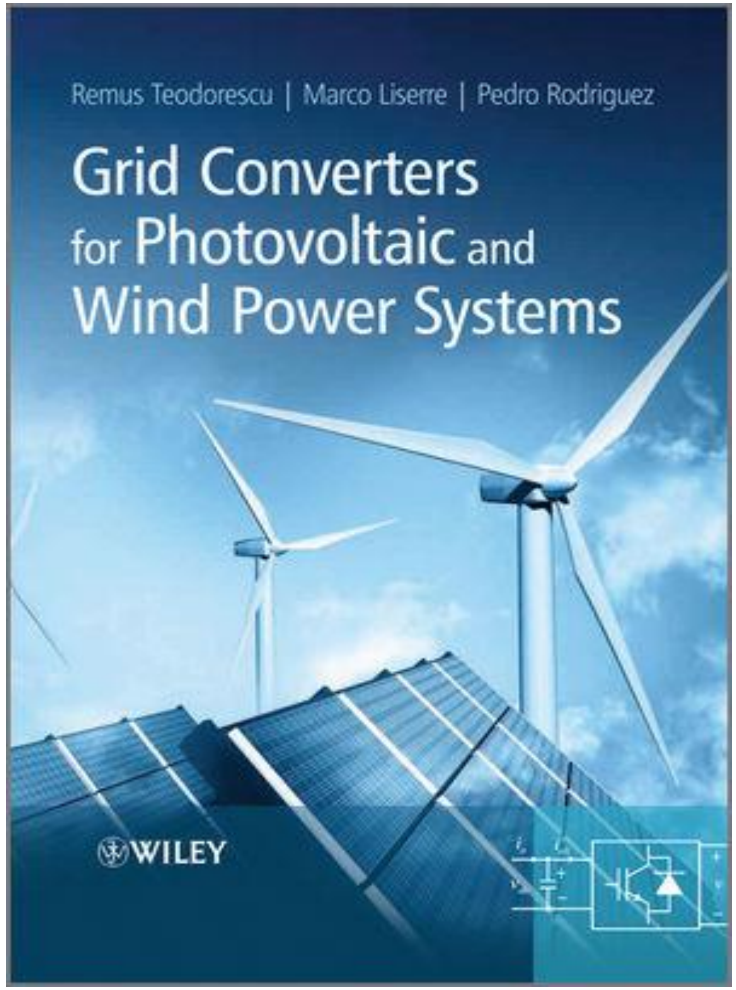
Renewable Electric Energy Systems EE—546

Photovoltaic Inverter Structures

Dr. U. T. Shami

Slides are prepared from:—Chapter 2



R Teodorescu, M Liserre, P Rodriguez- Grid Converters for Photovoltaic and Wind Power Systems

Photovoltaic Inverter Structures:

- DC/AC Inverter Structures Derived from H-Bridge Topology
- Inverter Structures Derived from NPC Topology
- Multilevel Inverter for PV applications

Introduction: Source Voltage Consideration

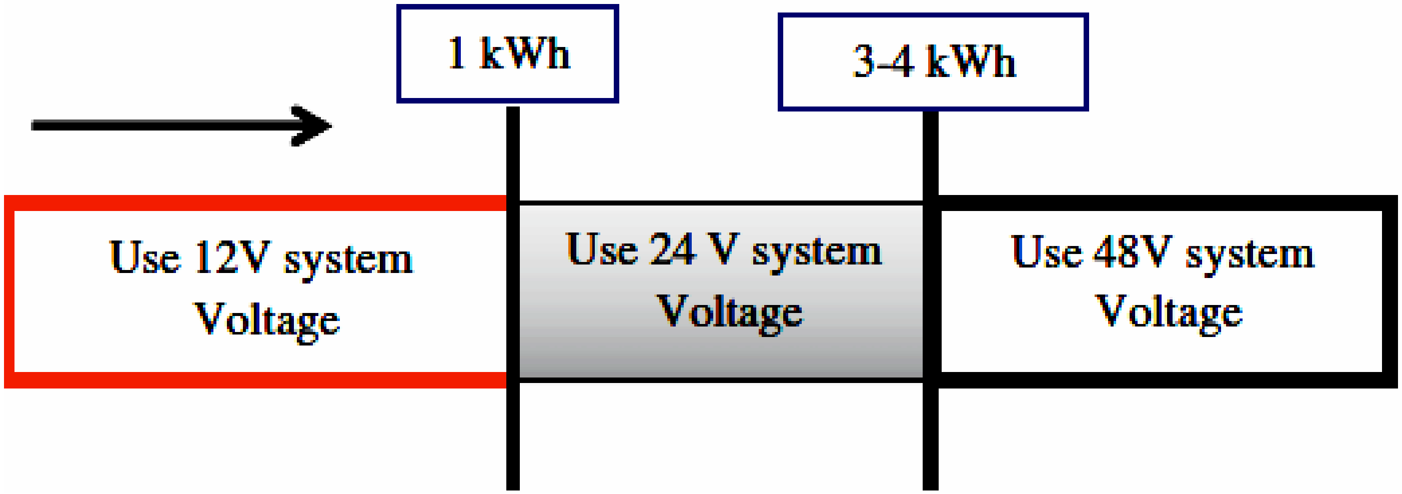


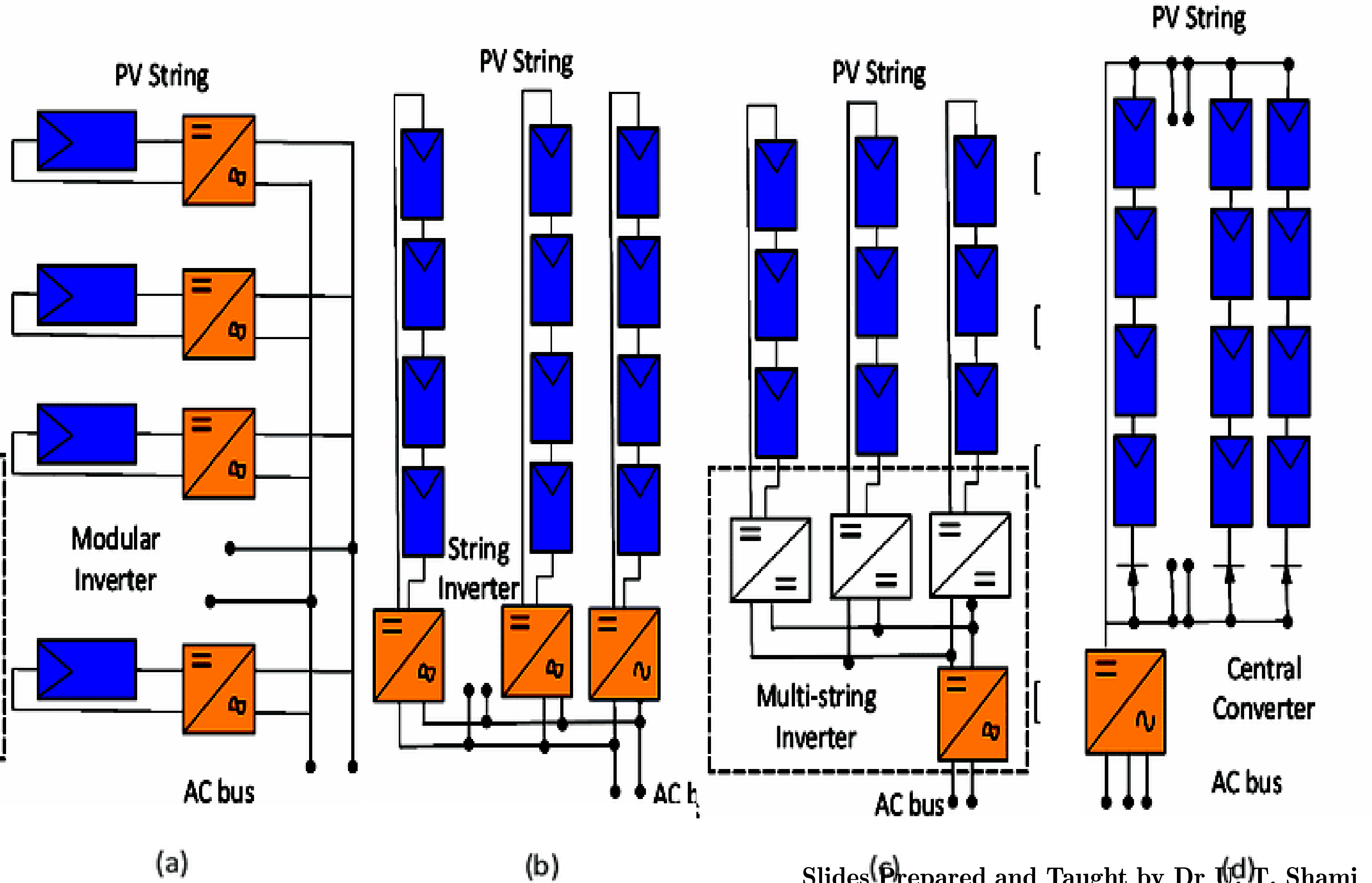
Fig. 3 A typical load variation with voltage

Introduction

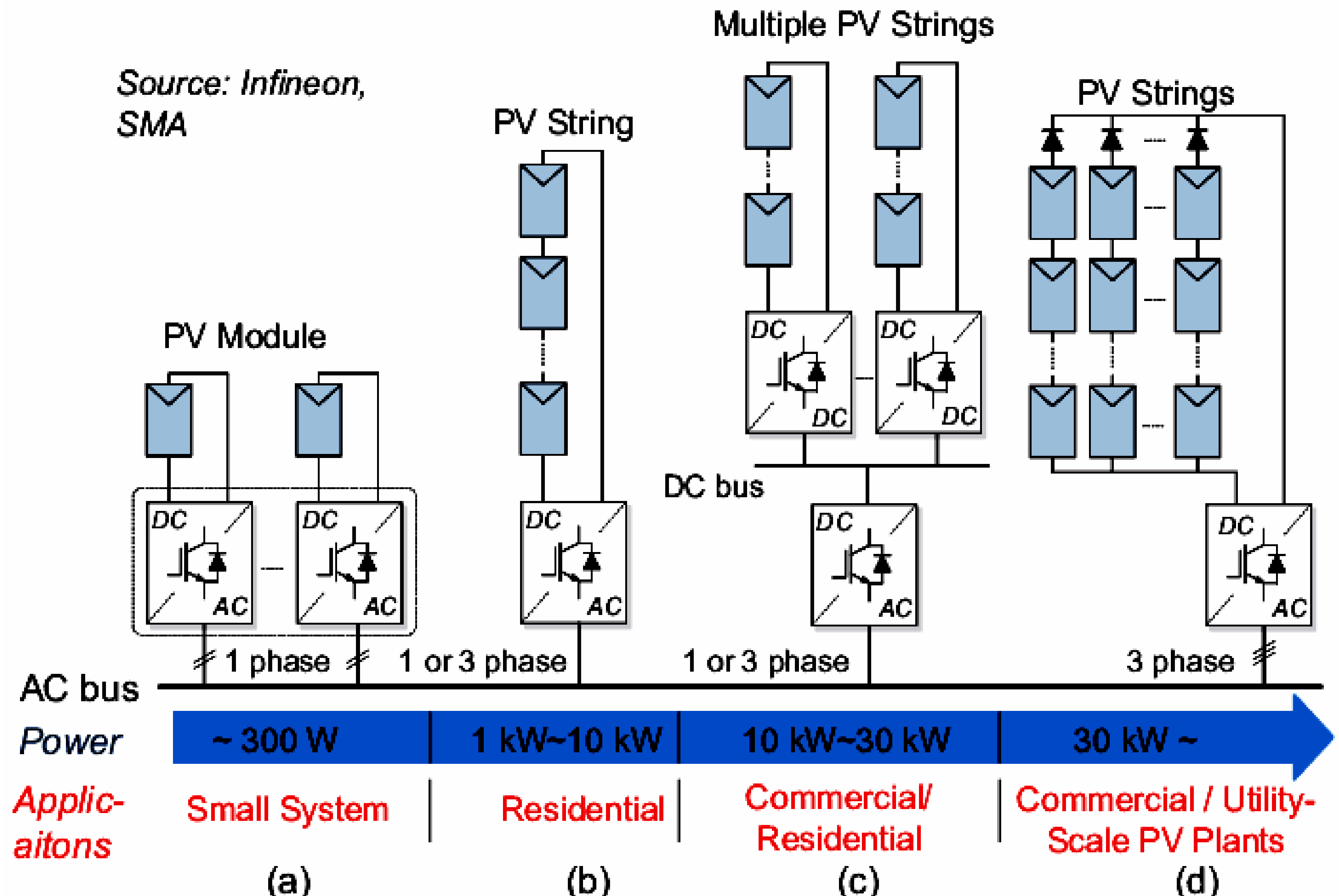
Depending on the PV power plant configuration, the PV inverters can be categorized as:

