COMMON-MODE BEHAVIOR OF SWITCH-MODE CONVERTERS

by Tamas Kerekes

Agenda

- DC-DC and DC-AC converters
- Differential-mode voltage and current
- Common-mode voltage and current
- PWM of switch-mode converters
- DC-DC converter applications
- DC-AC converter applications
- Exercise

Converter types

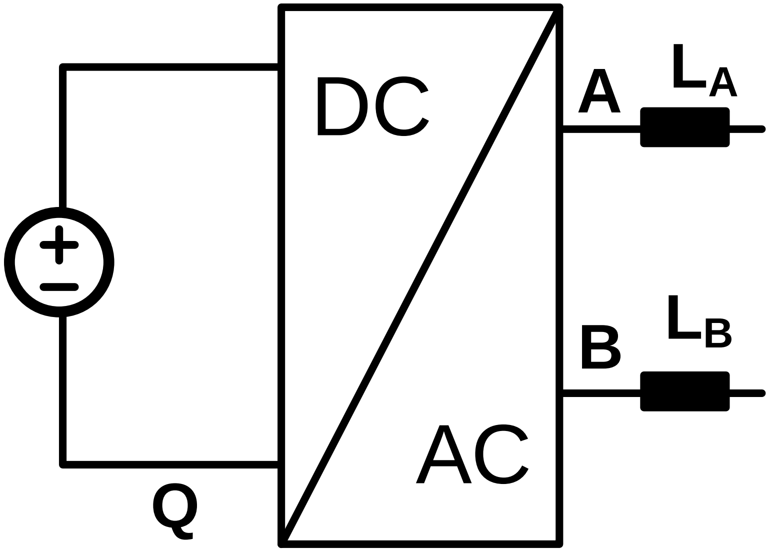
- DC-DC converters:
  - Buck, boost, buck-boost, forward, push-pull, …
- DC-AC (AC-DC) converters
  - Half-bridge
  - H-bridge
  - Full-bridge
  - Multilevel
  - …

What is differential mode

- Differential mode voltage is the potential difference between two terminals

- **line to line voltage** is a differential mode voltage
- **phase voltage** is also a differential mode voltage

- Differential mode current is the current flowing due to the differential mode voltage



DC
AC
A
B
L_A
L_B
Q

Differential mode

- Voltage

$$V_{dm-AB} = V_{AQ} - V_{BQ} = V_{AB}$$

- Current

What is common mode

- Common-mode voltage is the potential that is common to both terminals

- Can be a constant voltage (constant DC offset)
- Can be a changing in time (PWM or AC offset)

- Common-mode current is the current flowing due to the common-mode voltage

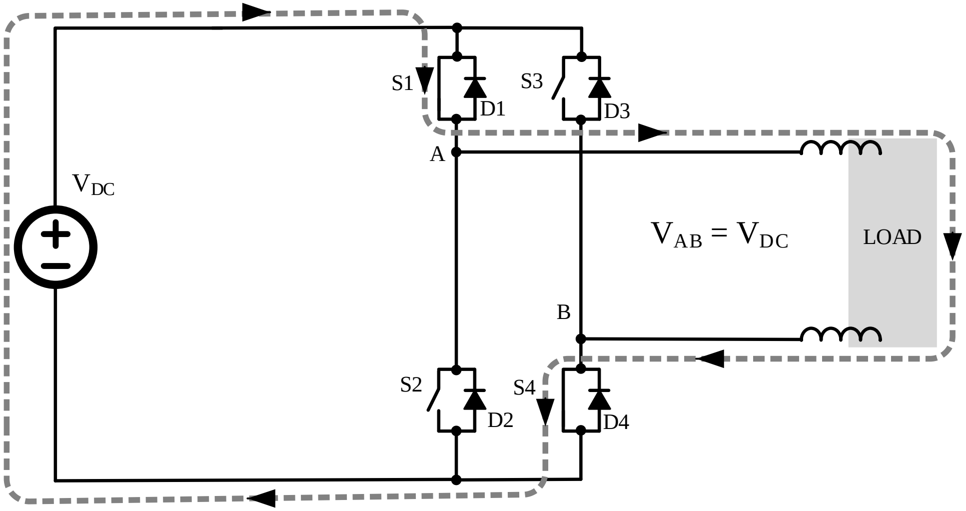
Common-mode

- Voltage

$$V_{cm-AB} = \frac{V_{AQ} + V_{BQ}}{2}$$

- Current

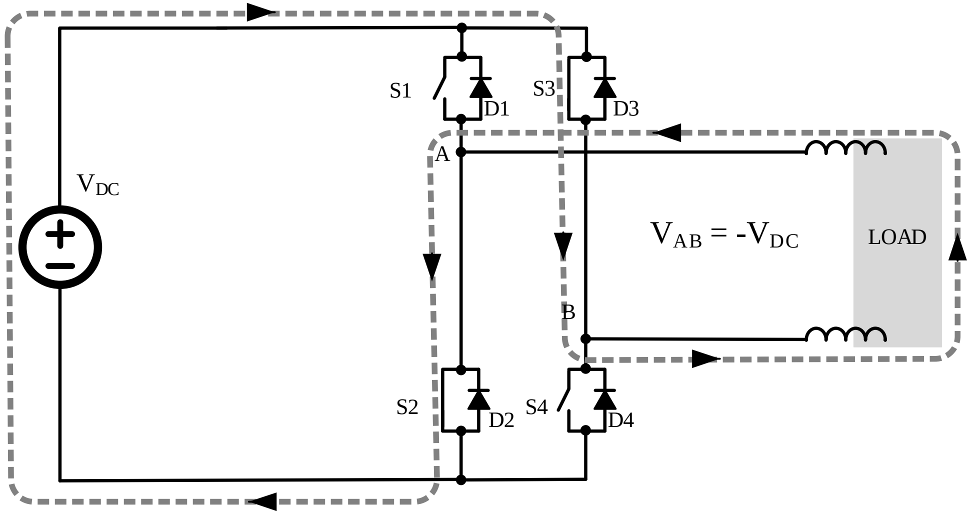
Switching states



S1 + S4 = ON

S1 + S4 and S2 + S3 are switched complementary at high frequency.

