

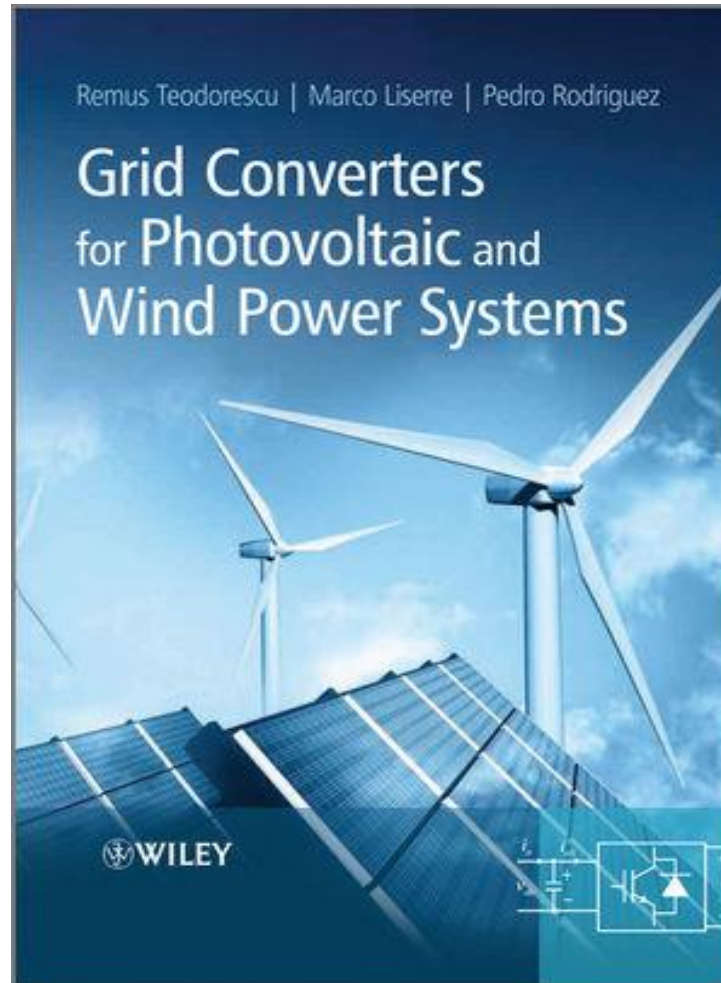
Renewable Electric Energy Systems EE—546

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

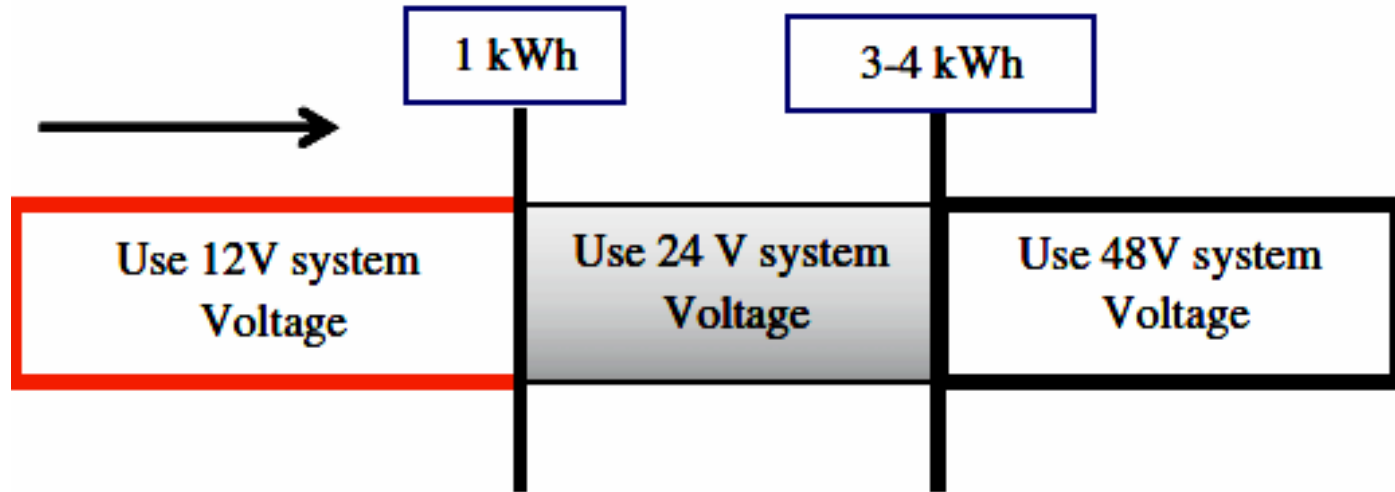


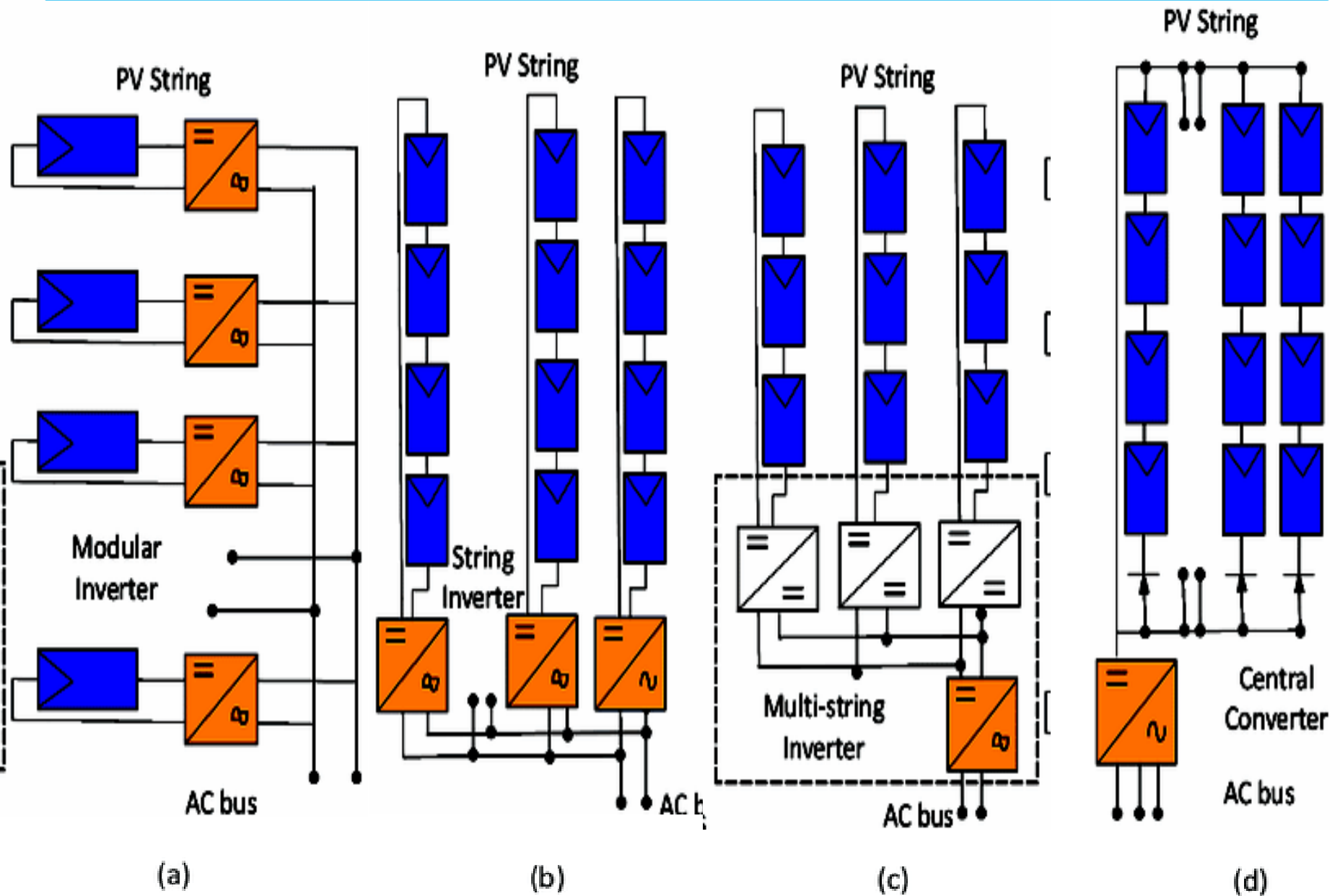
Fig. 3 A typical load variation with voltage

Introduction

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

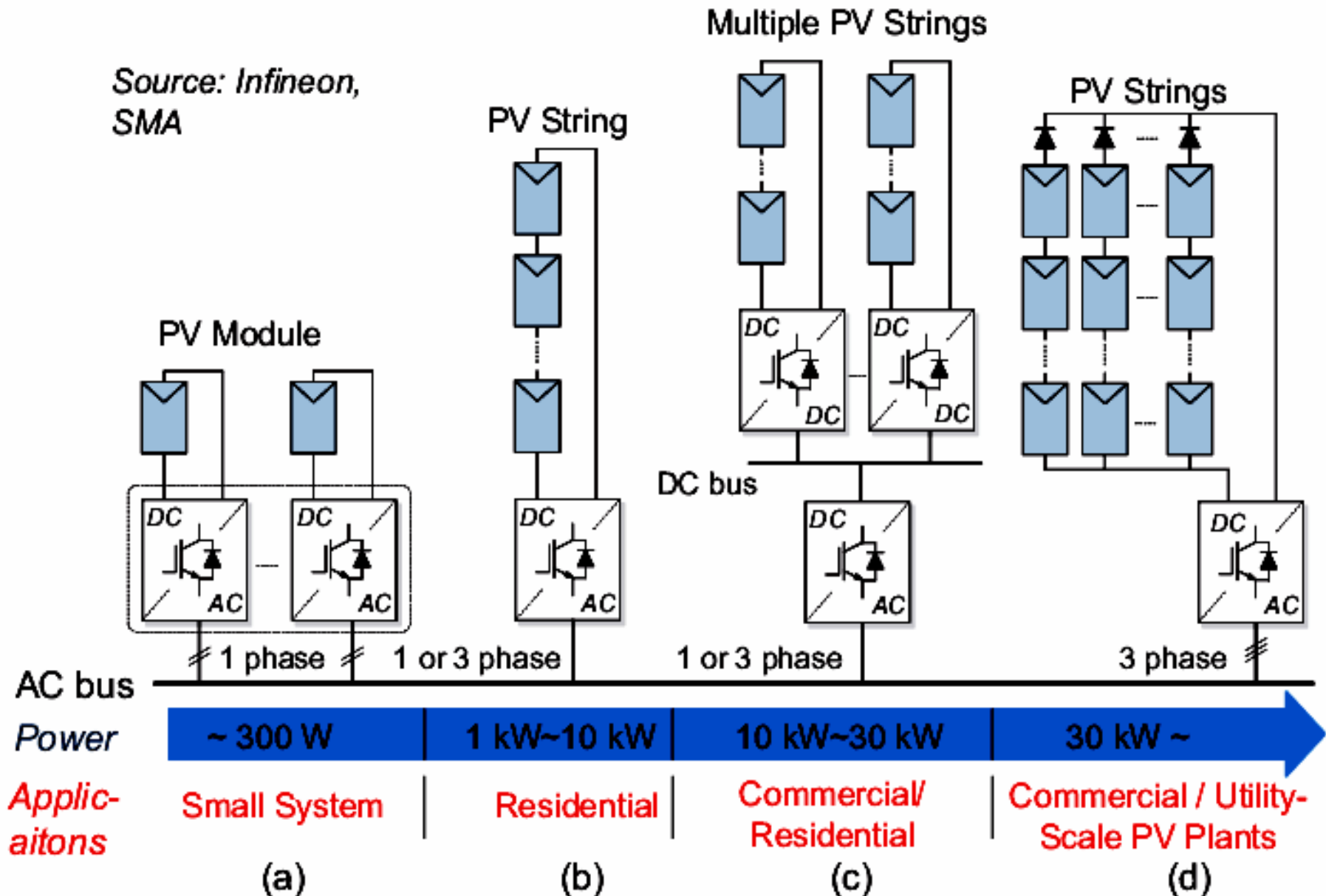
1. Module integrated inverters, typically in the 50–400 W range for very small PV plants (one panel).
2. String inverters, typically in the 0.4–2 kW range for small roof-top plants with panels connected in one string.
3. Multistring inverters, typically in the 1.5–6 kW range for medium large roof-top 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 100–1000kW range 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