1. Module integrated inverters, typically in the 50–400 W range for very small PV plants (one panel).
2. String inverters, typically in the 0.4–2 kW range for small roof-top plants with panels connected in one string.
3. Multistring inverters, typically in the 1.5–6 kW range for medium large roof-top plants with panels configured in one to two strings.
4. Mini central inverters, typically > 6 kW with three-phase topology and modular design for larger roof-tops or smaller power plants in the range of 100 kW and typical unit sizes of 6, 8, 10 and 15 kW.
5. Central inverters, typically in the 100–1000kWrange with three-phase topology and modular design for large power plants ranging to tenths of a MW and typical unit sizes of 100, 150, 250, 500 and 1000 kW.

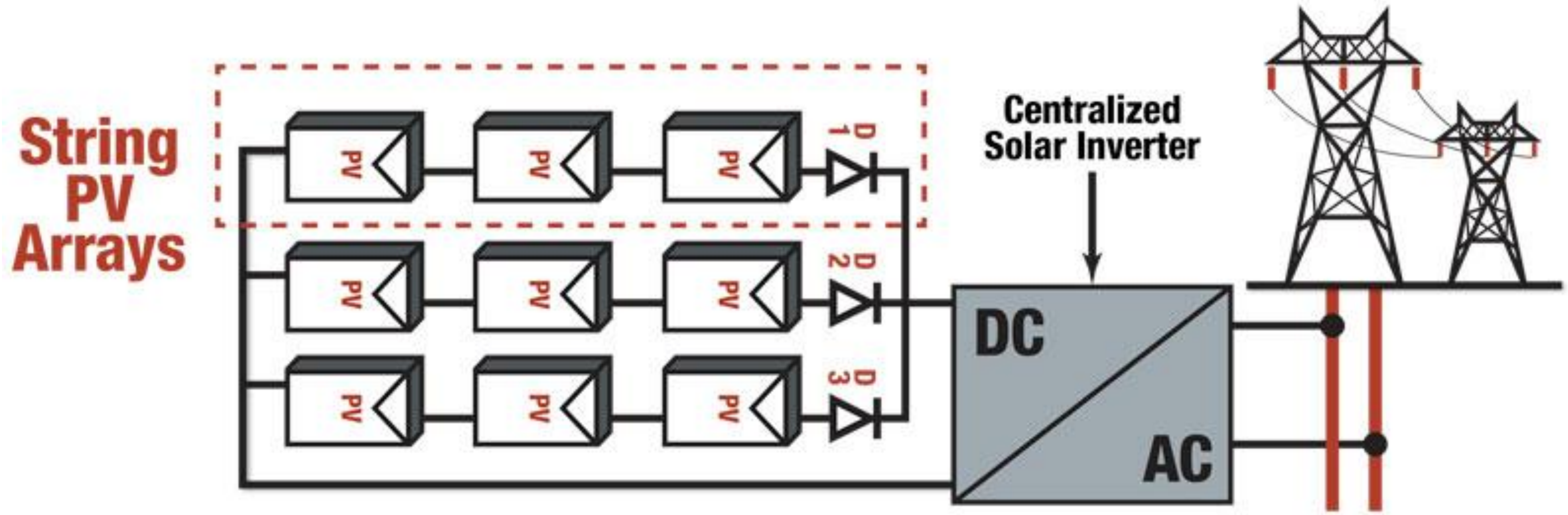
PV power plant configuration: Review



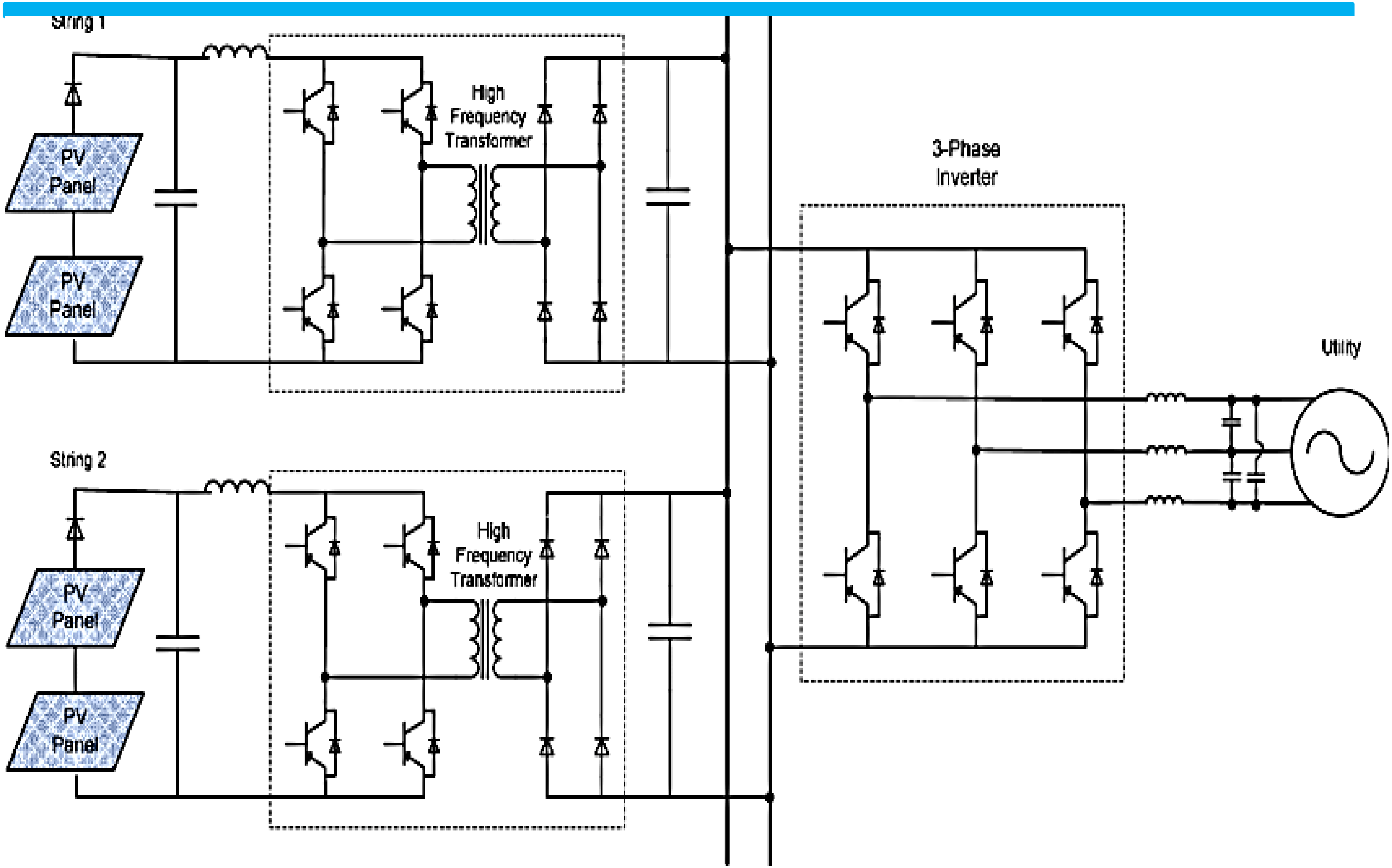
PV power plant configuration: Rating by Power Max



PV power plant Grid solution



PV power plant Grid solution: Alternate Technique



Multi-string PV topology with high-frequency transformer-based isolation

PV Inverters

In comparison with the motor drive inverters, the PV inverters are more complex in both hardware and functionality.

Thus, the need to boost the input voltage, the grid connection filter, grid disconnection relay and DC switch are the most important aspects responsible for increased hardware complexity.

Maximum power point tracking, anti-islanding, grid synchronization and data logger are typical functions required for the PV inverters.

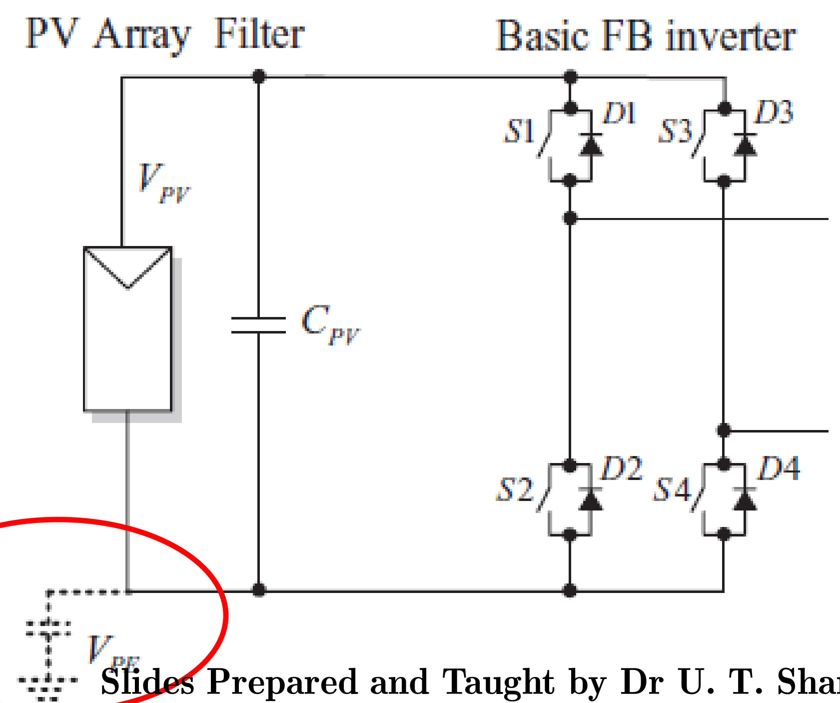
New innovative topologies have recently been developed for PV inverters with the main purpose of increasing the efficiency and reducing the manufacturing cost.