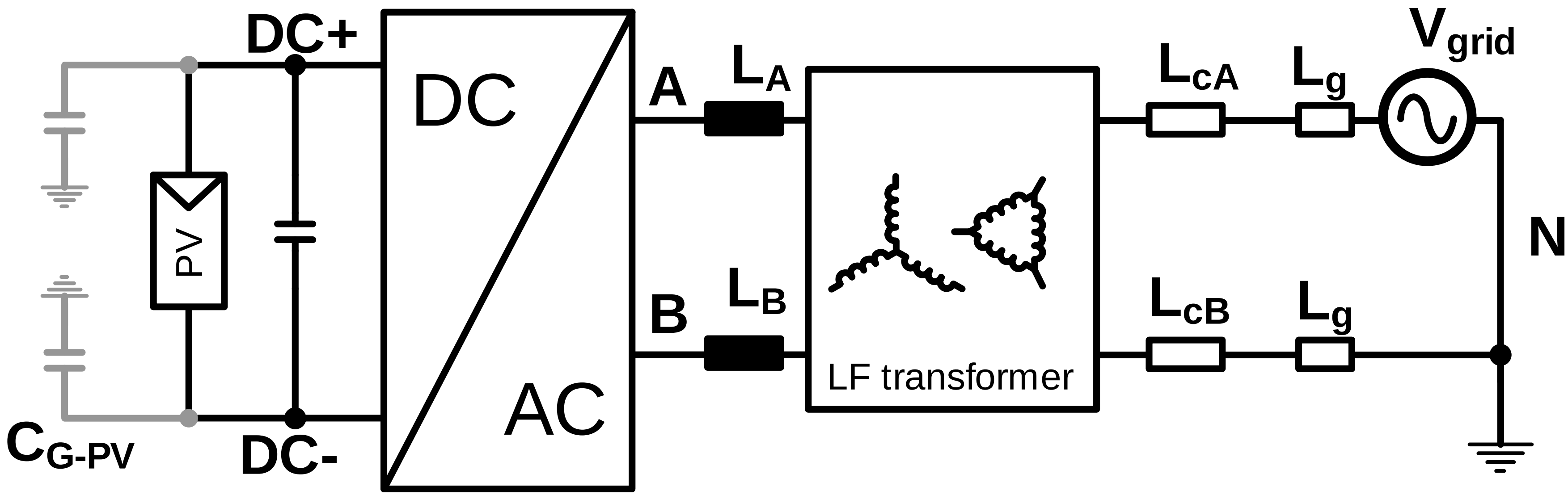
Switching states

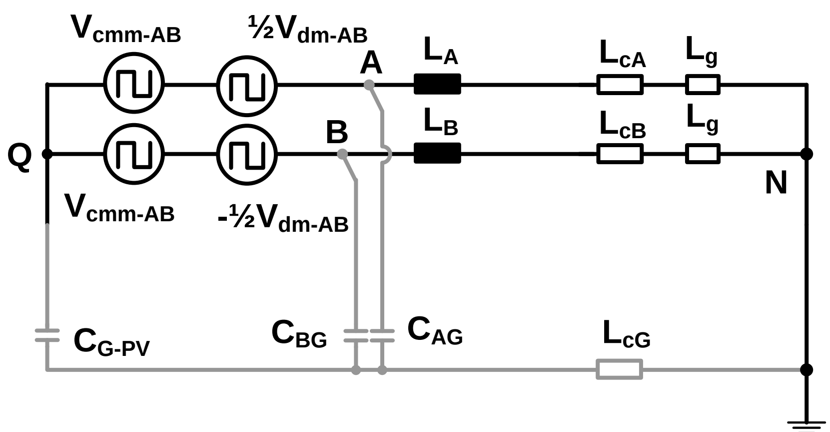


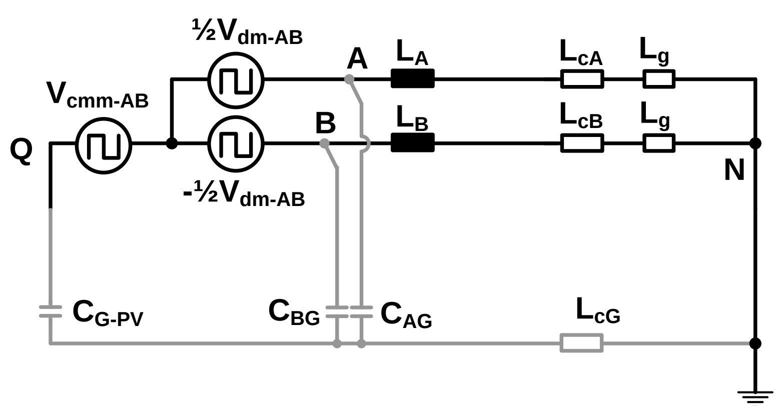
S2 + S3 = ON

S1 + S4 and S2 + S3 are switched complementary at high frequency.