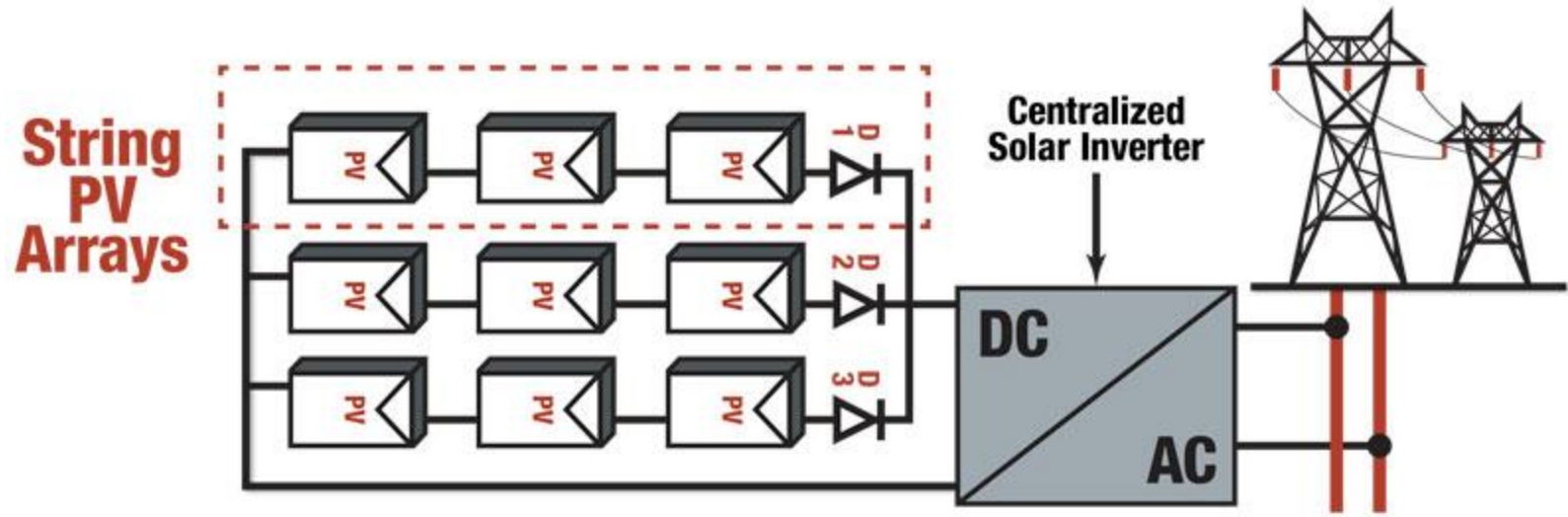


PV power plant configuration: Rating by Power Max

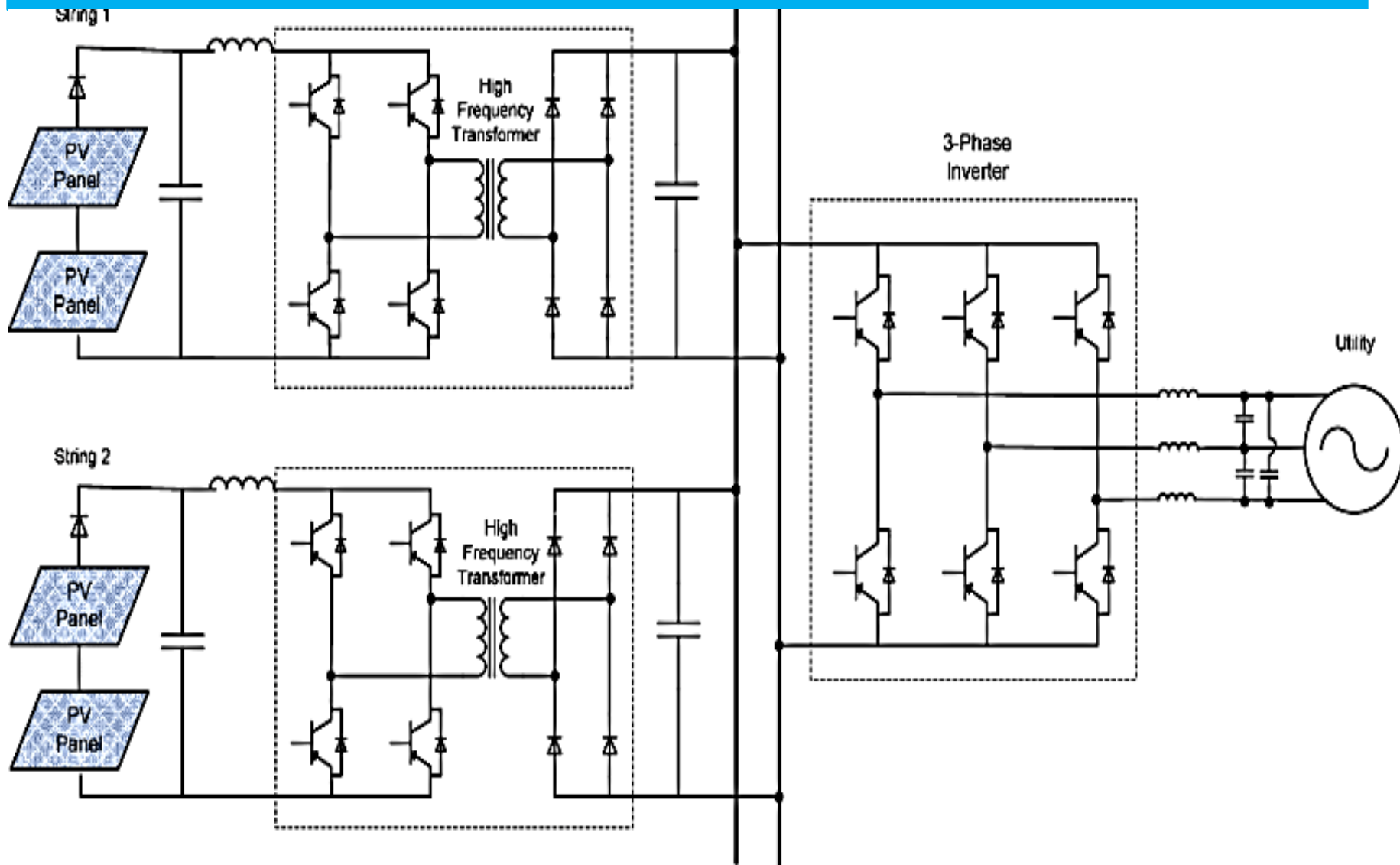
Source: Infineon,
SMA



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.

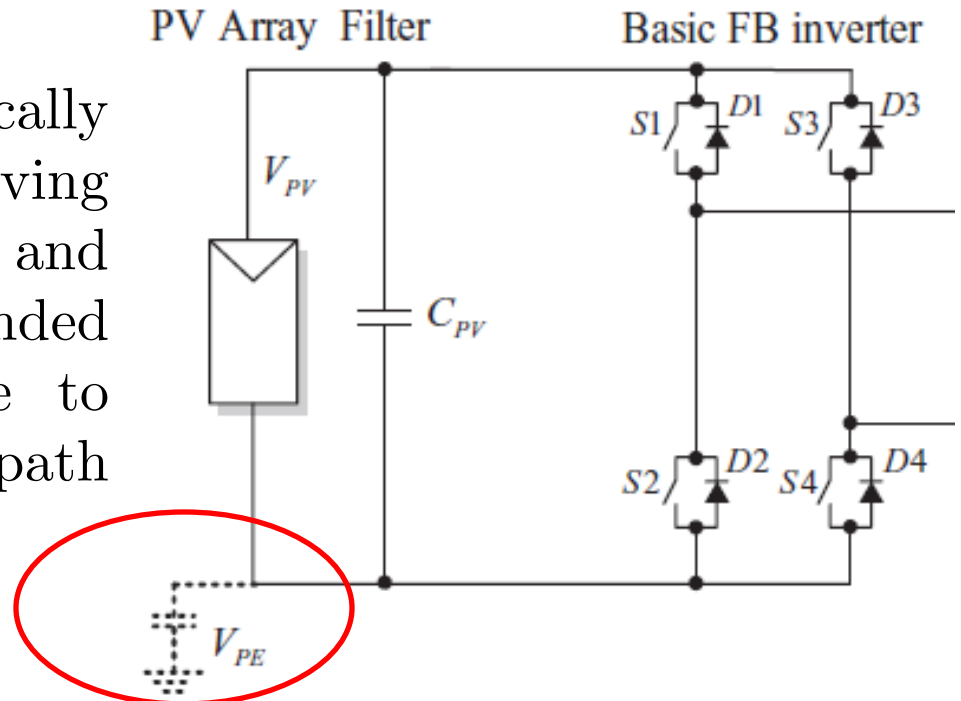
New innovative topologies have recently been developed for PV inverters with the main purpose of increasing the efficiency and reducing the manufacturing cost.

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.