PV Inverters

As the lifetime of PV panels is typically longer than 20 years, efforts to increase the lifetime of PV inverters are also under way. Today, several manufacturers are offering extended service for 20 years.

The first method used to increase the efficiency was to eliminate the galvanic isolation typically provided by high-frequency transformers in the DC–DC boost converter or by a low-frequency transformer on the output. Thus a typical efficiency increase of 1–2 % can be obtained.

As the PV panels are typically built in layers structure involving glass, silicon semiconductor and backplane framed by a grounded metallic frame, a capacitance to earth is formed that creates a path for leakage current.



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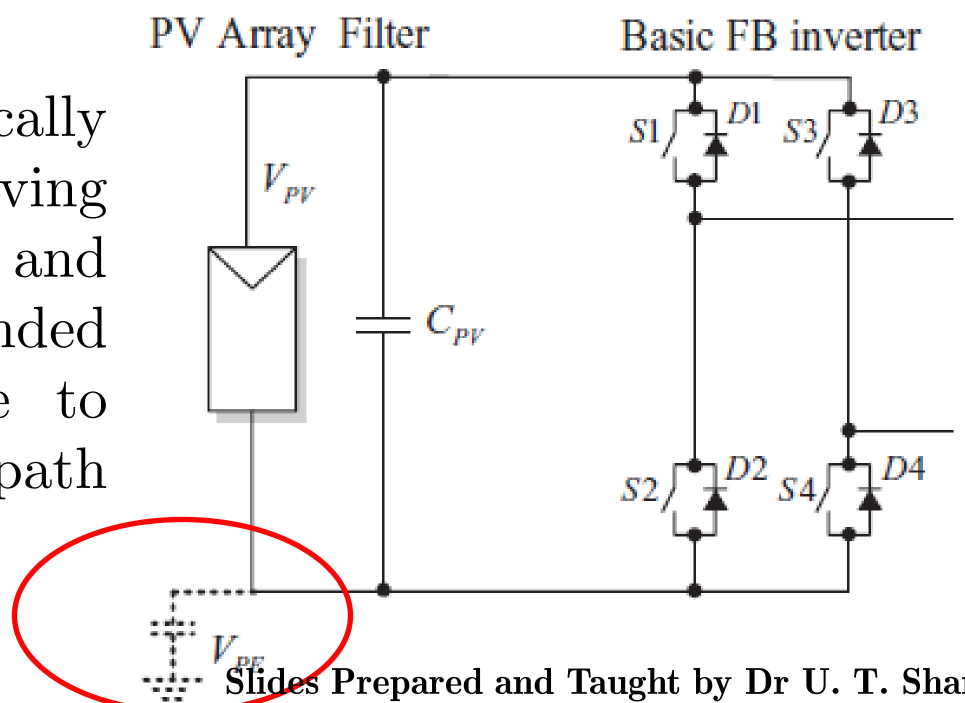

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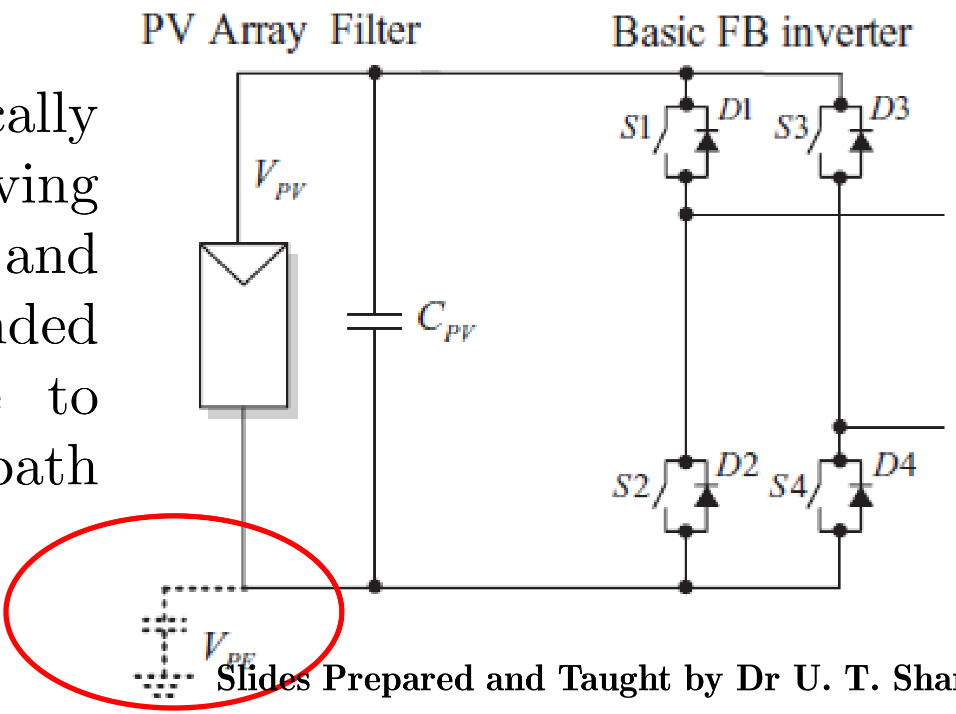

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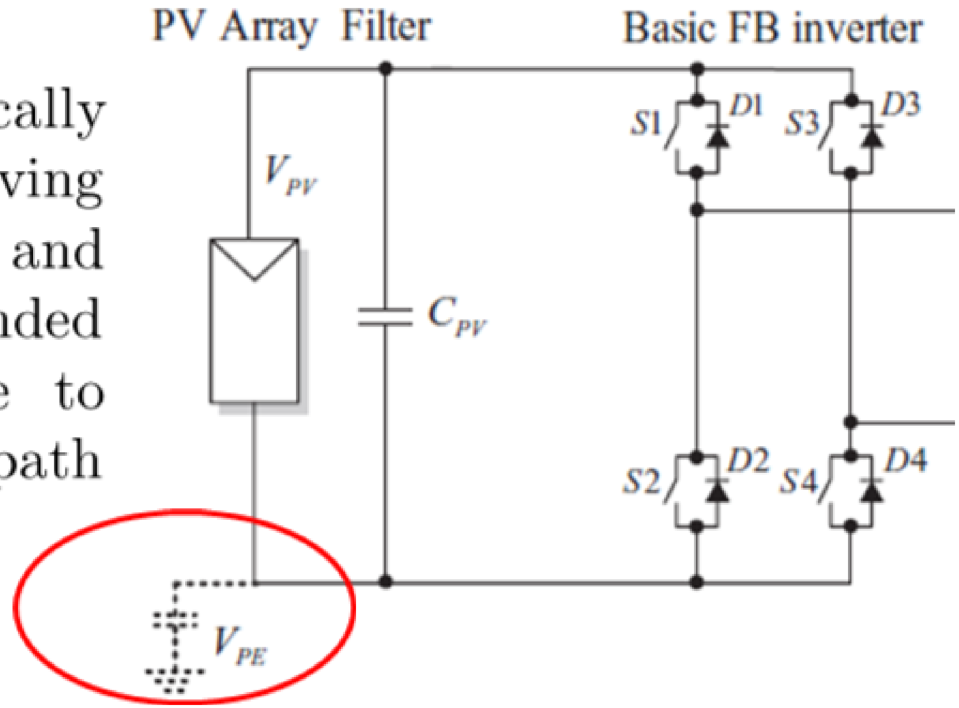