Common mode modelling

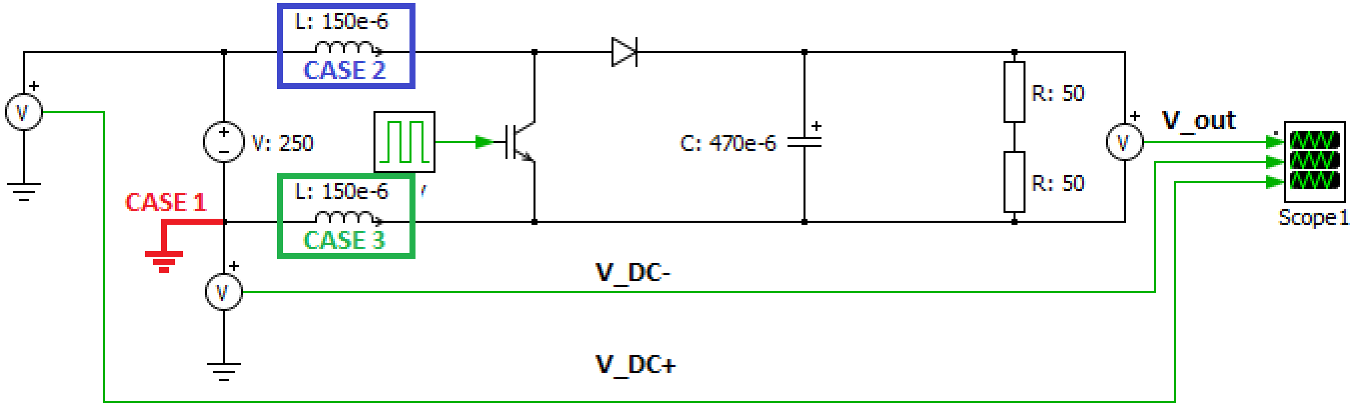






Common-mode behavior

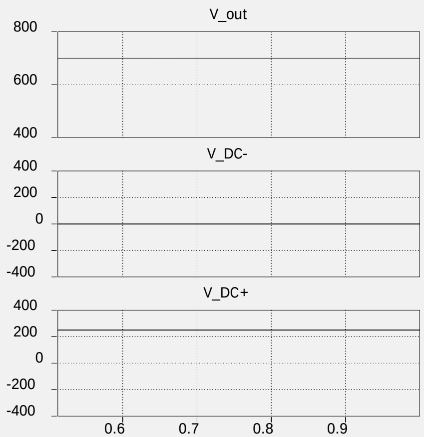
DC-DC converter

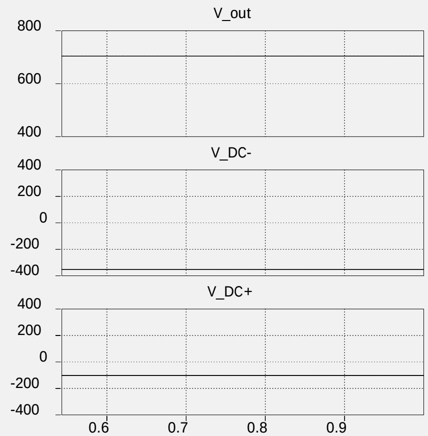


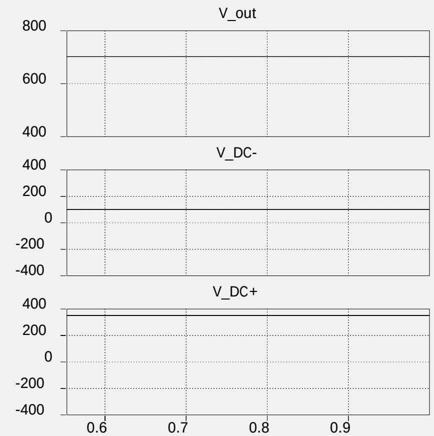
Common-mode behavior

DC-DC converter

DC- grounded	No ground inductor on DC+	No ground inductor on DC-



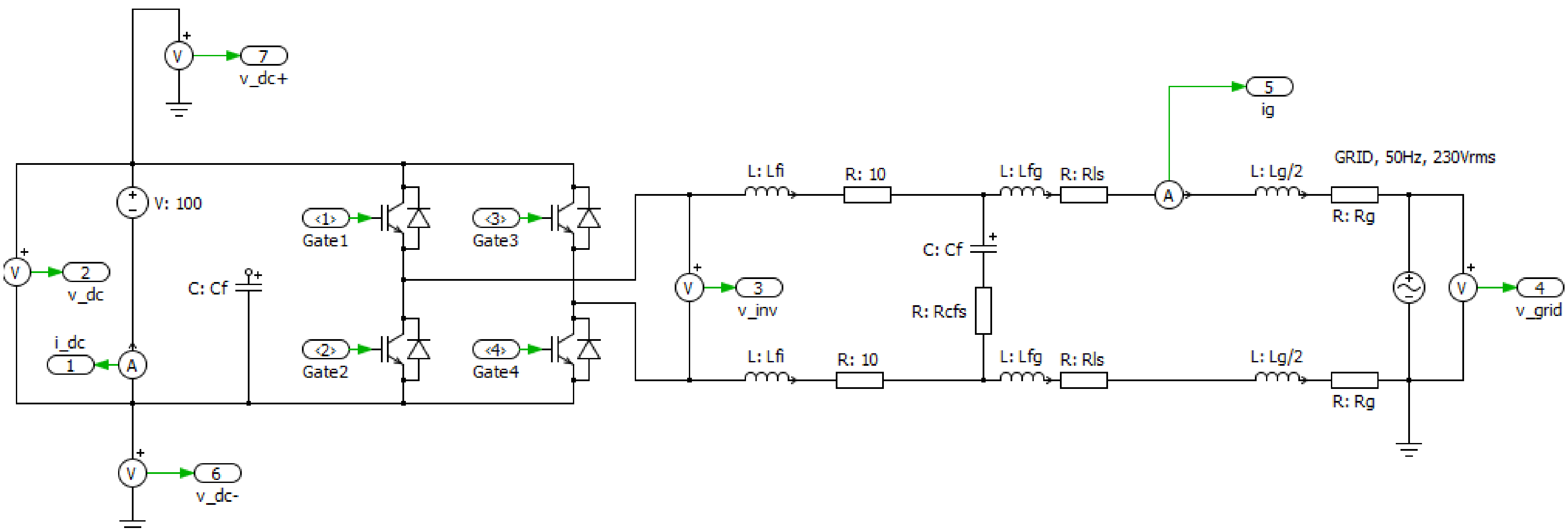




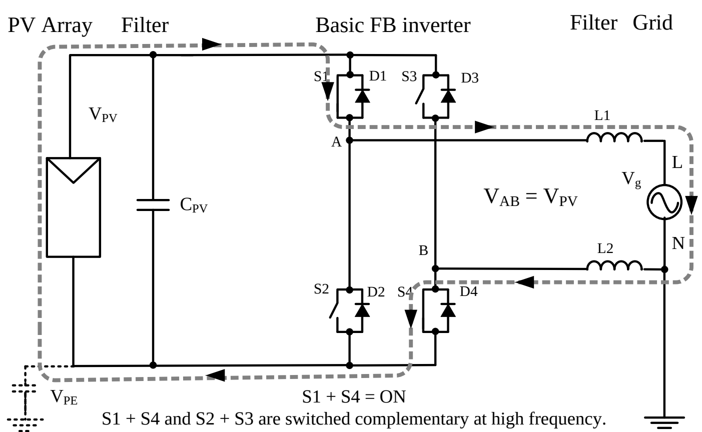
CASE 1	**CASE 2**	**CASE 1**

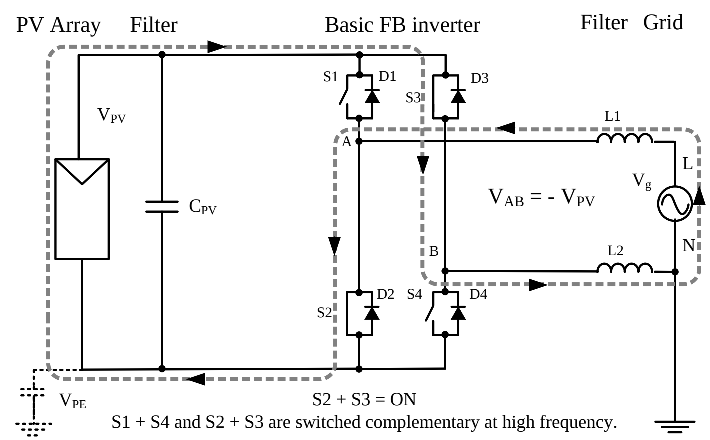
Common-mode behavior