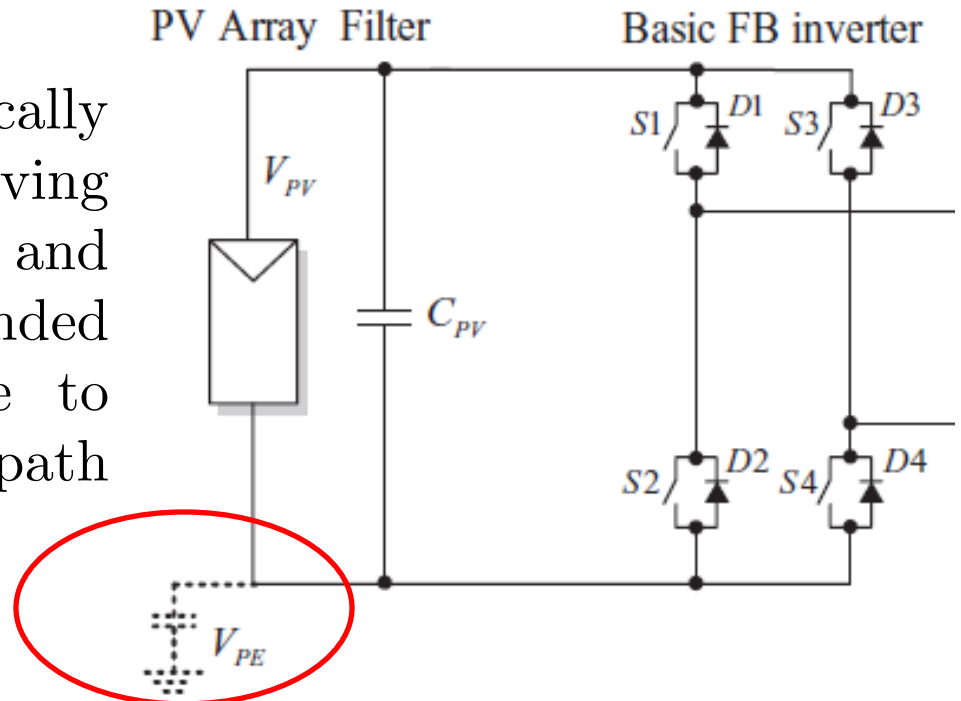


PV Inverters

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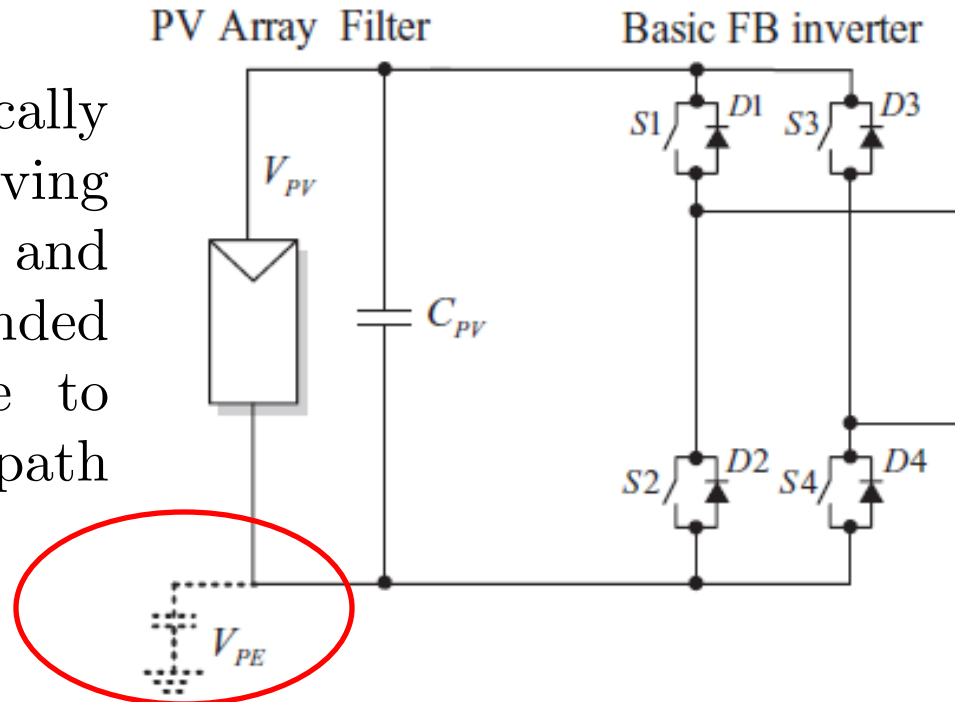
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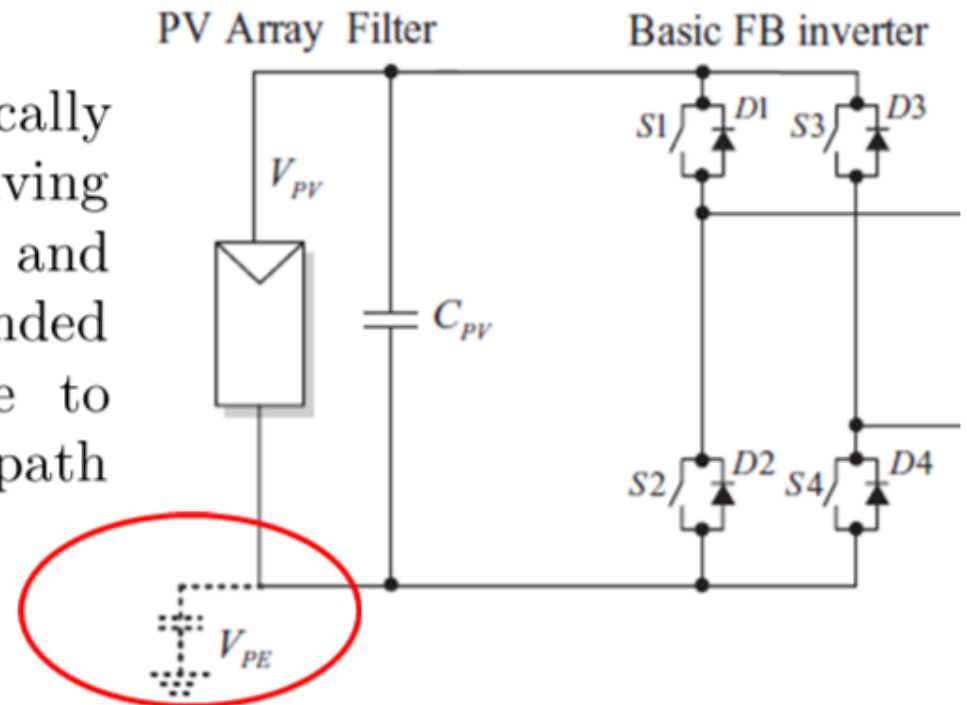
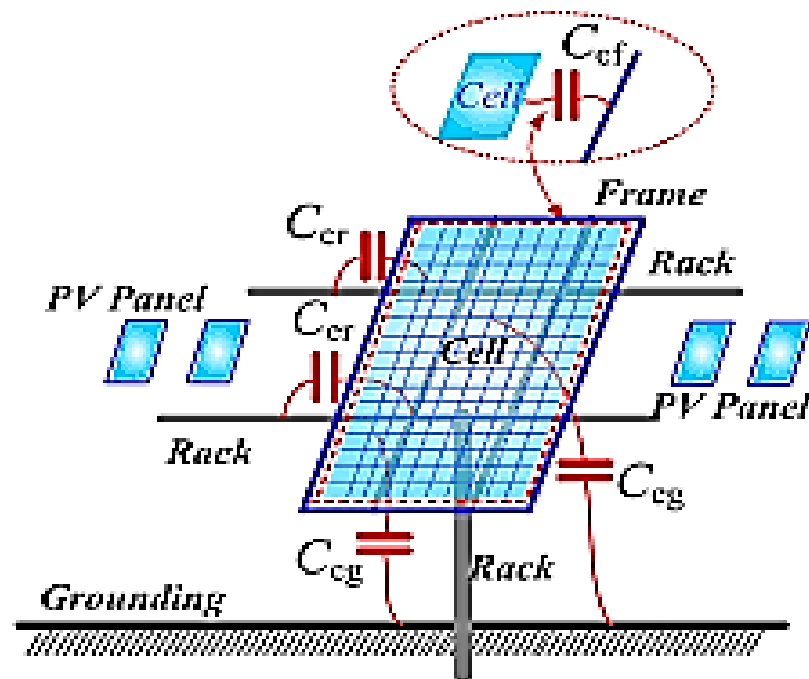
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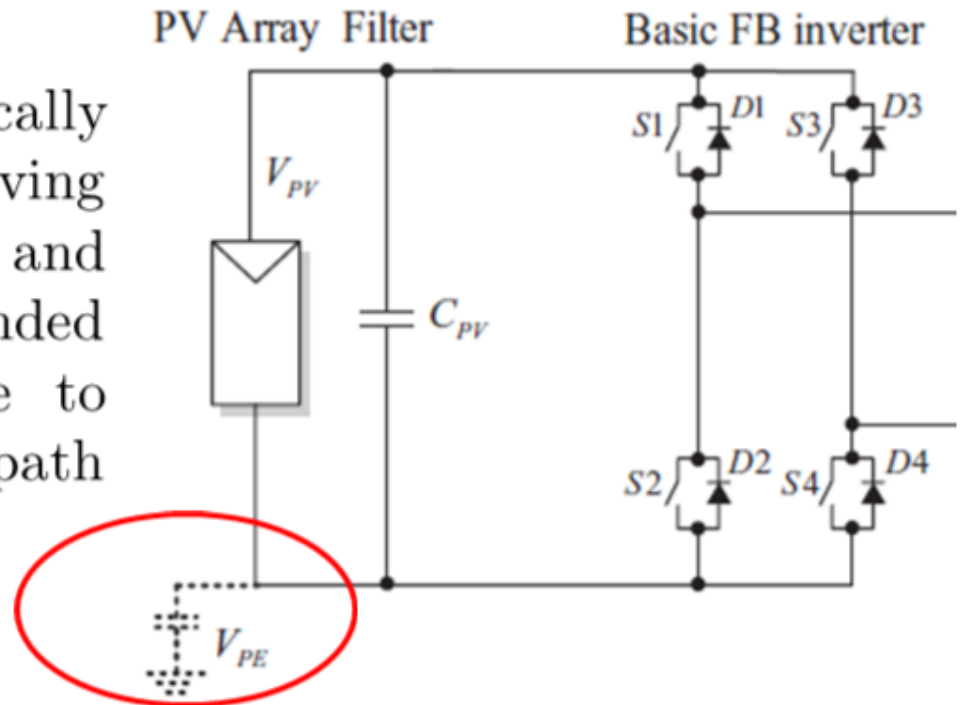
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PV Inverters

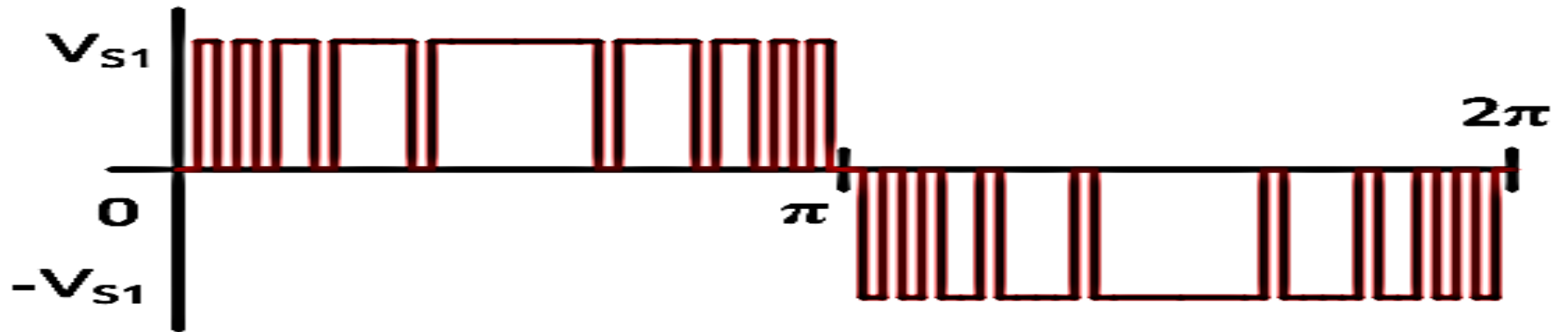
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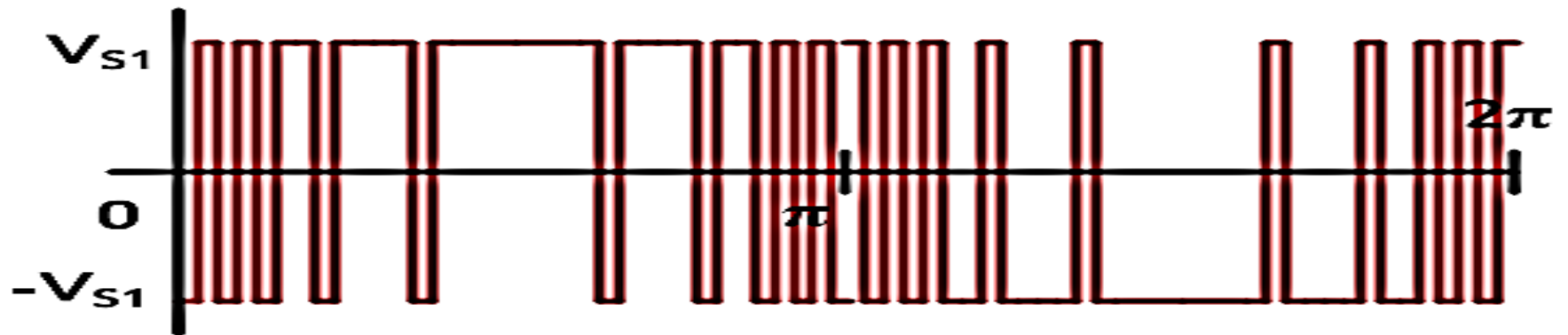
The leakage current is a fault, especially in residential applications.

