{oB,max}$$

For a given D with constant V_o: if I_o drops below I_{oB} (or I_L drops below I_{LB}) Boost converter changes its mode from CCM to DCM

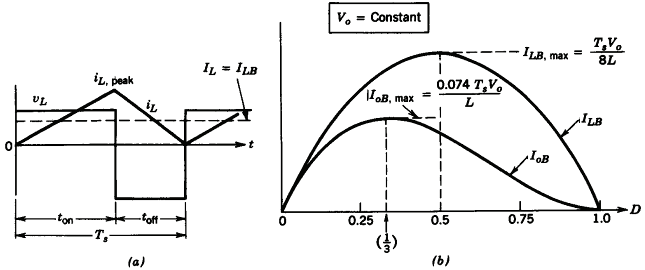


Figure 21 Current waveform at the boundary of CCM and DCM.

BOOST CONVERTER - DCM - CONSTANT V_o

We assume that Boost converter:

- operates with constant V_d and D when a load decreases
- while D would be modified by control, we assume that is not changed
- decrease of load ($P_o = P_d$) reduces inductor average current
- t_{off} interval is split into two sub-intervals
- during $\Delta_1 T_s$ the inductor current is reducing to zero
- during $\Delta_2 T_s$ the inductor current/voltage is zero and load is supplied by capacitor

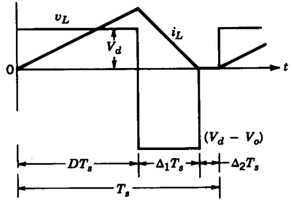


Figure 22 Boost Converter during DCM.

The average voltage across the inductor is zero

$$\int_0^{T_s} v_L dt = 0 \quad \Rightarrow \quad V_d D T_s + (V_d - V_o)\Delta_1 T_s = 0 \quad \Rightarrow \quad \frac{V_o}{V_d} = \frac{\Delta_1 + D}{\Delta_1} = \frac{I_d}{I_o}$$

Inductor peak current, average input and output currents are:

$$i_{L,peak} = \frac{V_d}{L} D T_s \quad \Rightarrow \quad I_d = i_{L,peak} \frac{D + \Delta_1}{2} = \frac{V_d}{2L} D T_s (D + \Delta_1)$$

$$\Rightarrow \quad I_o = \frac{T_s V_d}{2L} D \Delta_1$$

Finally D as function of load current (valid only for DCM) for various V_o/V_d is:

$$D = \left[\frac{4}{27} \frac{V_o}{V_d} \left(\frac{V_o}{V_d} - 1 \right) \frac{I_o}{I_{oB,max}} \right]^{1/2}$$

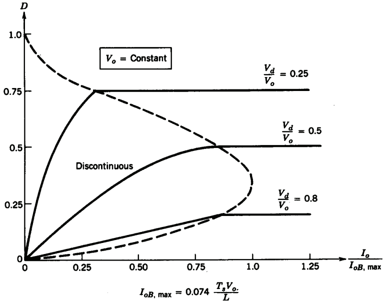


Figure 23 Boost characteristic with constant V_o.

BOOST CONVERTER - INDUCTOR CURRENT RIPPLE

For the CCM operation:

- I_L - inductor current has average component equal to the input current
- ΔI_L - peak-to-peak ripple

Considering $t_{on} = DT_s$ interval, current rise for ΔI_L

$$\Delta I_L = \frac{V_d}{L} DT_s$$

Similarly, considering $t_{off} = (1-D)T_s$ interval, current fall for ΔI_L

$$\Delta I_L = \frac{V_d - V_o}{L}(1-D)T_s = \frac{(1-D)V_o - V_o}{L}(1-D)T_s = -\frac{V_o}{L}D(1-D)T_s$$

It is desired to reduce ΔI_L in the range of 10% to 20% of I_L, where:

$$I_L = I_d = \frac{I_o}{1-D} = \frac{V_o}{R}\frac{1}{1-D} = \frac{V_d}{R}\frac{1}{(1-D)^2}$$

L can be selected based on that requirement as:

$$L = \frac{V_d}{\Delta I_L} DT_s = \frac{V_o}{\Delta I_L} D(1-D)T_s$$

Normally, the worst case operating conditions are considered, so that current ripple is below maximum desired for most of the operating range

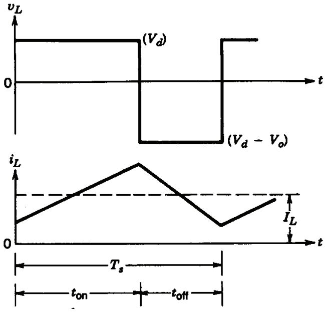


Figure 24 Boost converter input current ripple.