- DC-AC converter



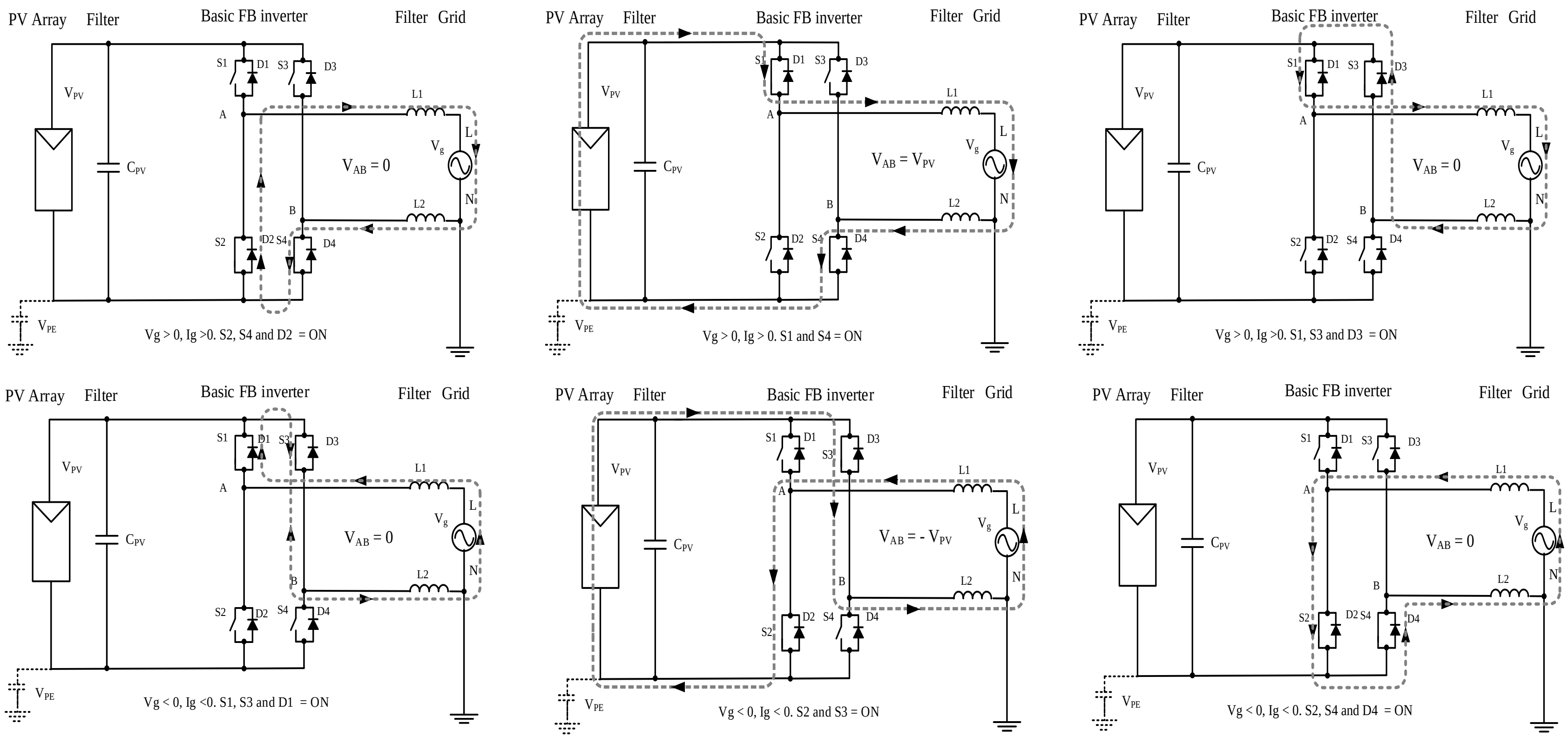
Bipolar PWM





- S1 + S4 and S2 + S3 are switched complementary at high frequency (PWM)
- No 0 output voltage possible
- The switching ripple in the current equals 1x switching frequency → large filtering
- Voltage across filter is bipolar → high core losses
- No common mode voltage → V_{PE} free for high frequency →low leakage current
- Reactive power exchange L1(2)<-> C_{PV} during freewheeling and that 2 devices are simultaneously switched every switching period