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.

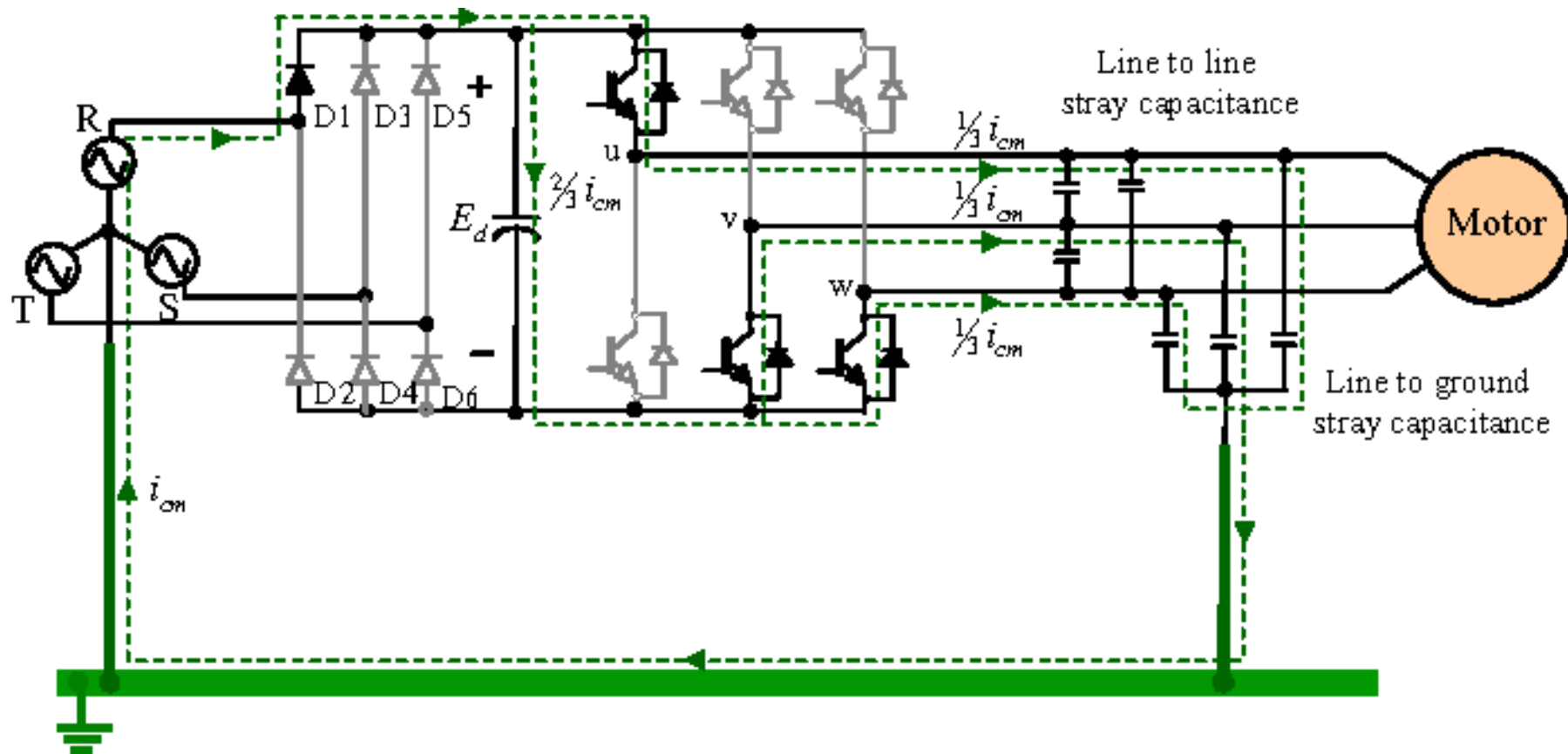
Unipolar Modulation



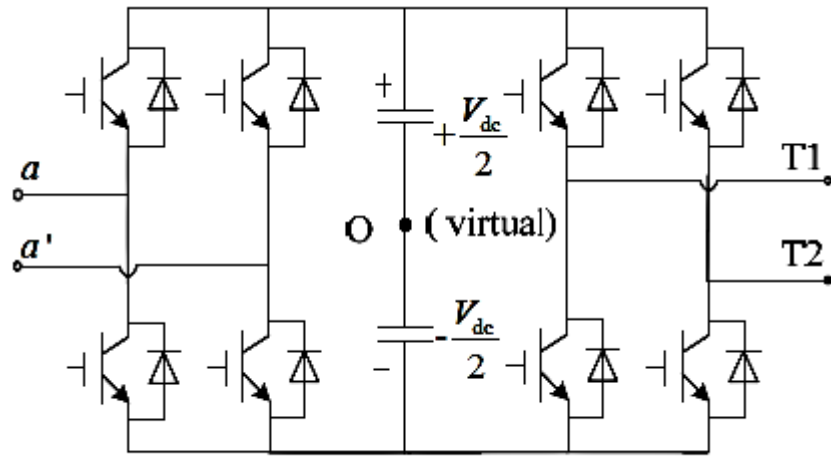
Bipolar Modulation



Common mode voltage resulting in leakage current

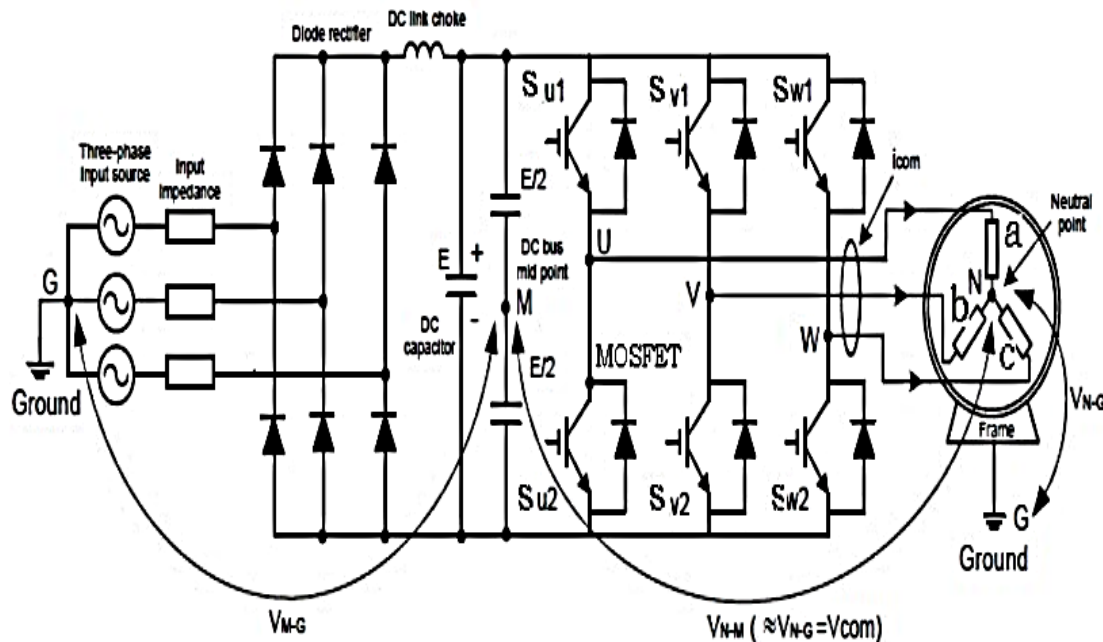


Common mode voltage resulting in leakage current



(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

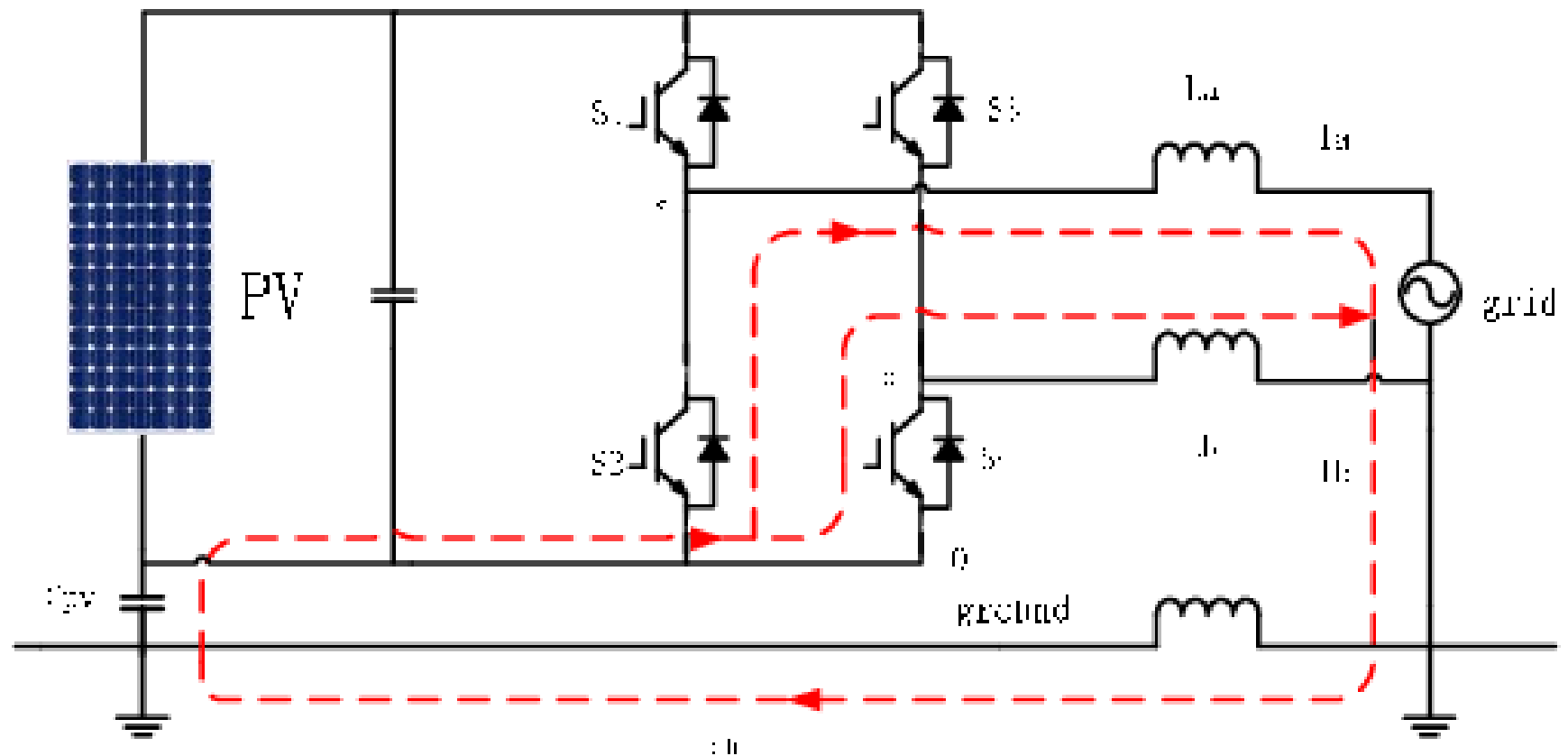
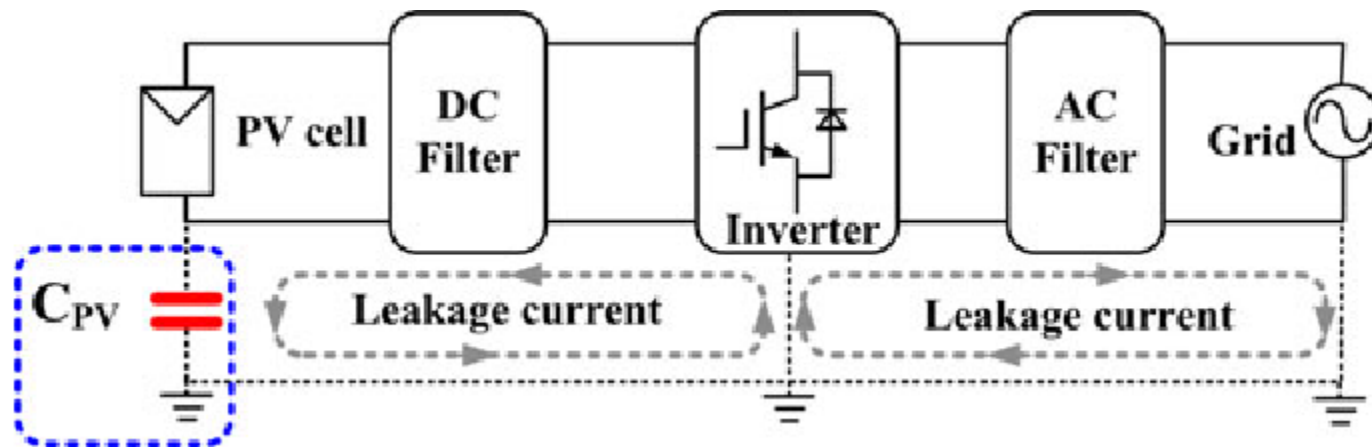


Fig. 1. The common-mode circuit of single-phase PV inverter.