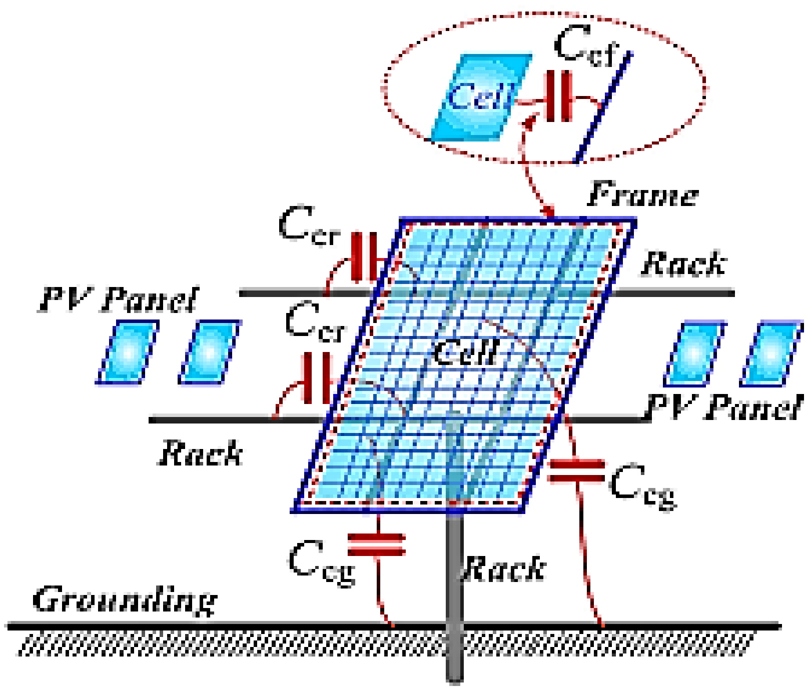

PV Inverters

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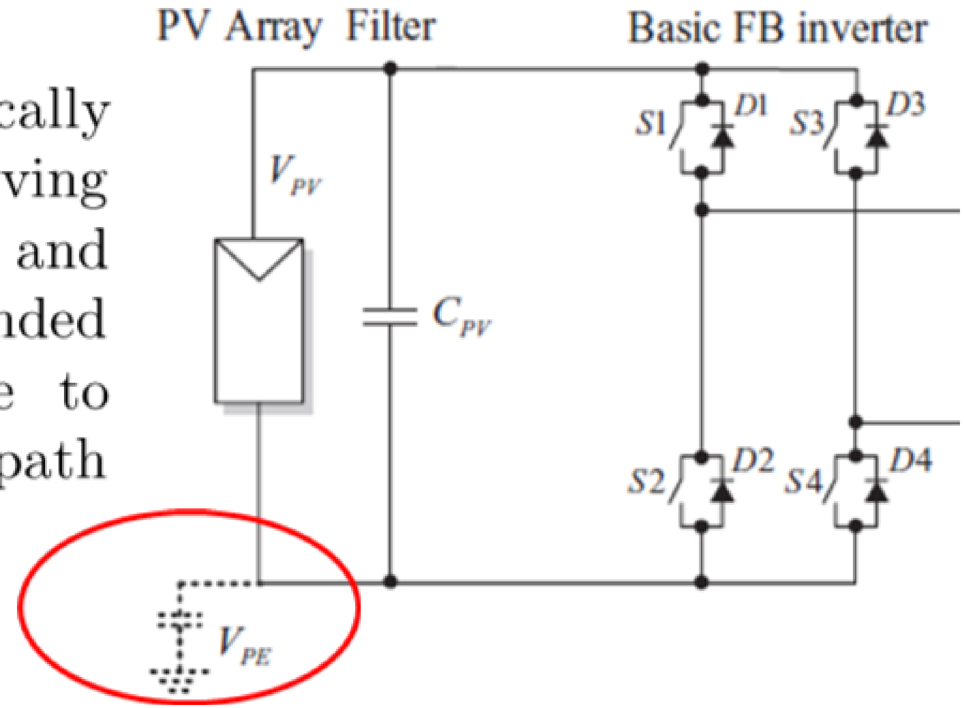
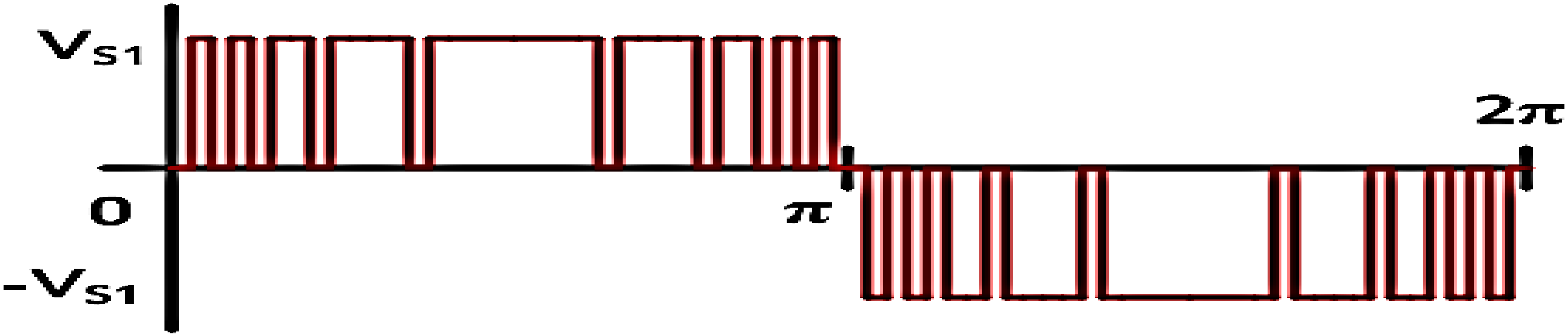


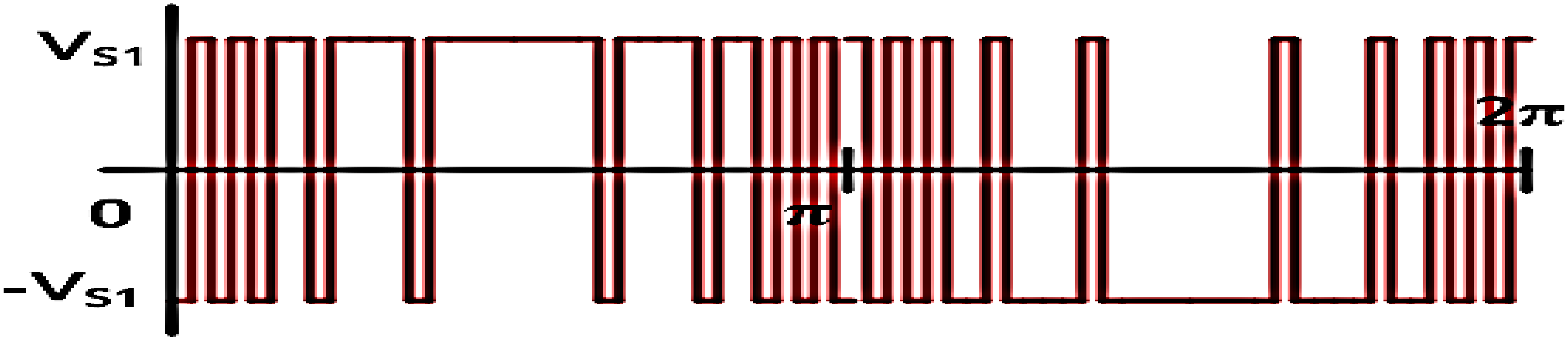
The leakage current is a fault, especially in residential applications.

This capacitance can vary greatly, depending on construction or weather conditions, and in reference [2] typical values of 10 nF/kW for PV are measured using the full-bridge with unipolar modulation as a well-known source of common mode voltage resulting in leakage current.

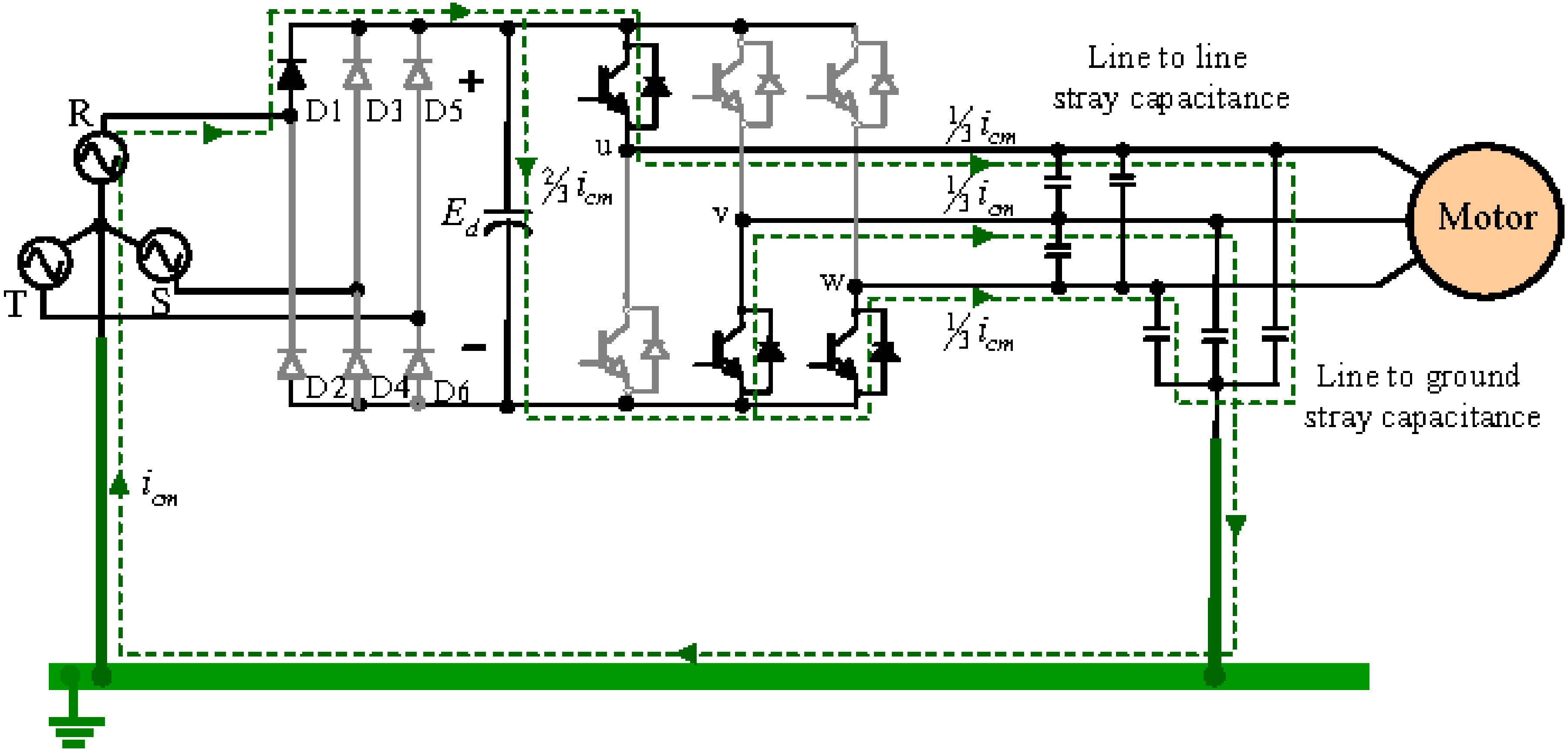
Unipolar Modulation



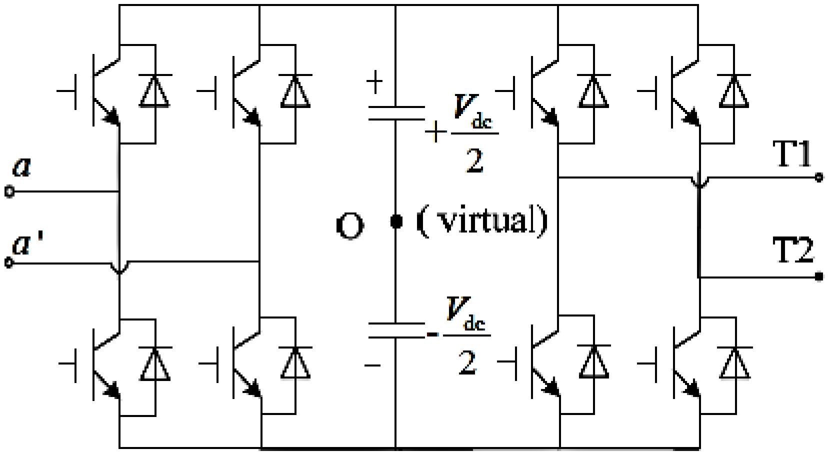
Bipolar Modulation



Common mode voltage resulting in leakage current

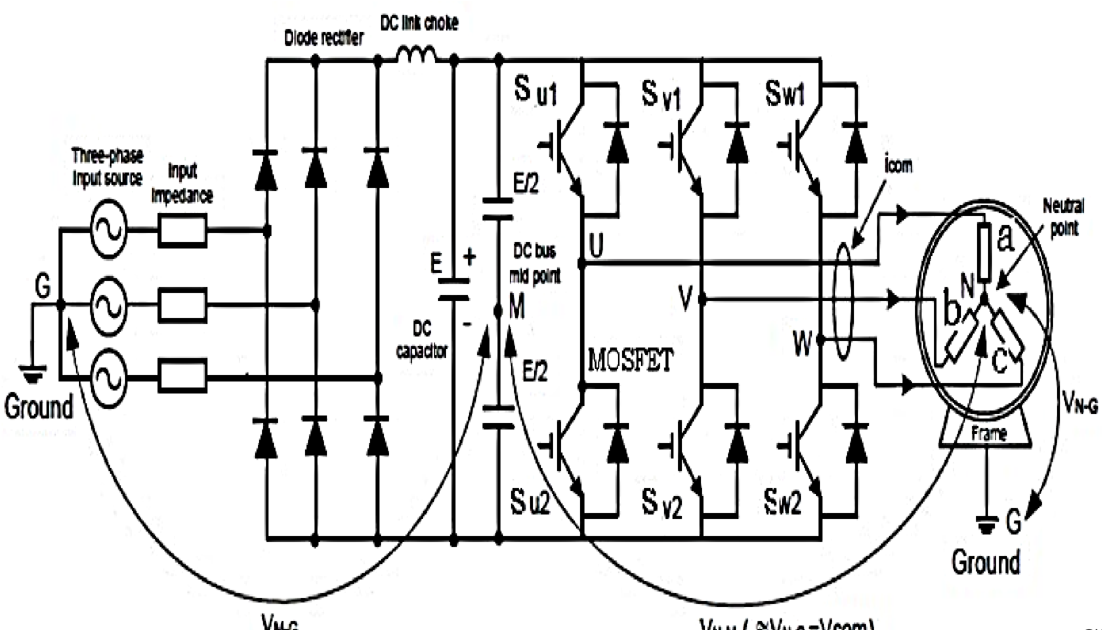


Common mode voltage resulting in leakage current



(a)