FB Unipolar PWM



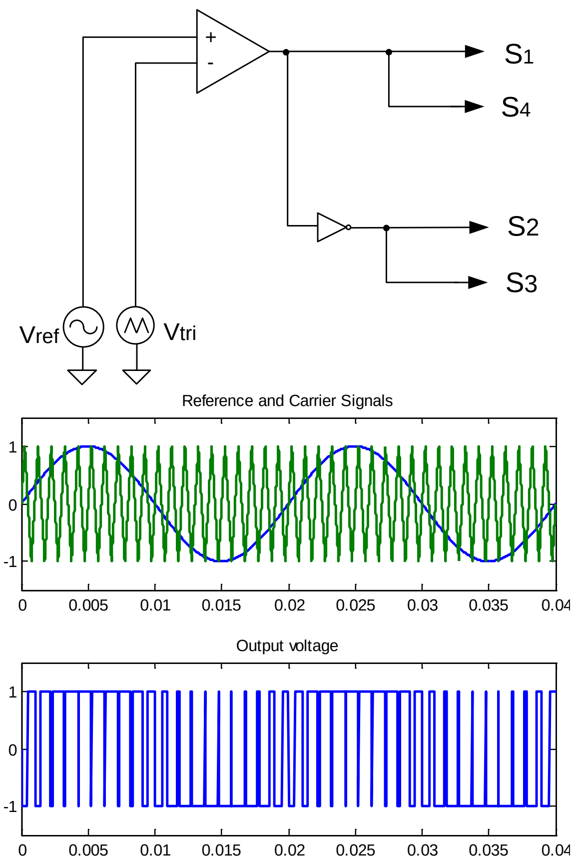
- Leg A and B are switched with high frequency with mirrored sinusoidal reference
- Two 0 output voltage states possible: S1 and S3 = ON and S2 and S4 = ON
- The switching ripple in the current equals 2x switching frequency → lower filtering
- Voltage across filter is unipolar → low core losses
- V_{PE} has switching frequency components → high leakage current and EMI

Common-mode behavior

- DC-AC converter PWM modulation

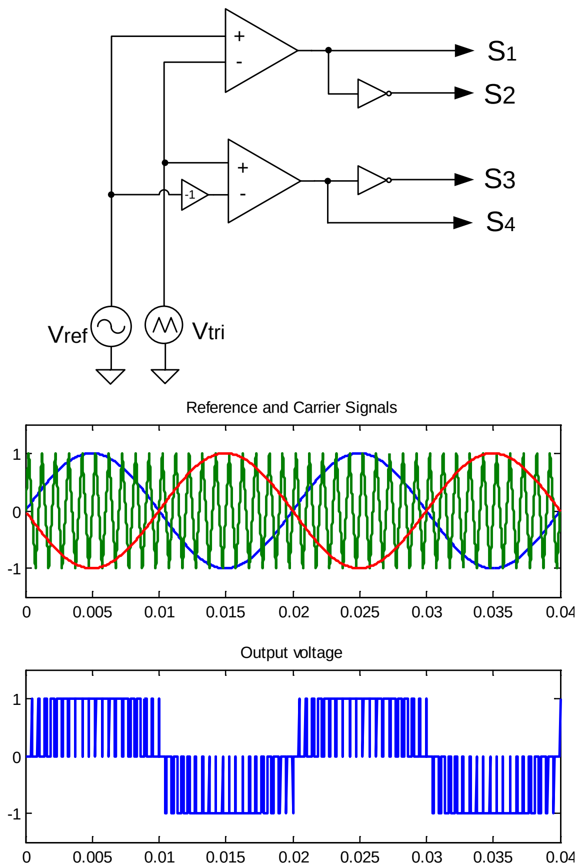
Bipolar PWM

S1 + S4 and S2 + S3 are switched complementary at high frequency



Unipolar PWM

Leg A and B are switched with high frequency with mirrored sinusoidal ref.

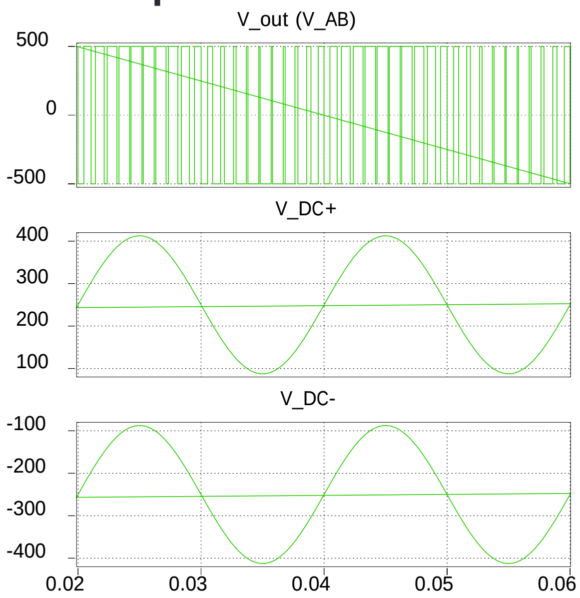


Common-mode behavior

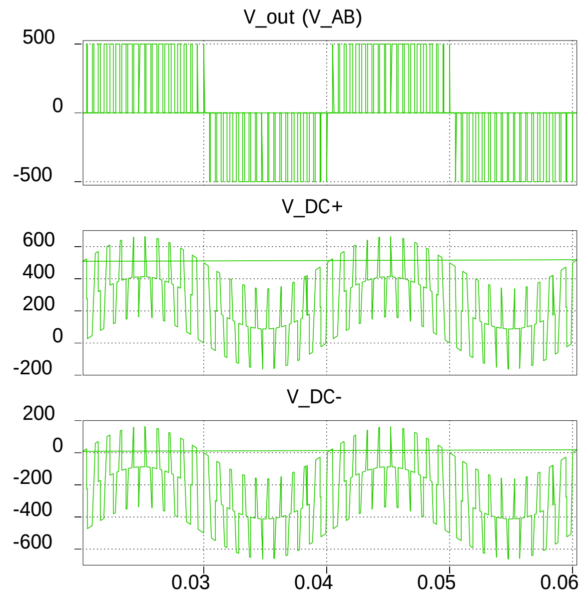
- DC-AC converter:

VDC=500V, Lfi=Lfg=1mH; Rls=0.05; Cf=4.7uF

Bipolar PWM

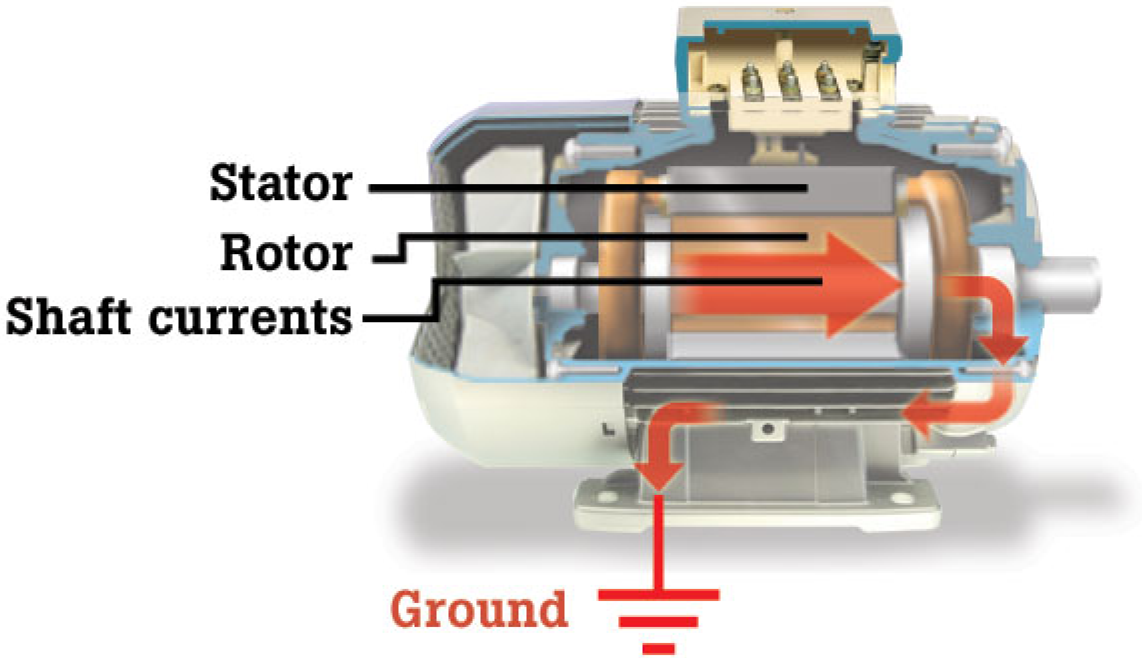


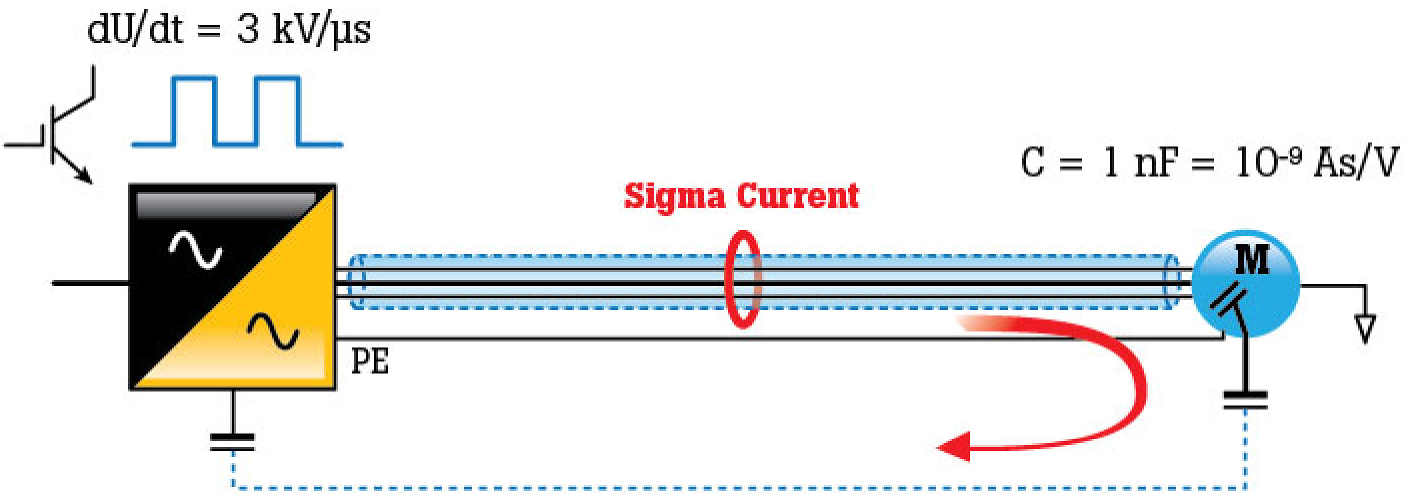
Unipolar PWM

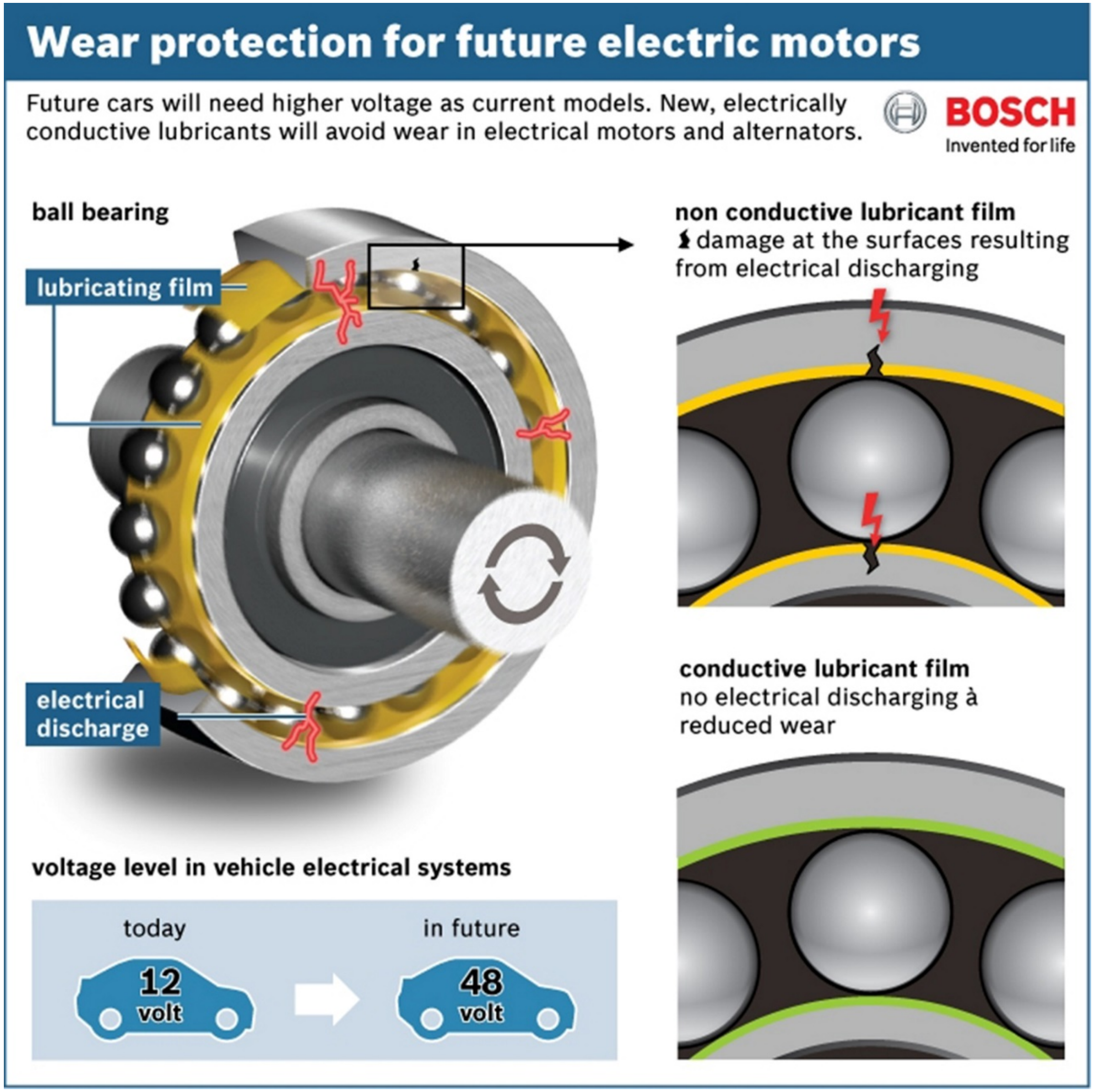


Leakage current in applications

- Bearing currents in motor drives (AC)
- Ground currents in PV (AC)
- Potential induced degradation in PV (DC)


Stator
Rotor
Shaft currents
Ground


dU/dt = 3 kV/µs
C = 1 nF = 10-9 As/V
Sigma Current
M
PE

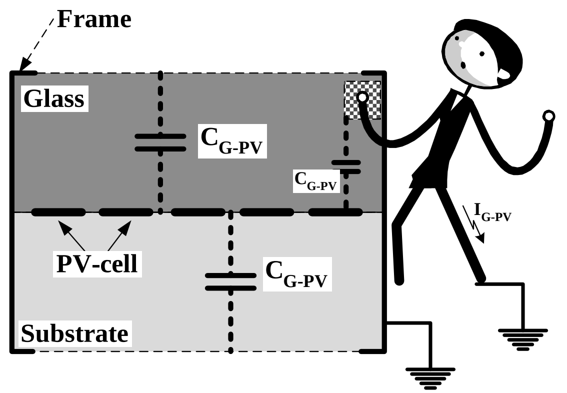

Wear protection for future electric motors
Future cars will need higher voltage as current models. New, electrically conductive lubricants will avoid wear in electrical motors and alternators.
BOSCH
Invented for life
ball bearing
lubricating film
electrical discharge
non conductive lubricant film