Notice that for all other parameters being constant, current ripple function has a peak for D=0.5

BOOST CONVERTER - OUTPUT VOLTAGE RIPPLE

To calculate output capacitor ripple, we will assume for CCM operation:

- average diode current flows through the load resistor
- ripple diode current flows through the capacitor
- ΔQ represents additional charge
- ΔV_o peak-to-peak voltage ripple can be written as

$$\Delta V_o = \frac{\Delta Q}{C} = \frac{I_o D T_s}{C} = \frac{V_o}{R}\frac{DT_s}{C}$$

From here we have:

$$\frac{\Delta V_o}{V_o} = \frac{DT_s}{RC} = \frac{DT_s}{\tau}$$

Output capacitor can be chosen for desired output voltage ripple, e.g. 1%

$$C = \frac{DT_s}{R}\frac{V_o}{\Delta V_o}$$

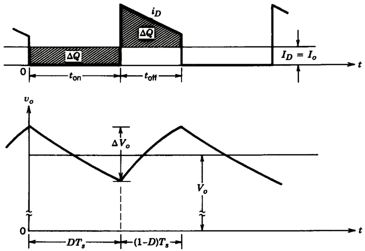


Figure 25 Boost converter output voltage ripple.

BOOST CONVERTER - EFFECT OF PARASITIC ELEMENTS

Boost converter transfer function indicates infinite gain when $D = 1$, which is not realistic

$$\frac{V_o}{V_d} = \frac{1}{1-D}$$

Practical converters are made out of real components with parasitic elements:

- switches and diodes are not ideal
- inductors have finite resistance of winding R_L
- capacitors have finite equivalent series resistance (ESR)

Simple inclusion of inductor resistance R_L already influences ideal transfer function
During the t_{on} and t_{off} we have:

$$\underbrace{v_L = V_d - R_L i_L, \quad i_C = -\frac{V_o}{R}}_{t_{on}} \qquad \underbrace{v_L = V_d - R_L i_L - V_o, \quad i_C = i_L - \frac{V_o}{R}}_{t_{off}}$$

From the inductor volt-second balance and capacitor charge-balance we get:

$$\int_0^{T_s} v_L dt = 0 \quad \Rightarrow \quad (V_d - R_L I_L)D + (V_d - R_L I_L - V_o)(1-D) = 0$$

$$\int_0^{T_s} i_C dt = 0 \quad \Rightarrow \quad -\frac{V_o}{R}D + (I_L - \frac{V_o}{R})(1-D) = 0$$

Device characteristic will also influence realistic conversion ratio

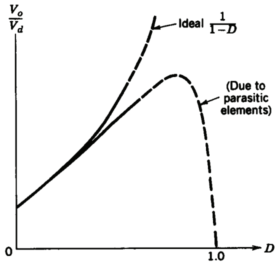


Figure 26 Effects of parasitic elements on the conversion ratio.

Solving yields:

$$\frac{V_o}{V_d} = \frac{1}{1-D} \frac{1}{1 + \frac{R_L}{R(1-D)^2}}$$

Maximum output voltage is thus limited and influenced by inductor resistance

BOOST CONVERTER MODELING (I)

Nomenclature:

- I_{PV} - PV panel is represented as a variable current source
- C_{PV} - capacitance at the output of a PV panel
- V_{PV} - PV panel output voltage
- $I_{C,PV}$ - input capacitance current
- L_B - Boost converter inductance
- $V_{L,B}$ - instantaneous inductor voltage
- R_B - Boost inductor internal resistance
- V_{in} - voltage across the switch
- C_{dc} - output capacitor
- V_{dc} - voltage across the output capacitor
- R_{load} - load at the output is represented as a resistance

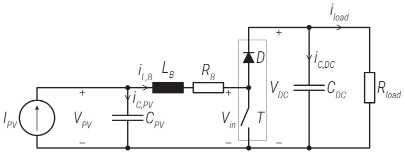


Figure 27 Boost converter.

The Boost DC-DC converter function is to extract the maximum available power from the PV panels / string with a maximum Power Point Tracking (MPPT) algorithm

For the time being, the output capacitor C_{dc} and load R_{load} are ignored

Control system development will be treated next week

Basic relations between different elements can be easily established

The voltage and current of a capacitor are related as:

$$I_{C,PV} = C_{PV}\frac{dV_{PV}}{dt} \quad \rightarrow V_{PV} = \frac{1}{C_{PV}}\int_0^{\infty} I_{C,PV}\mathrm{d}t$$

Using the Laplace transform t-integral rule:

$$\mathcal{L}\left\{\int_0^{\infty} g(t)\mathrm{d}t\right\} = \frac{1}{s}\mathcal{L}\{f(t)\} \quad \rightarrow V_{PV} = \frac{1}{sC_{PV}}I_{C,PV}$$

Replacing with the capacitor current expression from the circuit:

$$V_{PV} = \frac{1}{sC_{PV}}(I_{PV} - I_{L,B})$$

Finally, the transfer function linking the output V_{PV} to the input $I_{L,B}$ is

$$G_v(s) = \frac{V_{PV}}{I_{PV} - I_{L,B}} = \frac{1}{sC_{PV}}$$

Structural diagram can be easily established in PLECS

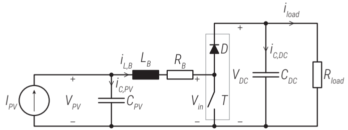


Figure 28 Boost converter.