$$v_{Tcm} = \frac{v_{T1} + v_{T2}}{2}$$



$$V_{com} = V_{N-G} \approx V_{N-M}$$

$$= \frac{V_{U-M} + V_{V-M} + V_{W-M}}{3}$$

Common mode voltage resulting in leakage current

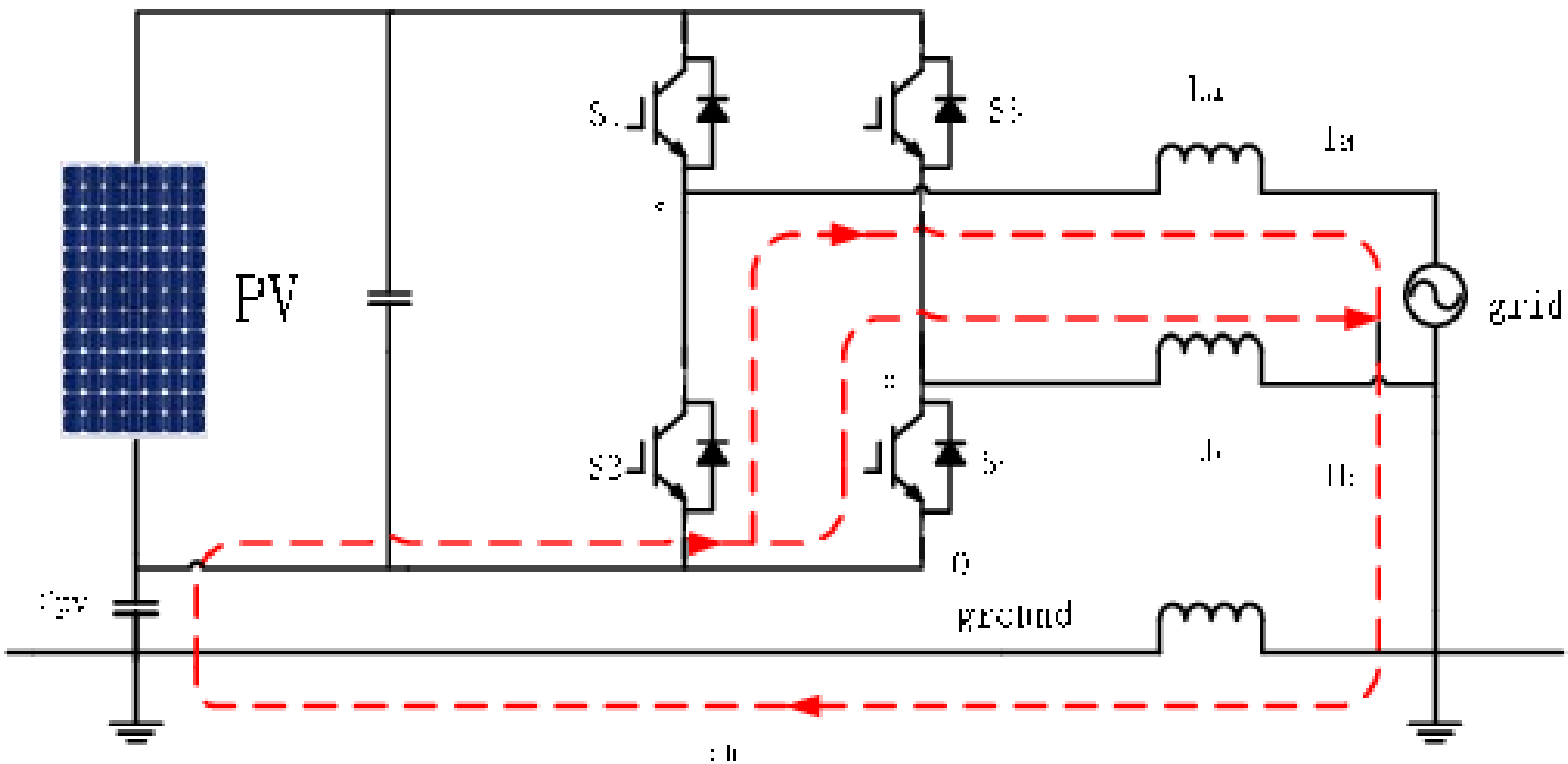
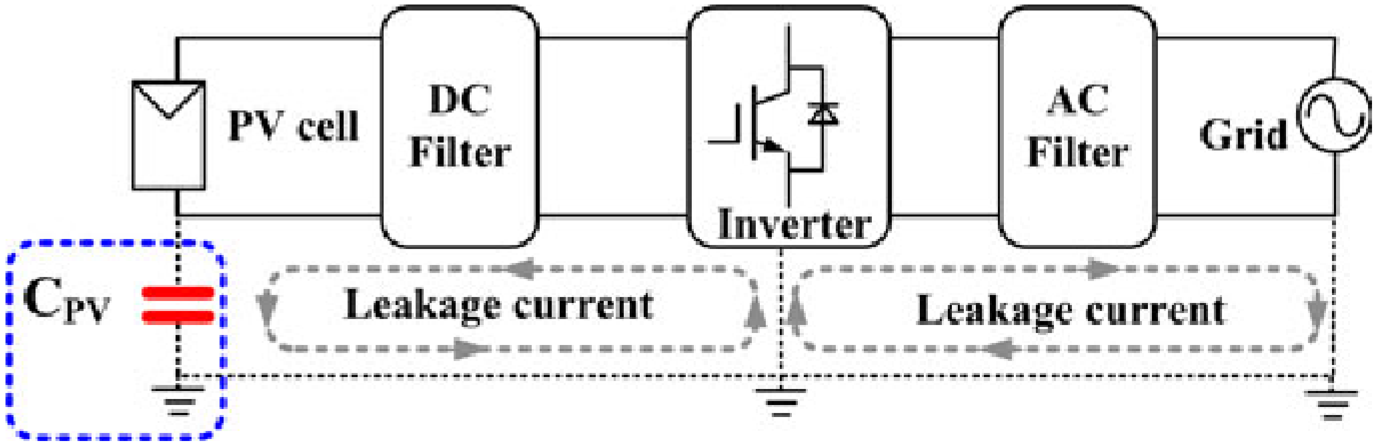


Fig. 1. The common-mode circuit of single-phase PV inverter.


PV cell
DC
Filter
Inverter
AC
Filter
Grid
CPV
Leakage current
Leakage current

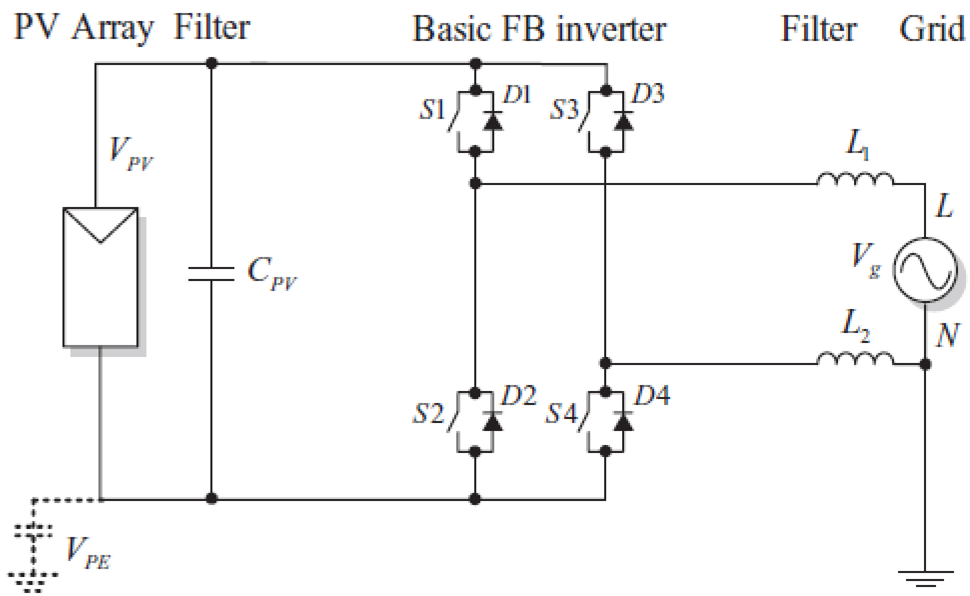
PV Inverter Topology Development

Today there are many PV inverter manufacturers in the market, offering a wide range of transformer—less PV inverters with maximum efficiency of up to 98 %.

The topology development for the transformer—less PV inverters has been taking the starting point in two ‘well-proven’ converter families:

1) H-bridge.
2) Neutral point clamped (NPC).

2.2 Inverter Derived from H-Bridge Topology



2.2.1 Basic Full-Bridge Inverter

Three main modulation strategies can be used:

1. Bipolar (BP) modulation.
2. Unipolar (UP) modulation.
3. Hybrid modulation.

Bipolar modulation

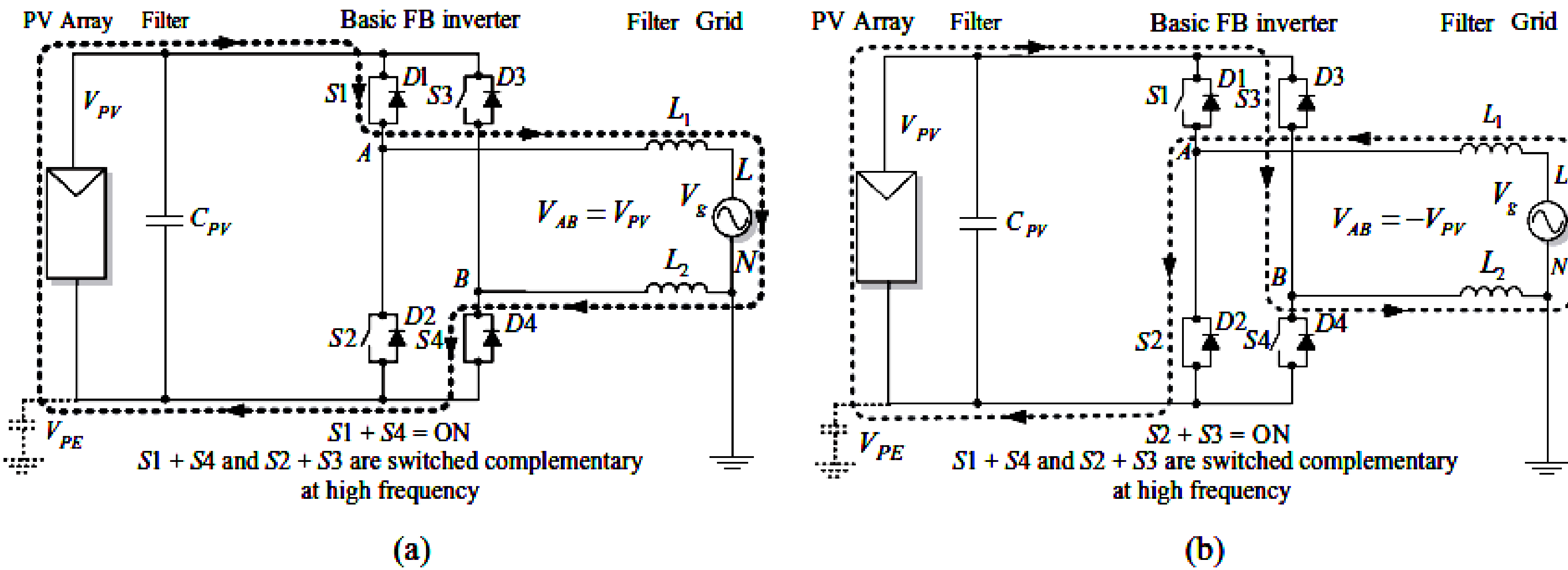


Figure 2.2 FB with BP modulation strategy in the case of: (a) positive output current and (b) negative output current

Bipolar modulation

The main features of this converter are:

- Leg A and leg B are switched synchronously in the diagonal ($S1 = S3$ and $S2 = S4$) with high frequency and the same sinusoidal reference.
- No zero output voltage state is possible.