damage at the surfaces resulting from electrical discharging
conductive lubricant film
no electrical discharging à reduced wear
voltage level in vehicle electrical systems
today
12 volt
in future
48 volt

Bearing current

- Blackened lubricant shows the effects of electrical currents produced by variable frequency drives, which can create hot spots within the bearing.

Common-mode voltage (AC)

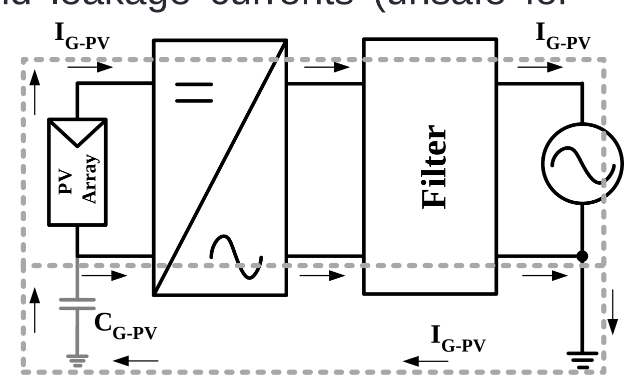
Parasitic capacitance of the PV array

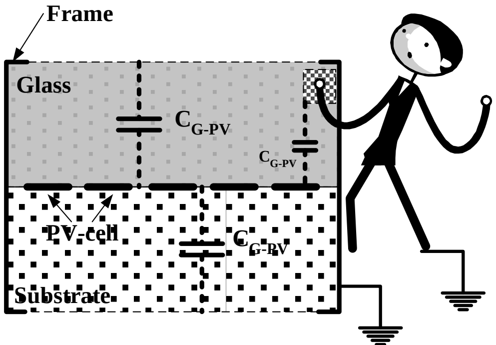


- PV array has large surface
- Parasitic capacitance formed between grounded frame and PV cells
- Its value depends on the:
  - Surface of the PV array and grounded frame
  - Distance of PV cell to the module
  - Atmospheric conditions and dust which can increase the electrical conductivity of the panel's surface