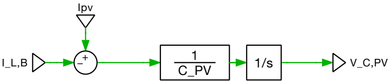


Figure 29 Plant model for the voltage control loop.

Switching cell can be also analyzed

When the switch S is turned ON (defined by the duty cycle D):

$$V_{in} = 0$$
$$V_{L,B} = V_{PV}$$

When the switch S is turned OFF (defined by the duty cycle $1 - D$):

$$V_{in} = V_{DC}$$
$$V_{L,B} = V_{PV} - V_{DC}$$

We can easily establish that V_{in} is related to V_{DC} through the duty cycle $1 - D$:

$$V_{in} = (1 - D)V_{DC}$$

The instantaneous inductor voltage V_L is given with:

$$V_{L,B} = V_{PV} - V_{in}$$

Duty cycle D is a result of a controller action...

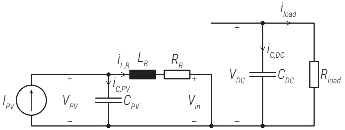


Figure 30 Boost converter: S = ON.

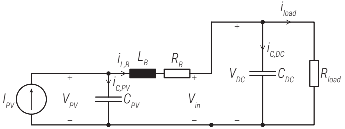


Figure 31 Boost converter: S = OFF.

The voltage and current of an inductor are related as:

$$V_{L,B} = L_B \frac{dI_{L,B}}{dt} \quad \rightarrow I_{L,B} = \frac{1}{L_B} \int_0^{\infty} V_{L,B} \mathrm{d}t$$

Using the Laplace transform *t*-integral rule:

$$\mathcal{L}\left\{\int_0^{\infty} g(t) \mathrm{d}t\right\} = \frac{1}{s} \mathcal{L}\{f(t)\} \quad \rightarrow I_{L,B} = \frac{1}{sL_B} V_{L,B}$$

KVL equation:

$$V_{PV} = sL_B I_{L,B} + R_B I_{L,B} + V_{in}$$
$$V_{PV} - V_{in} = (sL_B + R_B) I_{L,B}$$

Finally, the transfer function linking the output $I_{L,B}$ to the input $V_{PV} - V_{in}$ is

$$G_i(s) = \frac{I_{L,B}}{V_{PV} - V_{in}} = \frac{1}{R_B + sL_B} = \frac{K}{1 + sT}$$

The control of $I_{L,B}$ is made through V_{in} (converter action)

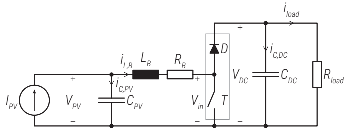


Figure 32 Boost converter.

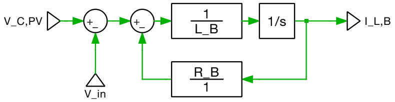


Figure 33 Plant model for the current control loop.

BOOST CONVERTER MODELING (V)

Complete system can be partitioned and described analytically:

- I_{PV} - PV panel is represented as a variable current source
- C_{PV} - capacitance at the output of a PV panel
- V_{PV} - PV panel output voltage
- $I_{C,PV}$ - input capacitance current
- L_B - Boost converter inductance
- R_B - Boost inductor internal resistance
- V_{in} - voltage across the switch
- C_{dc} - output capacitor
- V_{dc} - voltage across the output capacitor
- R_{load} - load at the output is represented as a resistance
- D - Duty cycle coming from the control system

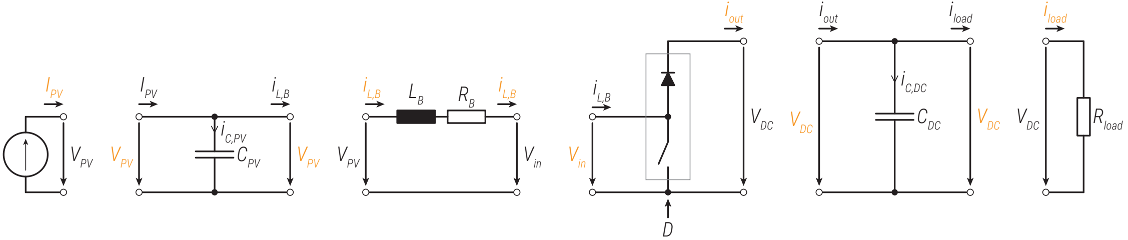


Figure 34 Partitioning Boost converter for the modeling.