Advantages:

- V_{PE} has only a grid frequency component and no switching frequency components, yielding a very low leakage current and EMI.

Drawbacks:

- The switching ripple in the current equals $1 \times$ switching frequency, yielding higher filtering requirements (no artificial frequency increase in the output!).
- The voltage variation across the filter is bipolar ($+V_{PV} \rightarrow -V_{PV} \rightarrow +V_{PV}$), yielding high core losses.
- Lower efficiency of up to 96.5 % is due to reactive power exchange between $L_{1(2)}$ and C_{PV} during freewheeling and high core losses in the output filter, due to the fact that two switches are simultaneously switched every switching period.

Unipolar modulation

Diagram from Book

Bipolar modulation

The main features of this converter are:

- Leg A and leg B are switched with high frequency with mirrored sinusoidal reference.
- Two zero output voltage states are possible: $S1$, $S3 = \text{ON}$ and $S2$, $S4 = \text{ON}$.

Advantages:

- The switching ripple in the current equals $2 \times$ switching frequency, yielding lower filtering requirements.
- Voltage across the filter is unipolar ($0 \rightarrow +V_{PV} \rightarrow 0 \rightarrow -V_{PV} \rightarrow 0$), yielding lower core losses.
- High efficiency of up to 98 % is due to reduced losses during zero voltage states.

Drawbacks:

- V_{PE} has switching frequency components, yielding high leakage current and EMI.

Hybrid Modulation

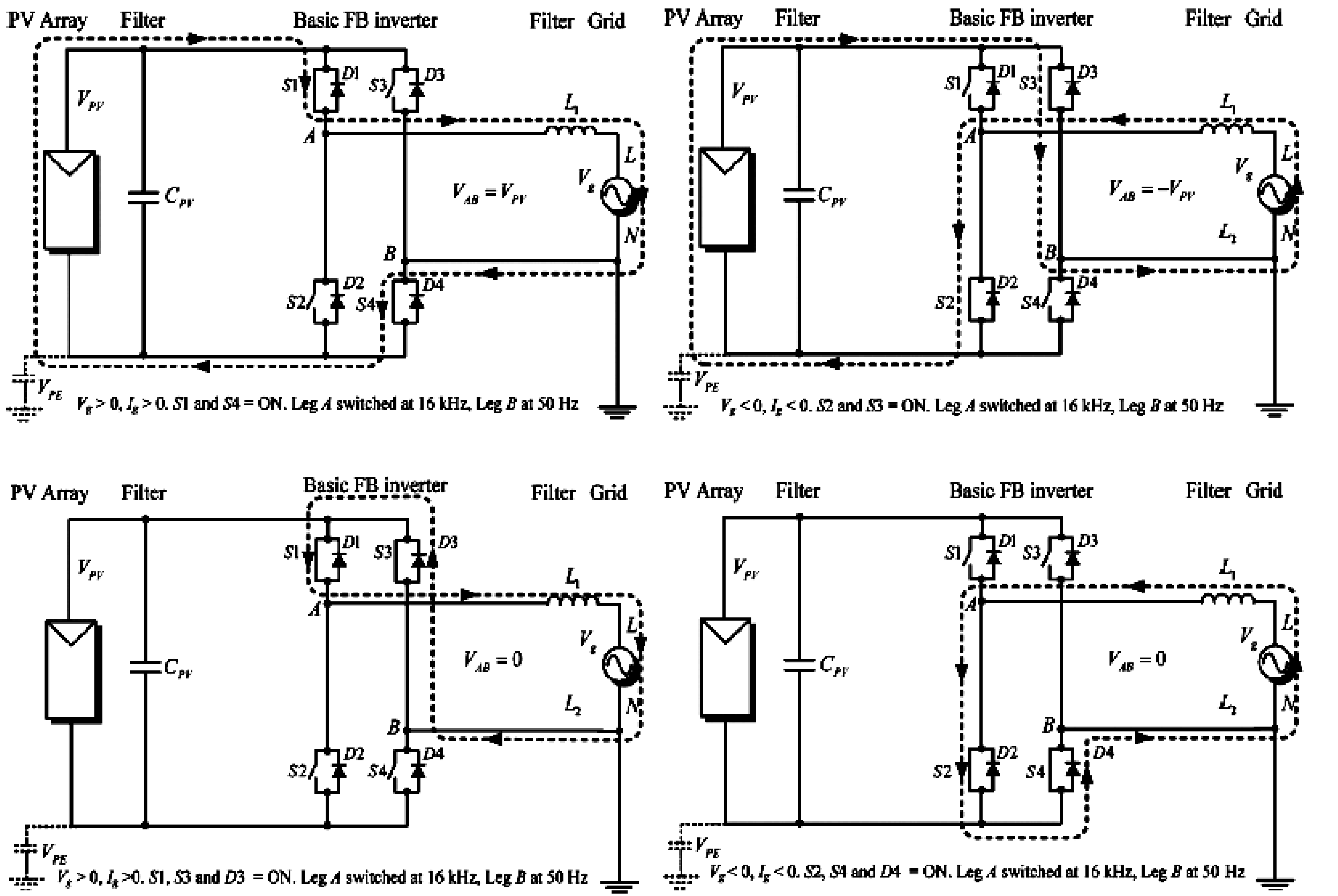


Figure 2.4 The switching states of FB with hybrid modulation in the case of generating: (a) positive current and (b) negative current

Hybrid Modulation

The main features of this converter are:

- Leg A is switched with grid low frequency and leg B is switched with high PWM frequency.
- Two zero output voltage states are possible: $S1$, $S2 = \text{ON}$ and $S3$, $S4 = \text{ON}$.

Advantages:

- Voltage across the filter is unipolar ($0 \rightarrow +V_{PV} \rightarrow 0 \rightarrow -V_{PV} \rightarrow 0$), yielding lower core losses.
- Higher efficiency of up to 98 % is due to no reactive power exchange between $L_{1(2)}$ and C_{PV} during zero voltage and to lower frequency switching in one leg.

Drawbacks: also a drawback is the fact that this modulation only works for a two quadrant operation.

- The switching ripple in the current equals $1 \times$ switching frequency, yielding higher filtering requirements (no artificial frequency increase in the output!).
- V_{PE} has square wave variation at grid frequency, leading to high leakage current peaks and large EMI filtering requirements.

2.2.2 H5 Inverter: Improved Version

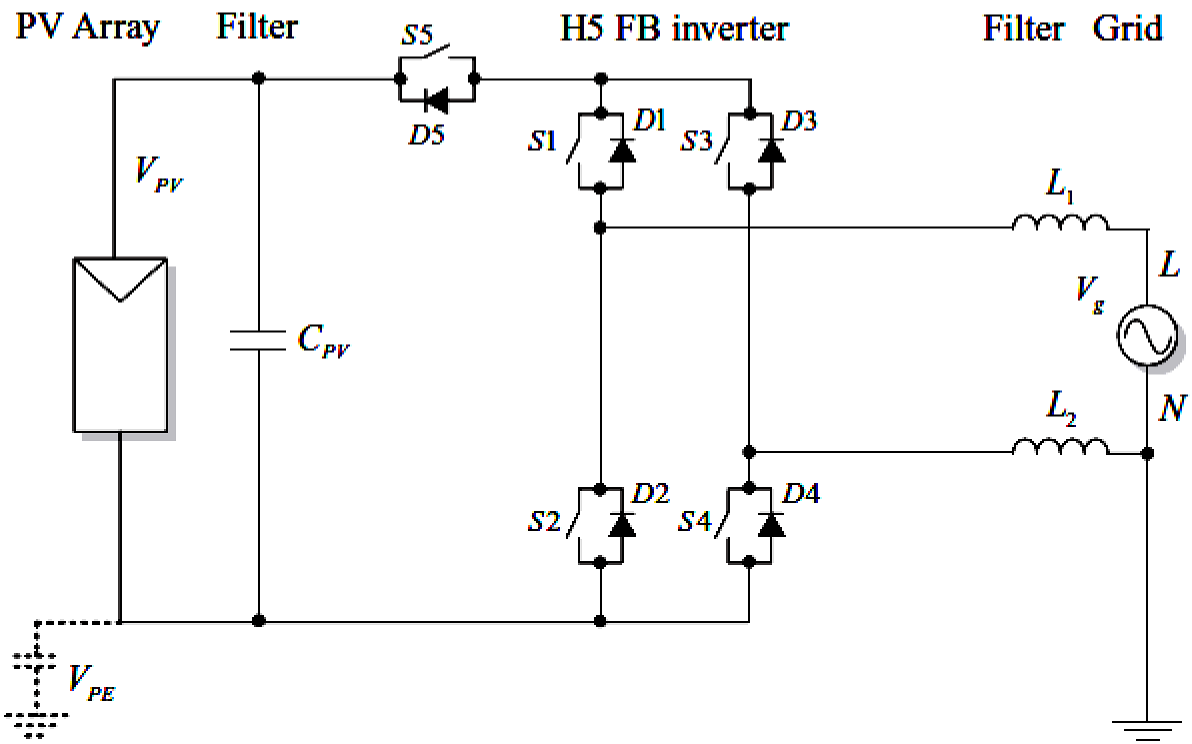


Figure 2.5 H5 inverter topology (SMA)