Leakage current

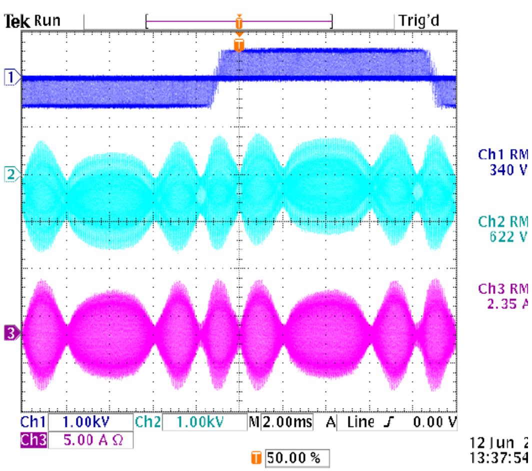
- Charging and discharging this capacitance leads to ground leakage currents (unsafe for human interaction; damage PV panels)
- Amplitude of leakage current depends on
  - Value of parasitic capacitance
  - Amplitude and frequency of imposed voltage
- RCM (Residual Current Monitoring) unit for monitoring leakage ground currents



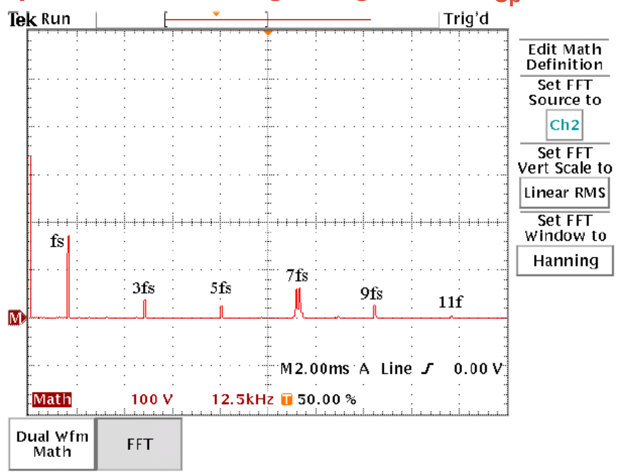


	Soleil FVG 36-125	Kyocera KS10	BPSolar MSX120
Surface of PV panel	*204 x 352mm²*	*1197 x 535mm²*	*1108 x 991mm²*
Power at MPP (STC)	*80W*	*10W*	*120W*
$C_{G\text{-}PV}$(1 panel)	*130pF*	*57pF*	*21pF*
$C_{G\text{-}PV}$(1panel) wet	*1,38nF @ 10kHz*	*2,39nF @ 10kHz*	*3nF @ 10kHz*
$C_{G\text{-}PV}$(2panels)	*247pF*	*101pF*	*not available*
$C_{G\text{-}PV}$(1panel+ palm)	*140pF*	*150pF*	*200pF*
$C_{G\text{-}PV}$ (1panel+palm) wet	*185pF @ 10kHz*	*230pF @ 10kHz*	*200pF @ 10kHz*
$C_{G\text{-}PV}$(1panel+ copper plate)	*160pF*	*140pF*	*150pF*
$C_{G\text{-}PV}$(1panel+ copper plate) wet	*210pF @ 10kHz*	*212pF @ 10kHz*	*257pF @ 10kHz*

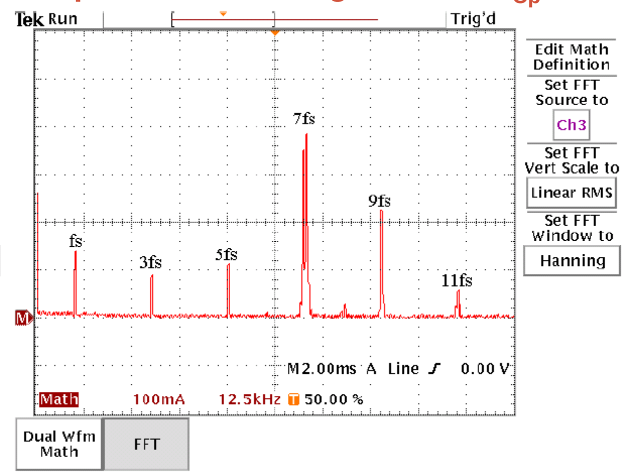
V_{AB}, V_{PE} and I_{PE} for FB-UP



Spectrum of voltage to ground V_{Cp}



Spectrum of leakage current: I_{Cp}



Based on I_{Cp} and V_{Cp} and different frequencies the leakage capacitance was calculated at: Cp=13.6nF (7.06nF/kWp). Cp is useful in high-frequency analysis and in damping resonances

Common-mode voltage (DC)

Thin-Film modules

- TCO corrosion: the electrochemical corrosion of thin film PV modules using transparent conductive oxides (TCO) as front contacts on the front cover glass

- In case of PV cells manufactured using the superstrate technology, the TCO used as the negative pole directly contacts the glass

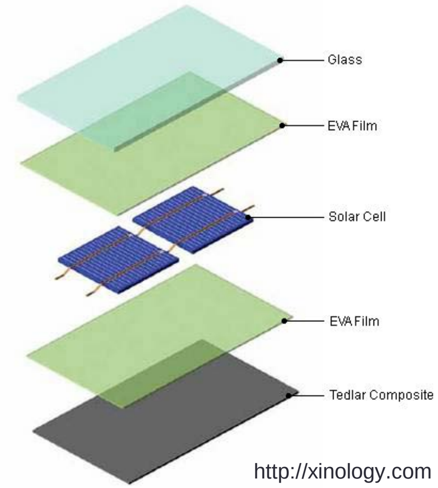
- The negative bias voltage, especially for thin-film modules, can cause TCO corrosion via sodium diffusion through the glass together with the presence of water molecules in the TCO/glass interface. This deterioration is permanent.

Ref: R. Gonzalez, Inverter Topology Issues for Grounded PV Modules

Common-mode voltage (DC)

Backside contact modules

- Metallization of the positive and negative contacts is done on the backside of the cell (cell efficiency > 20%)
- Polarization effect: leakage current flowing through the EVA (ethylene vinyl acetate) film and the upper glass will result in the accumulation of charge carriers on the cell surface, which cannot be released, thereby effecting the performance of the cell
- If the cell experiences positive potential respect to the ground, then these negative charges cannot be released
- If the cell experiences a negative potential respect to gro effect can be reversed and the cell returns to its original s



http://xinology.com

This bias voltage depends on the DC-DC converter top
For ex:

- **Boost (boost inductor position)**
- **Buck-boost**
- **Push-Pull**

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