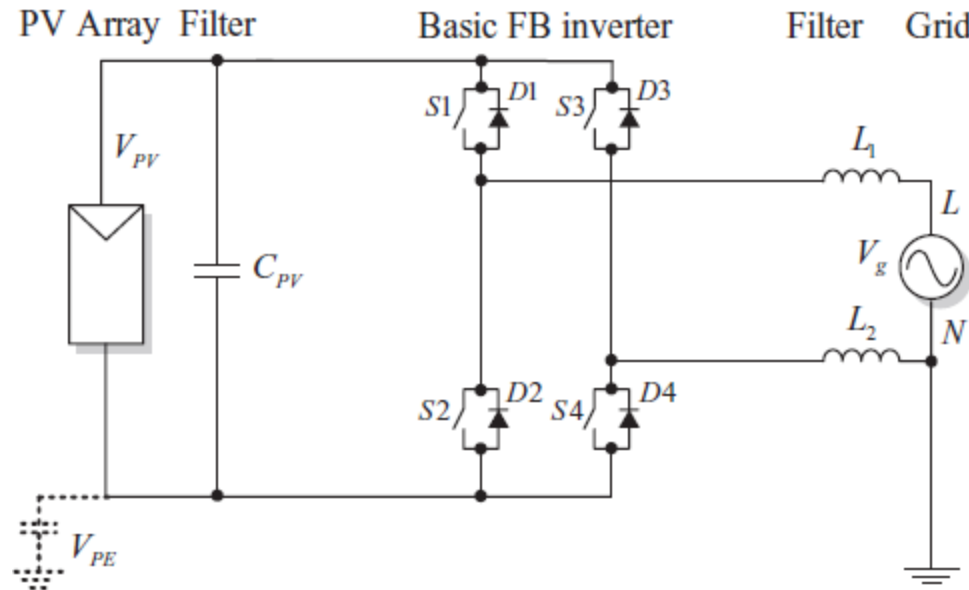
PV Inverter Topology Development

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

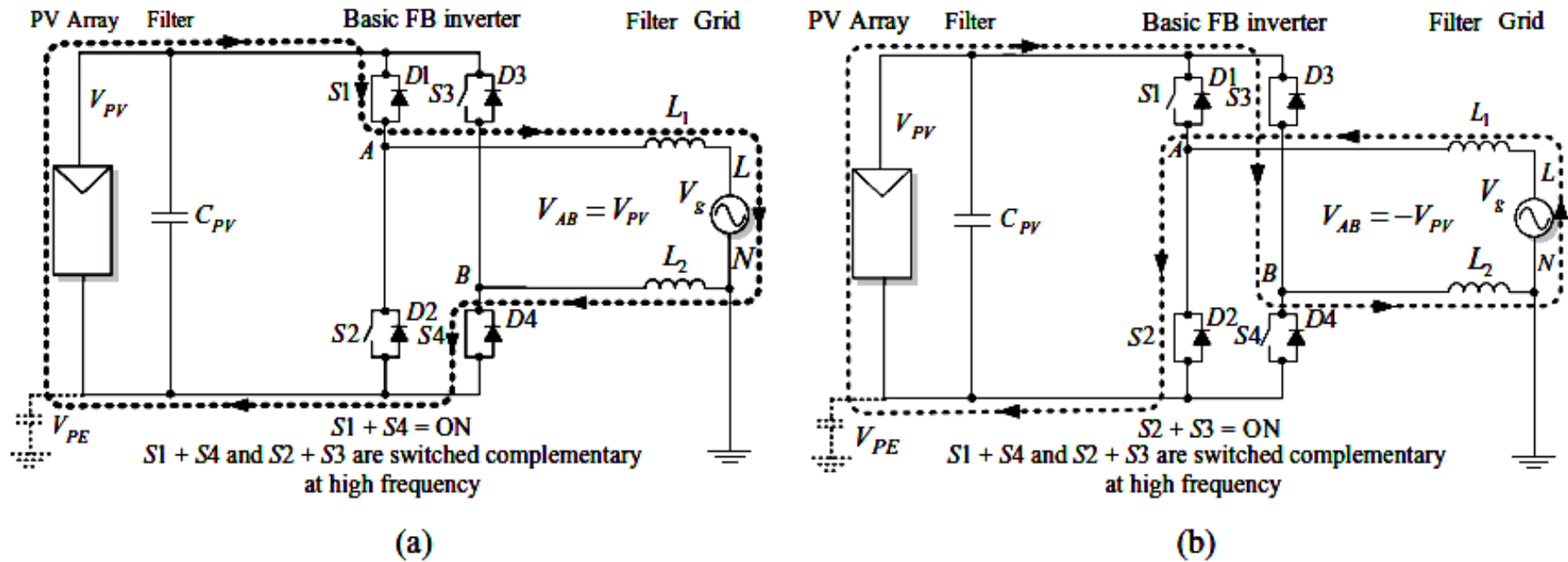


Figure 2.2 FB with BP modulation strategy in the case of: (a) positive output current and (b) negative output current

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

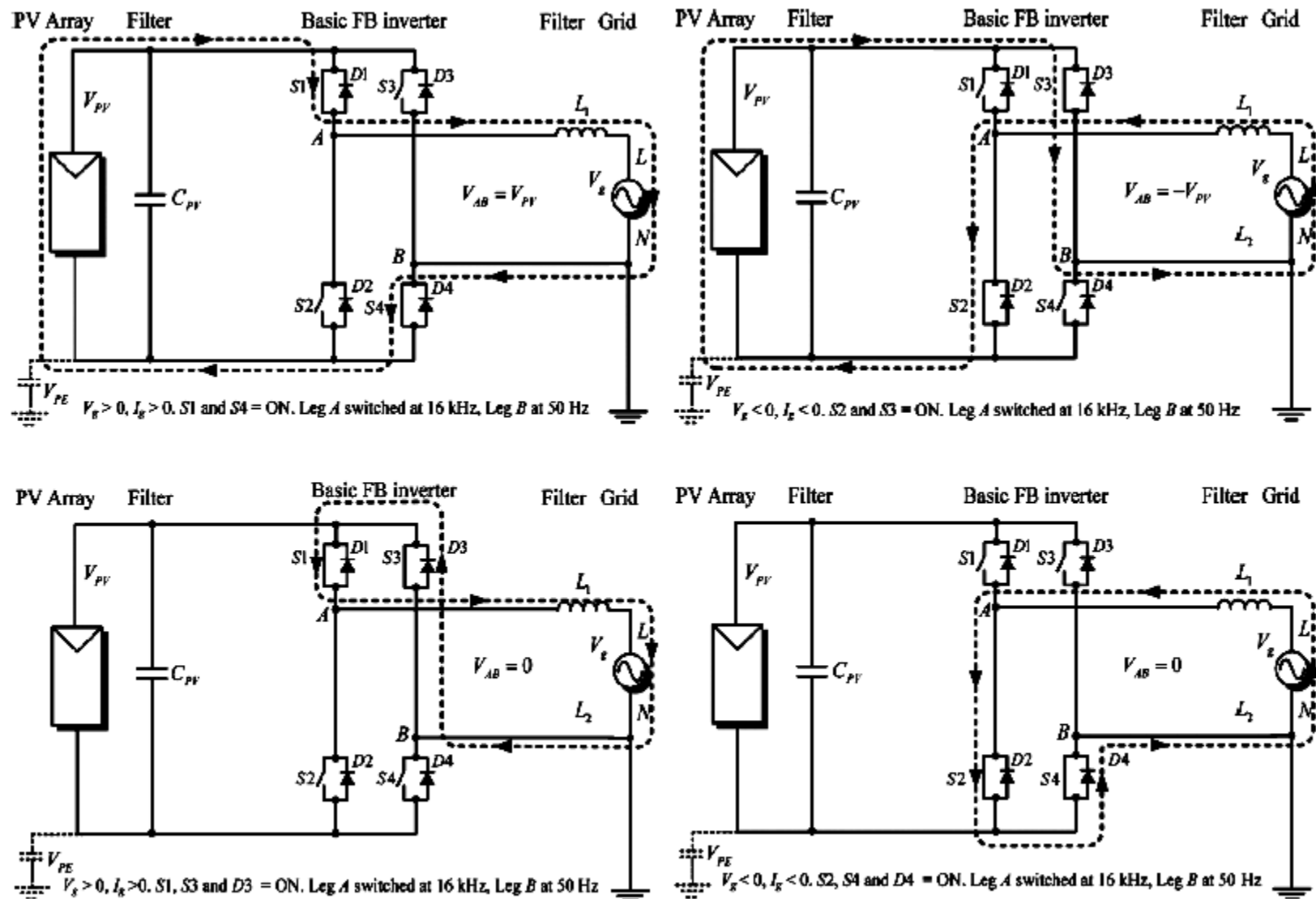


Figure 2.4 The switching states of FB with hybrid modulation in the case of generating: (a) positive current and (b) negative current

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

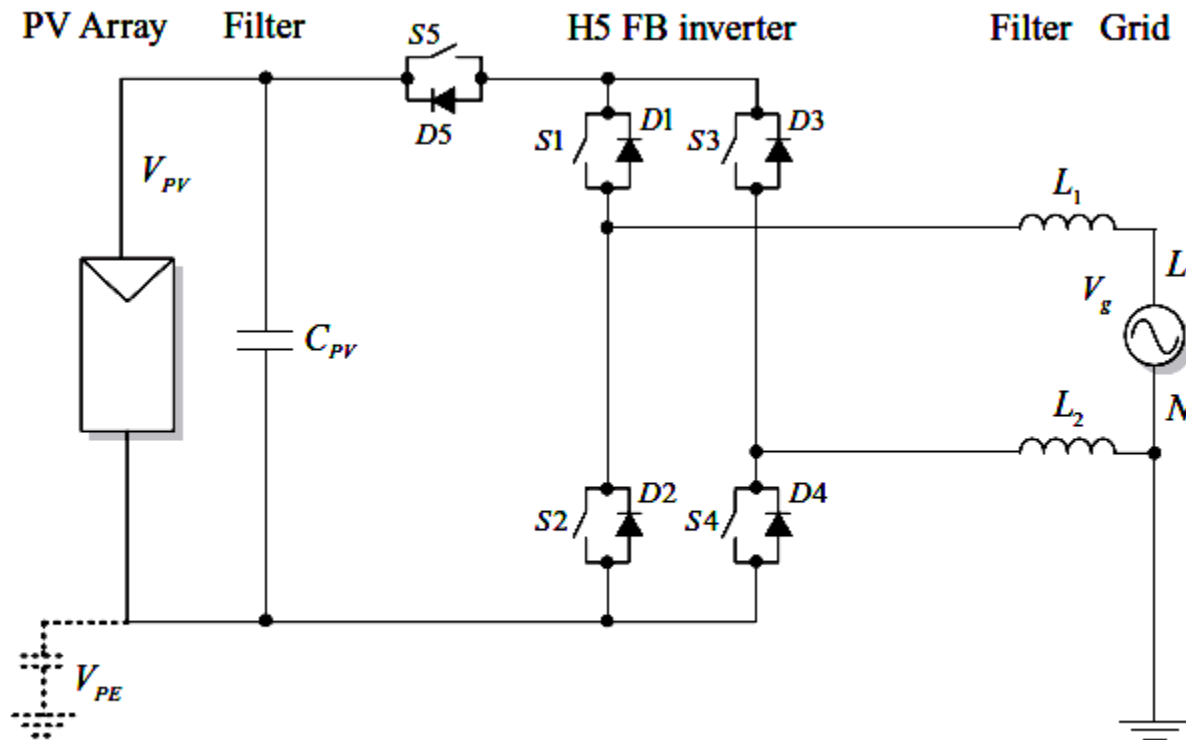


Figure 2.5 H5 inverter topology (SMA)