2.2.2 H5 Inverter: Improved Version

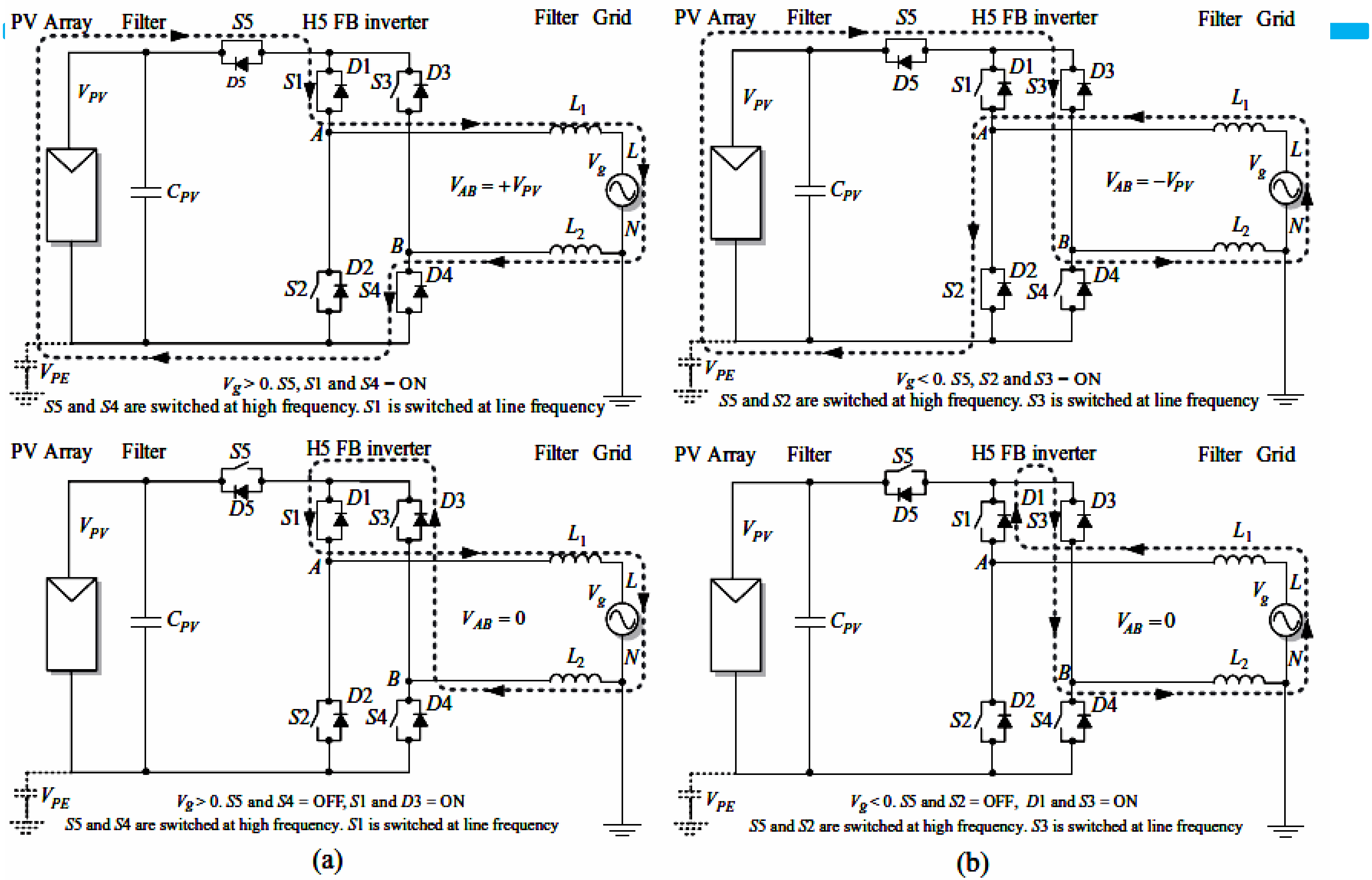


Figure 2.6 The switching states of the H5 inverter in the case of generating: (a) positive current and (b) negative current

2.2.2 H5 Inverter: Improved Version

- Prevents the reactive power exchange between $L_{1(2)}$ and C_{PV} during the zero voltage state, thus increasing efficiency.
- Isolates the PV module from the grid during the zero voltage state, thus eliminating the high-frequency content of V_{PE}.

The switching states for positive and negative generated AC currents are depicted in Figure 2.6.

The main features of this converter are:

- $S5$ and $S4$ ($S2$) are switched at high frequency and $S1$ ($S3$) at grid frequency.
- Two zero output voltage states are possible: $S5$ = OFF and $S1$ ($S3$) = ON.

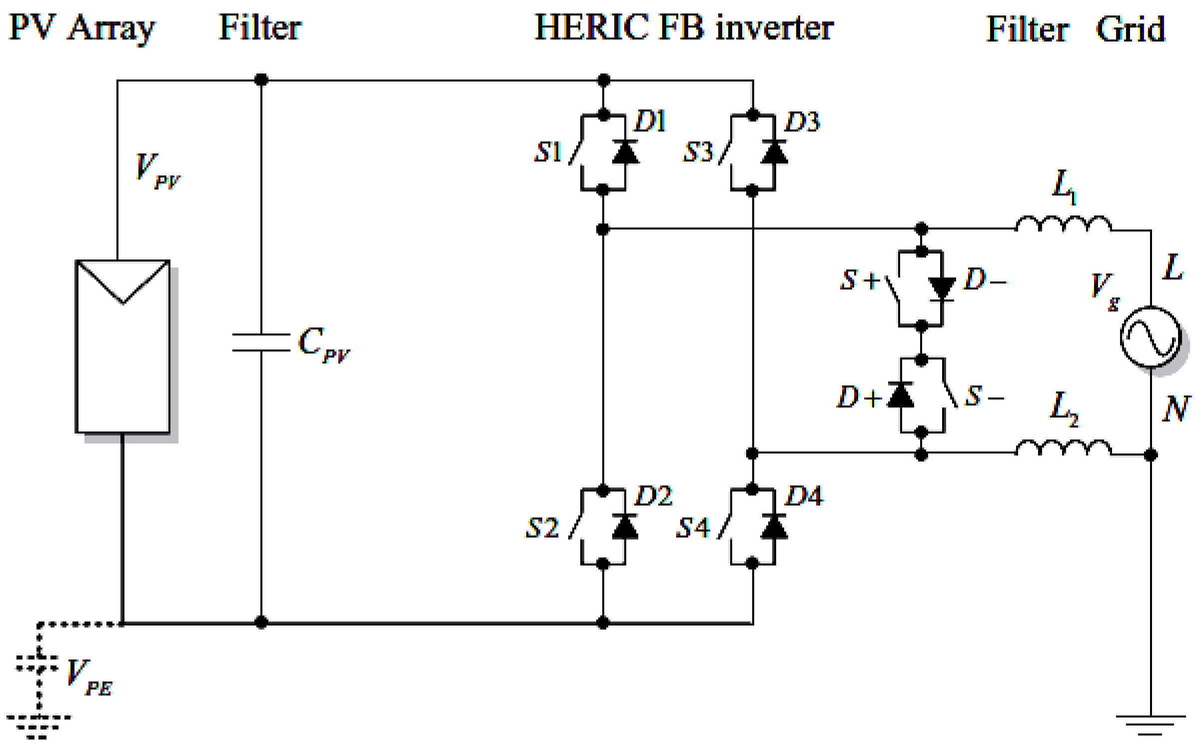
Advantages:

- Voltage across the filter is unipolar ($0 \rightarrow +V_{PV} \rightarrow 0 \rightarrow -V_{PV} \rightarrow 0$), yielding lower core losses.

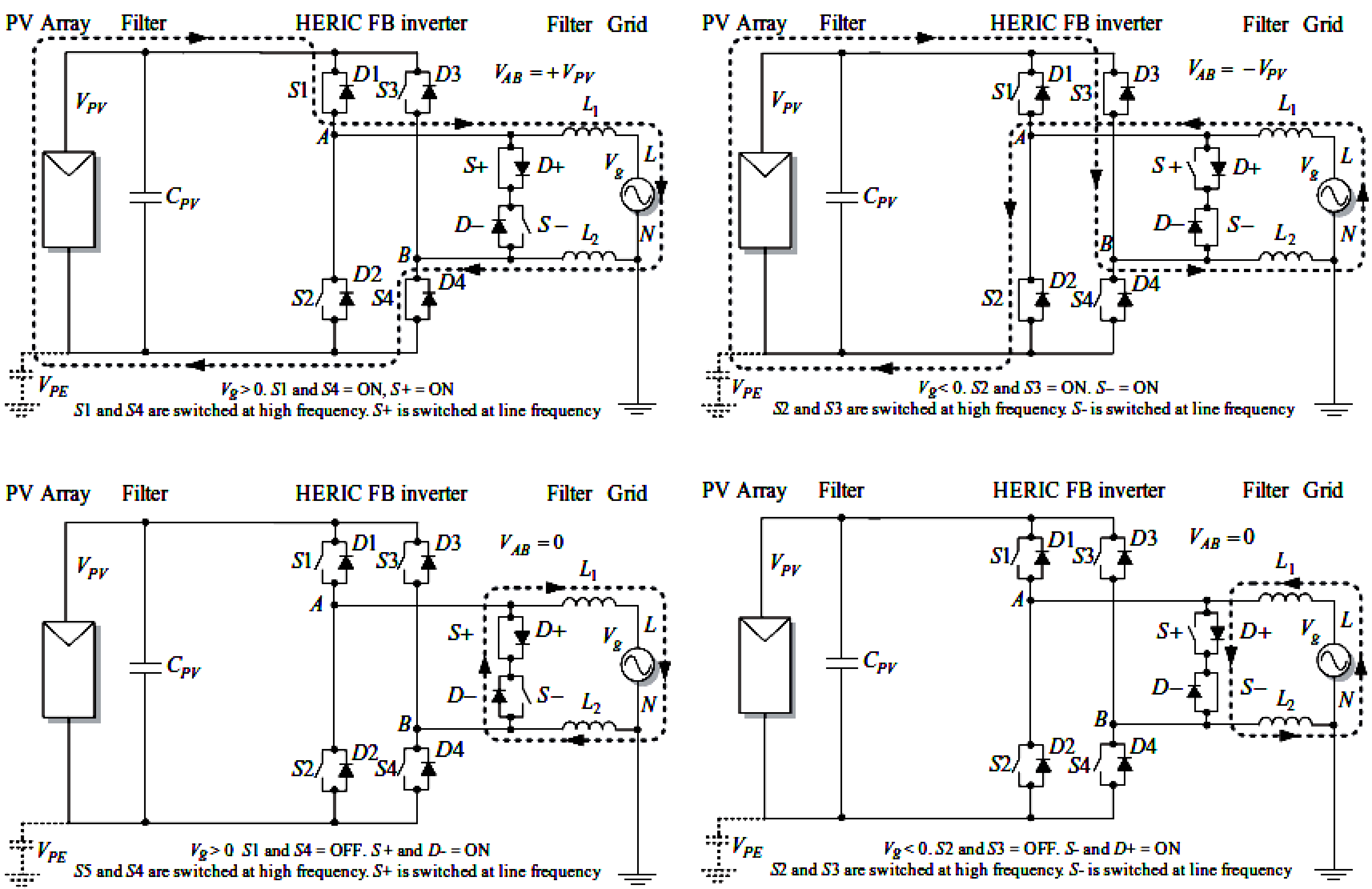
Drawbacks:

- One extra switch.
- Three switches are conducting during the active vector, leading to higher conduction losses but without affecting the overall high efficiency.

2.2.3 HERIC Inverter



2.2.3 HERIC Inverter



(a) (b)

- Prevents the reactive power exchange between $L_{1(2)}$ and C_{PV} during the zero voltage state, thus increasing efficiency.
- Isolates the PV module from the grid during the zero voltage state, thus eliminating the high-frequency content of V_{PE}.

The switching states for positive and negative generated AC currents are depicted in Figure 2.8.

The main features of this converter are:

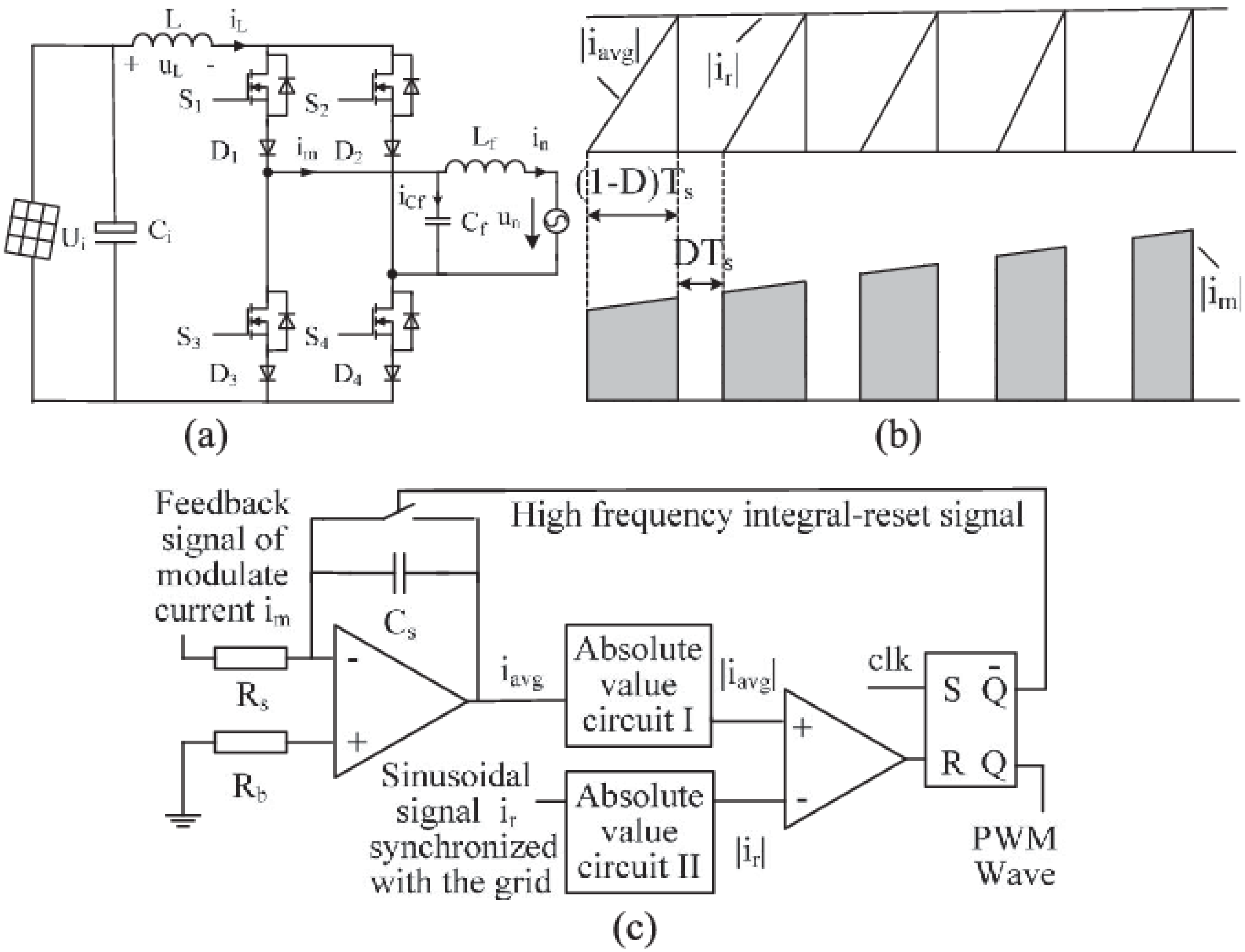
- $S1$–$S4$ and $S2$–$S3$ are switched at high frequency and $S+$ ($S-$) at grid frequency.
- Two zero output voltage states are possible: $S+ =$ on and $S- =$ on (providing the bridge is switched off).

Advantages:

- Voltage across the filter is unipolar ($0 \rightarrow +V_{PV} \rightarrow 0 \rightarrow -V_{PV} \rightarrow 0$), yielding lower core losses.
- Higher efficiency of up to 97 % is due to no reactive power exchange between $L_{1(2)}$ and C_{PV} during zero voltage and to lower frequency switching in one leg.
- V_{PE} has only a grid frequency component and no switching frequency components, yielding very low leakage current and EMI.

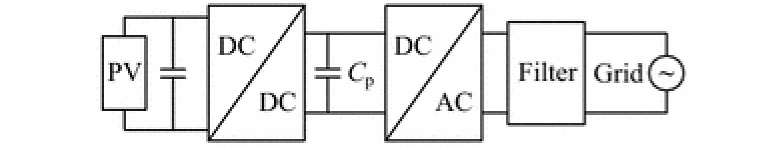
Drawbacks:

- Two extra switches.

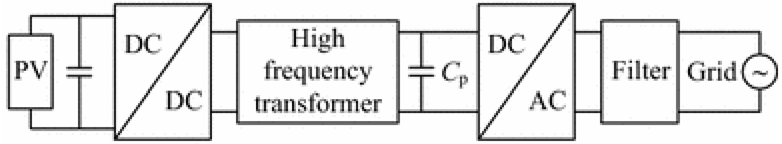

L
i_L
+ u_L -
S_1
S_2
D_1
i_m
D_2
L_f
i_n
i_{Cf}
C_f
u_n
U_i
C_i
S_3
S_4
D_3
D_4
$|i_{avg}|$
$|i_r|$
$(1-D)T_s$
DT_s
$|i_m|$
Feedback signal of modulate current i_m
High frequency integral-reset signal
C_s
R_s
R_b
i_{avg}
Absolute value circuit I
$|i_{avg}|$
clk
S $\bar{Q}$
R Q
Sinusoidal signal i_r synchronized with the grid
Absolute value circuit II
$|i_r|$
PWM Wave

(a) (b)

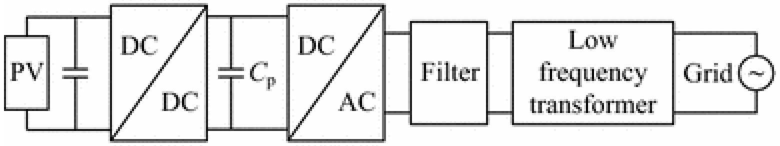
(c)



(a) A transformer-less inverter



(b) A high frequency transformer



(c) A low frequency transformer

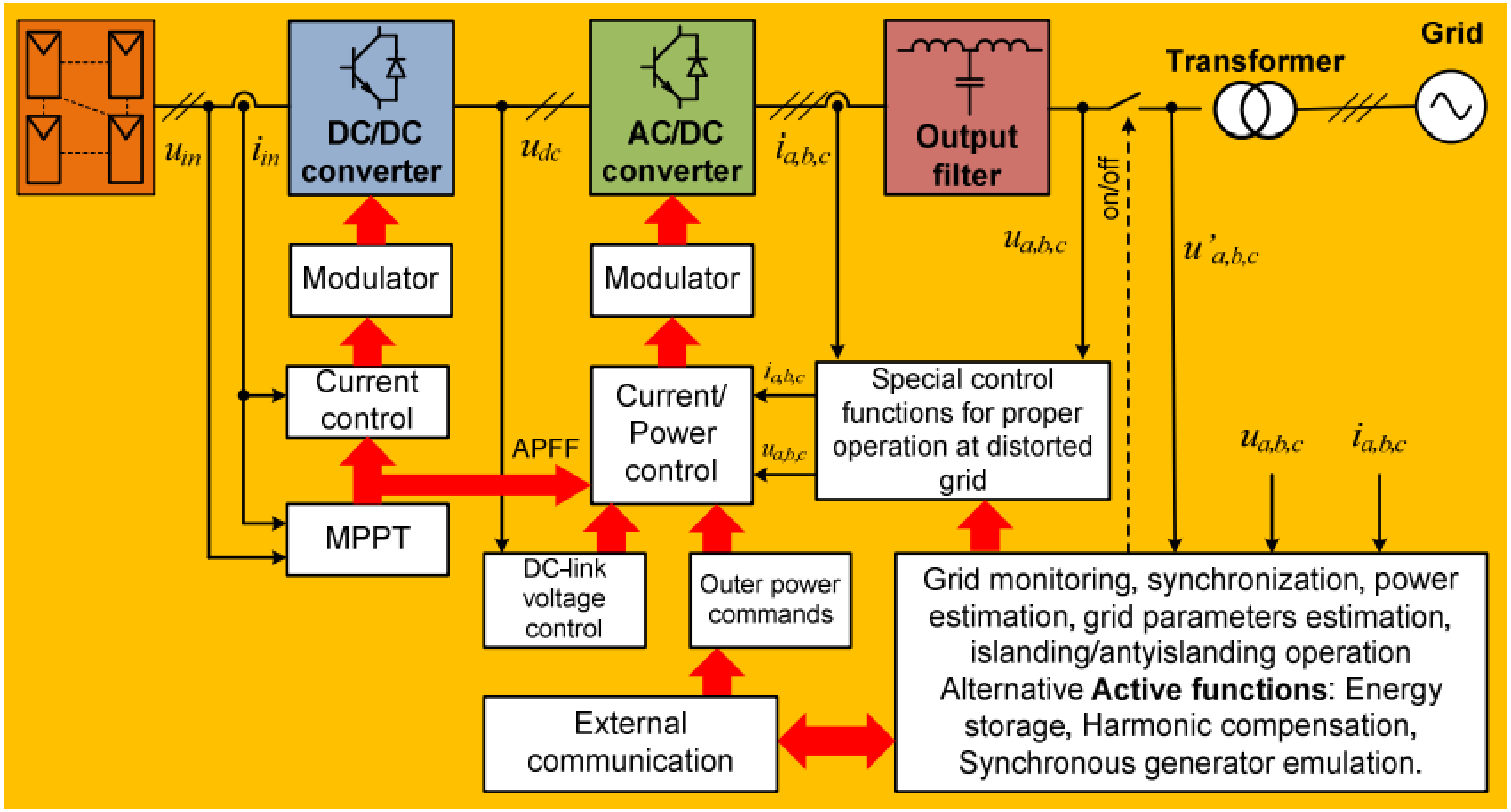


Fig. 4. General control structure of grid-connected PV plant.

https://hal.archives-ouvertes.fr/hal-01918172/document

End of Solar Energy—Semiconductor Part 5
Course Work