2.2.2 H5 Inverter: Improved Version

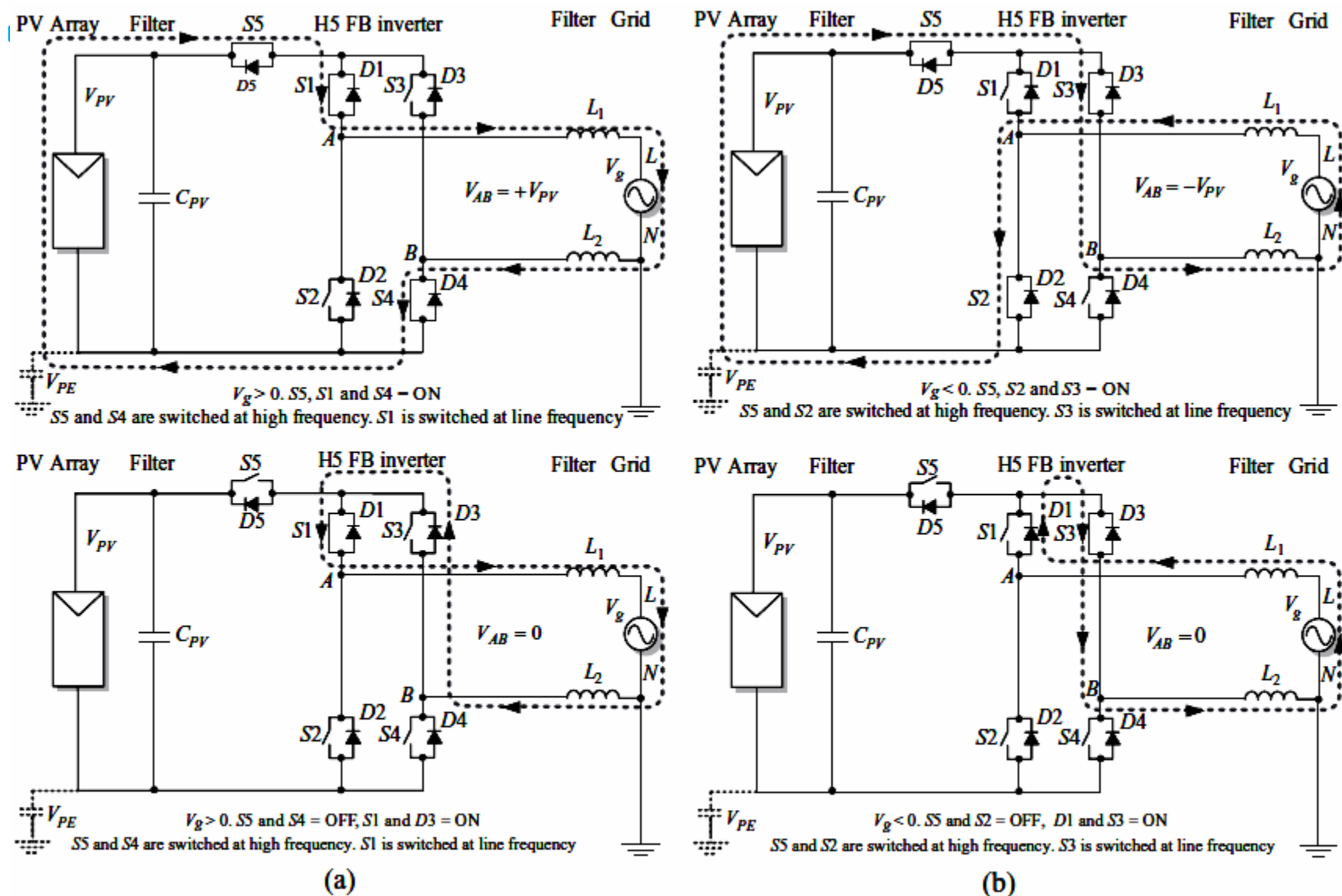


Figure 2.6 The switching states of the H5 inverter in the case of generating: (a) positive current and (b) negative current

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: $S5 = \text{OFF}$ and $S1$ ($S3$) = ON.

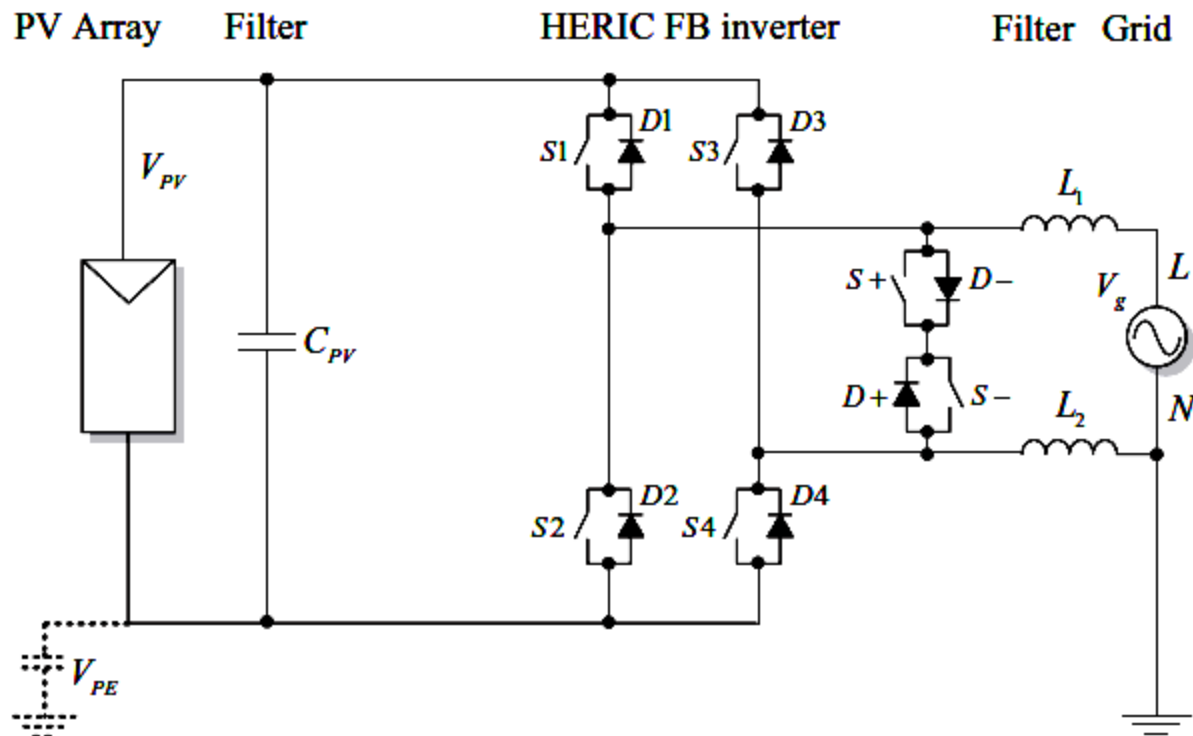
Advantages:

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

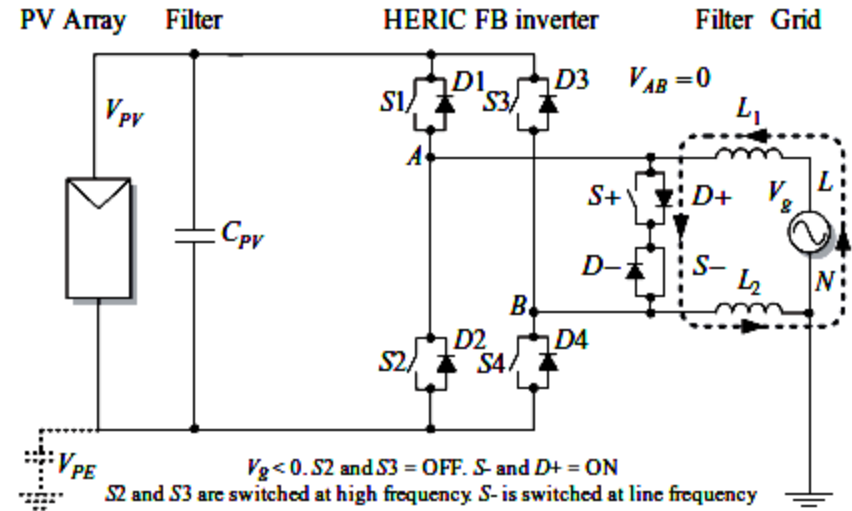
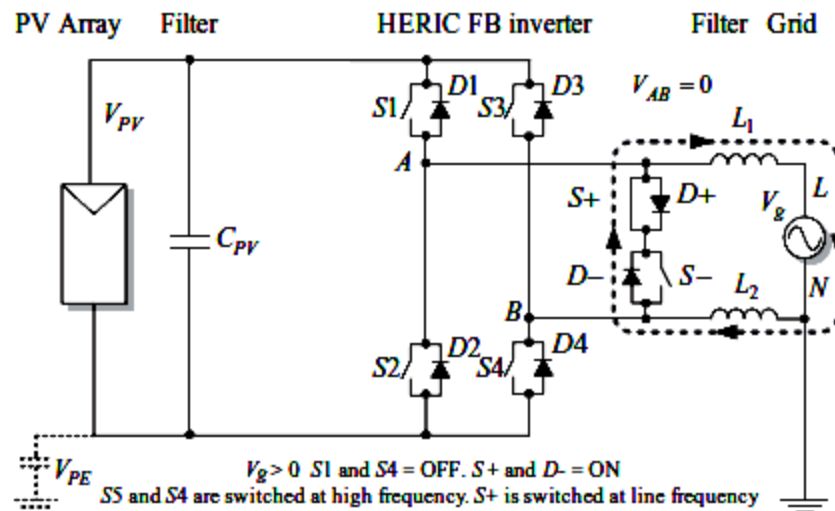
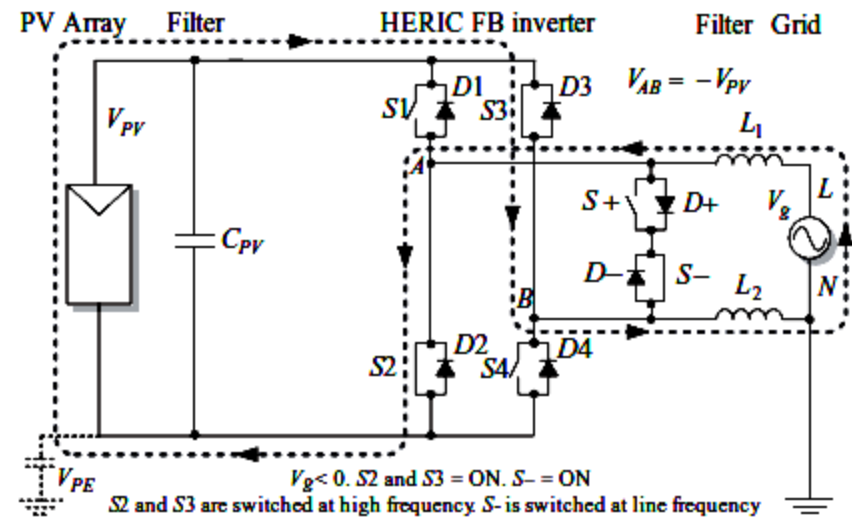
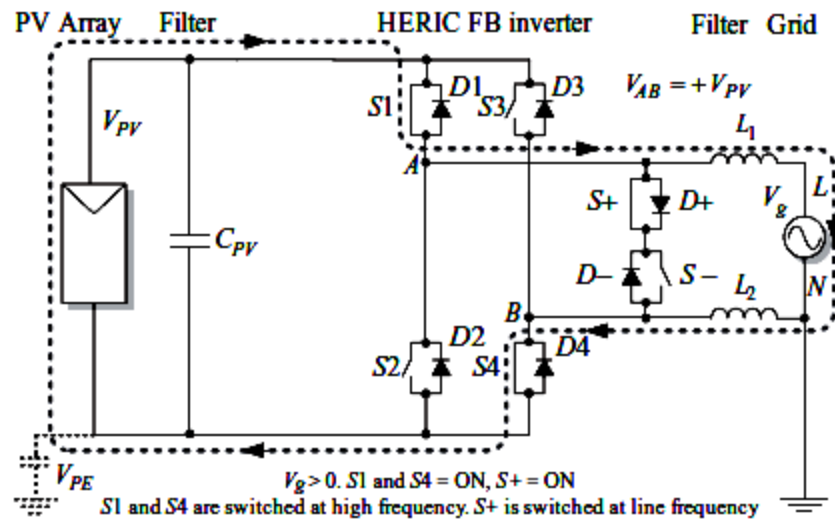
Drawbacks:

- 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: $S+ = \text{on}$ and $S- = \text{on}$ (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.

Slides OF Multilevel Inverters For Photovoltaics

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MULTILEVEL CONVERTERS FOR SINGLE-PHASE GRID CONNECTED PHOTOVOLTAIC SYSTEMS: AN OVERVIEW

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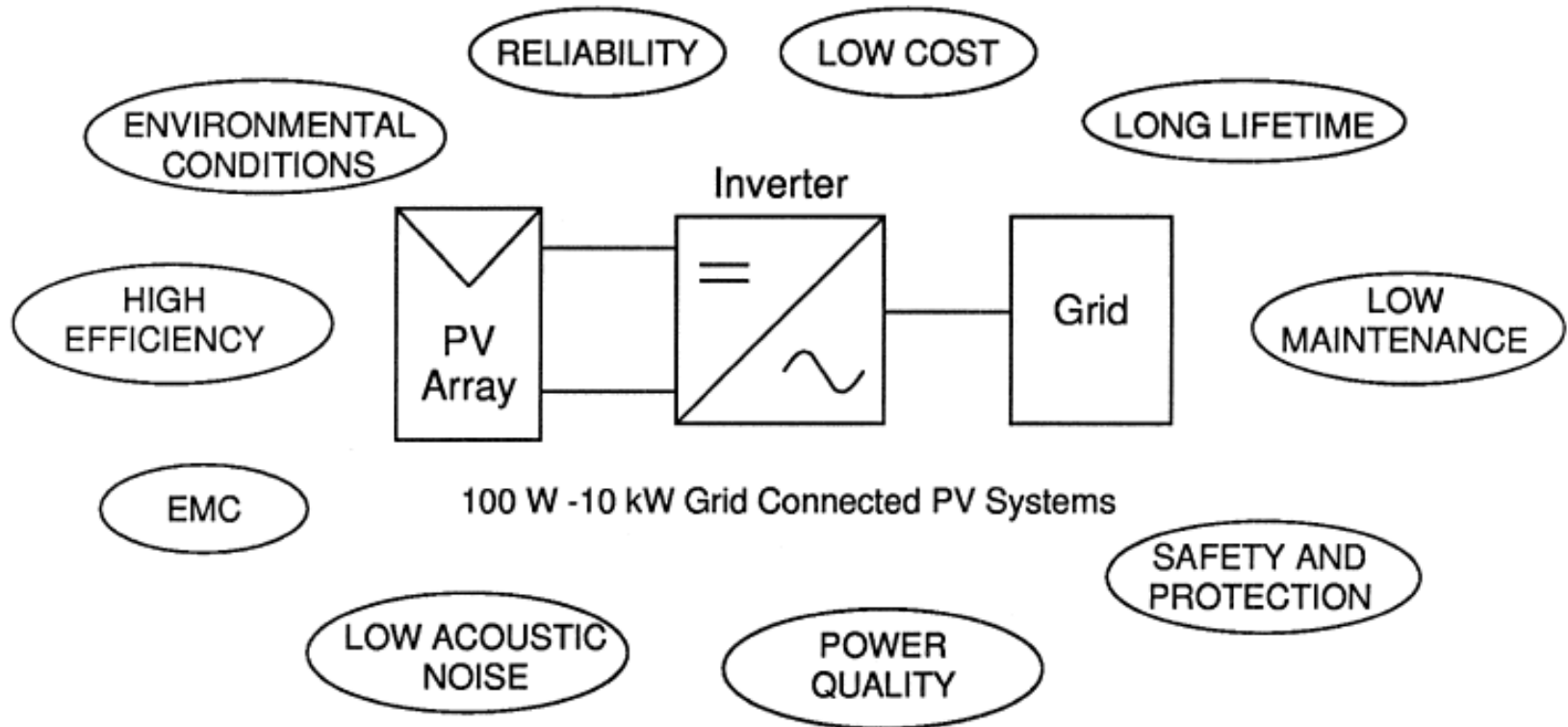
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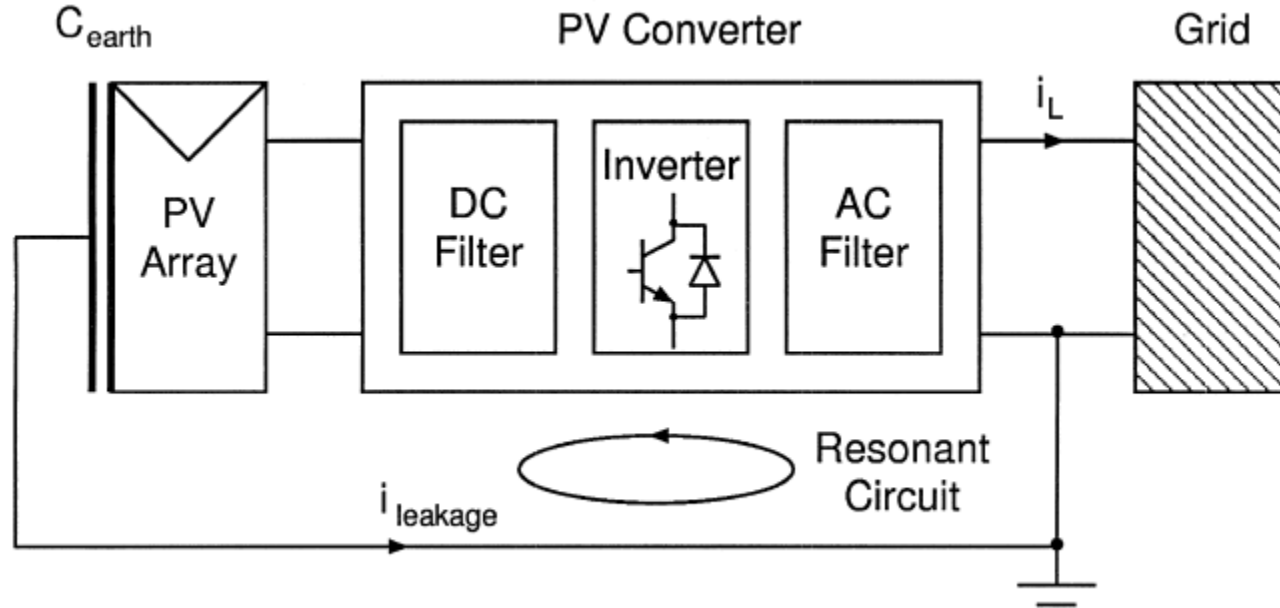
Communicated by ROBERT HILL

Abstract—Multilevel voltage source inverters offer several advantages compared to their conventional counterparts. By synthesising the AC output terminal voltage from several levels of DC voltages, staircase waveforms can be produced, which approach the sinusoidal waveform with low harmonic distortion, thus reducing filter requirements. The need of several sources on the DC side of the converter makes multilevel technology attractive for photovoltaic applications. This paper provides an overview on different multilevel topologies and investigates their suitability for single-phase grid connected photovoltaic systems. Several transformerless photovoltaic systems incorporating multilevel converters are compared regarding issues such as component count and stress, system power rating and the influence of the photovoltaic array earth capacitance. © 1999 Elsevier Science Ltd. All rights reserved.

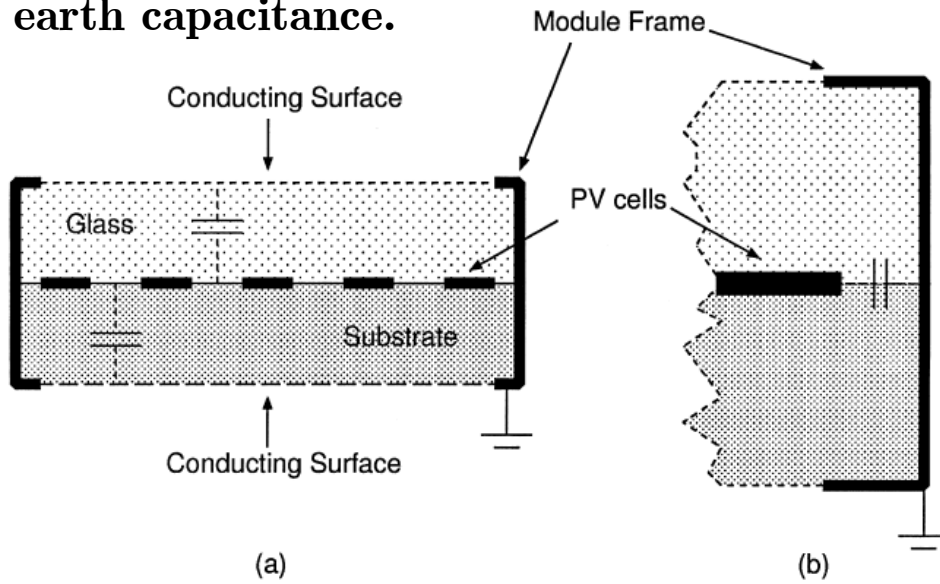
Issues Regarding Grid Connected PV Systems.



Grid connected PV system without transformer including the PV array earth capacitance.



Maximum and (b) minimum PV module earth capacitance.



PV Module Earth Capacitance Measurement

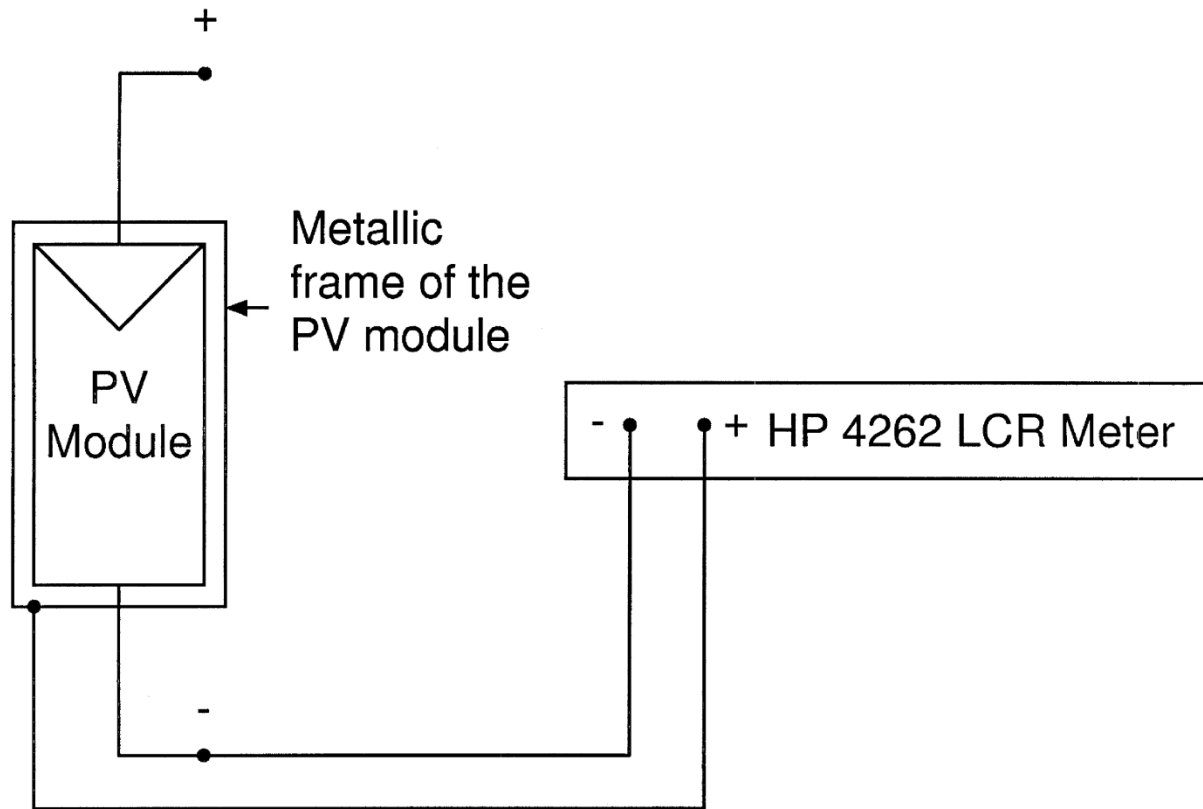


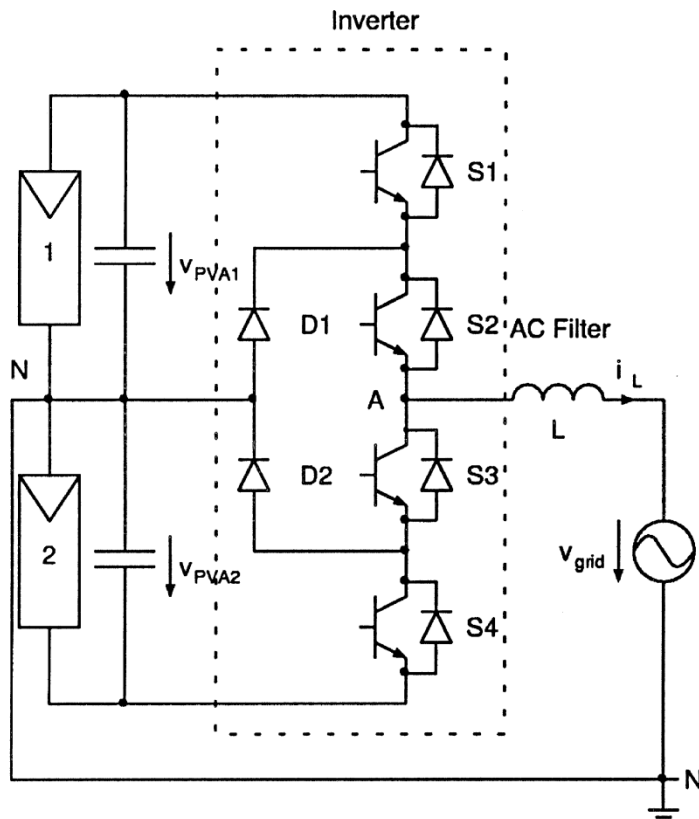
Table 1. PV module earth capacitances.

	$C_{PVearth,min}$	$C_{PVearth,max}$
Estimated	17.0 pF	6.64 nF
Measured	110 pF	4.2 nF

Multilevel Inverter Topologies

Half-bridge diode clamped

Half-bridge Diode Clamped Three-level Inverter

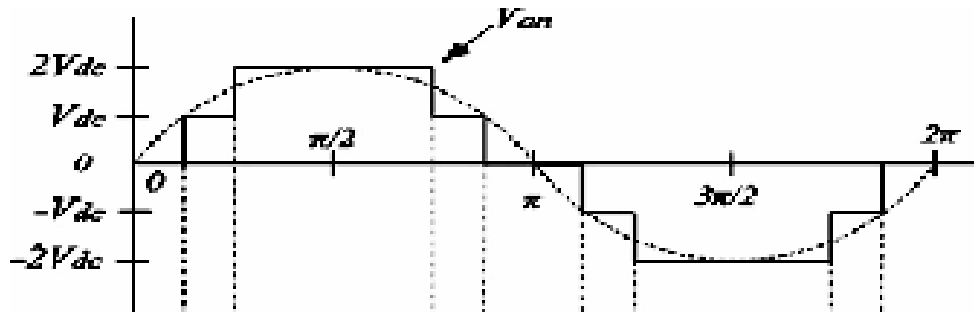


An advantage of this system is that the midpoint of the PV array is grounded which eliminates capacitive earth currents and their negative influence on the electromagnetic compatibility of the circuit.

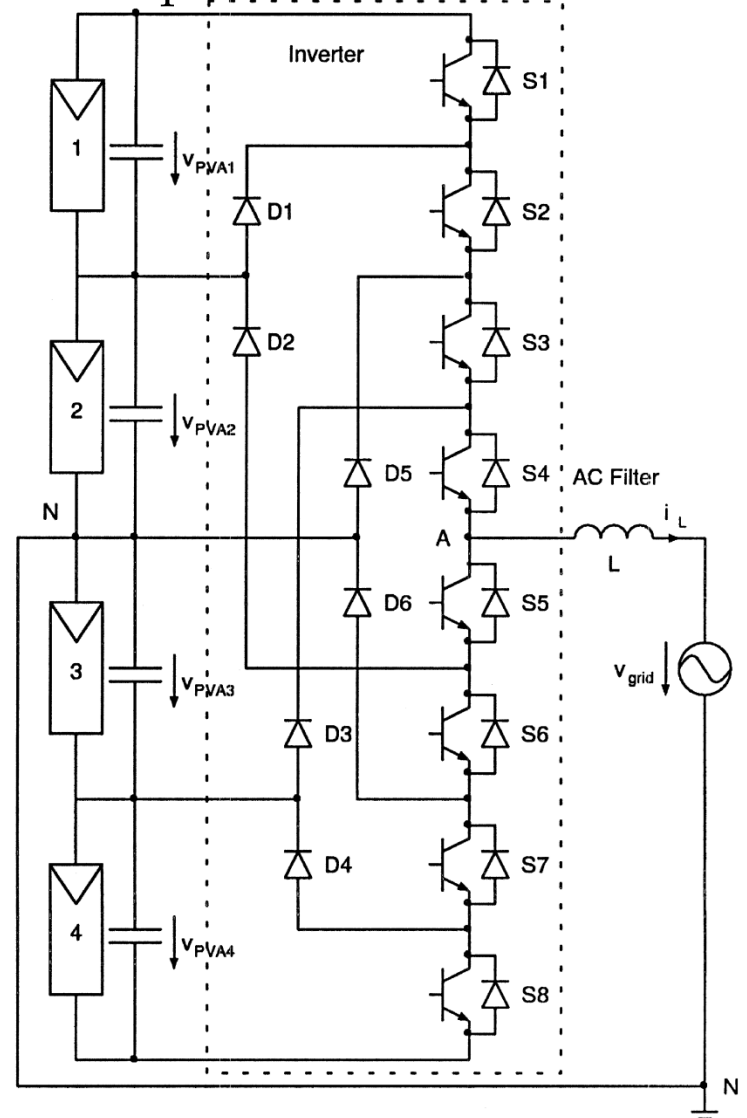
S1	S2	S3	S4	V_{RO}
1	1	0	0	$0.5V_{dc}$
0	1	1	0	0
0	0	1	1	$-0.5V_{dc}$

Multilevel Inverter Topologies

Half-bridge diode clamped

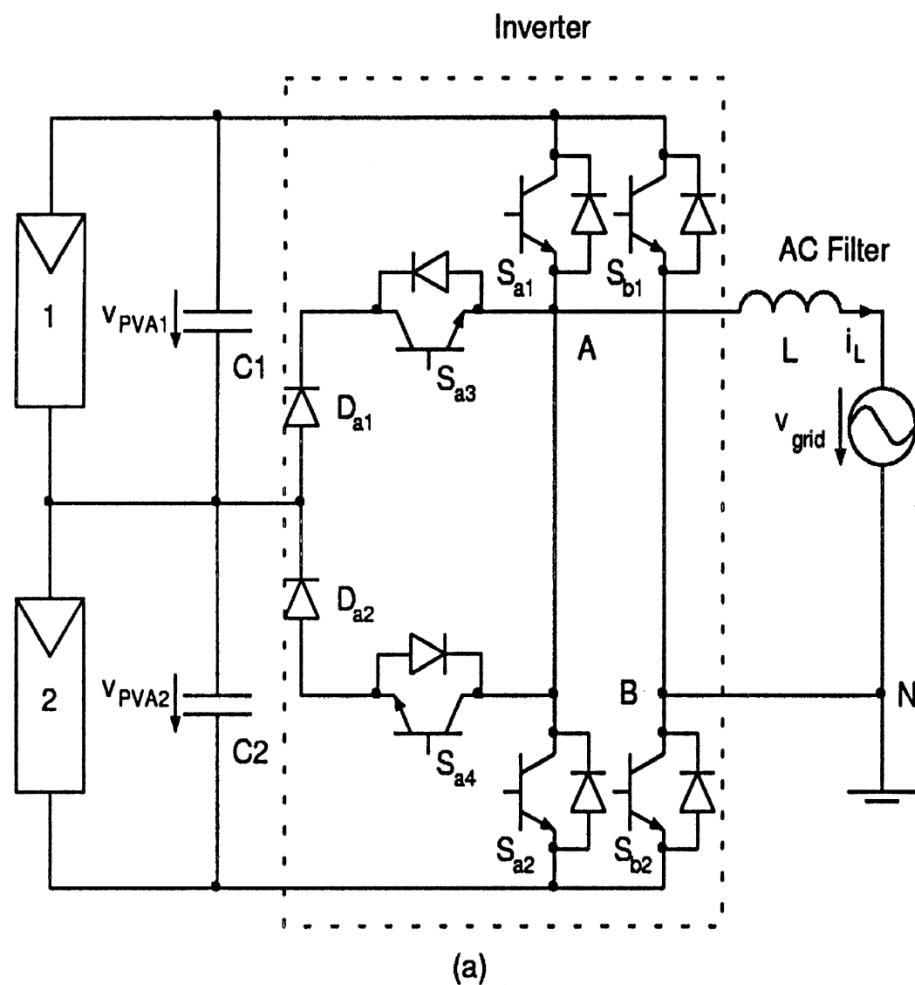


Half-bridge Diode Clamped Five-level Inverter

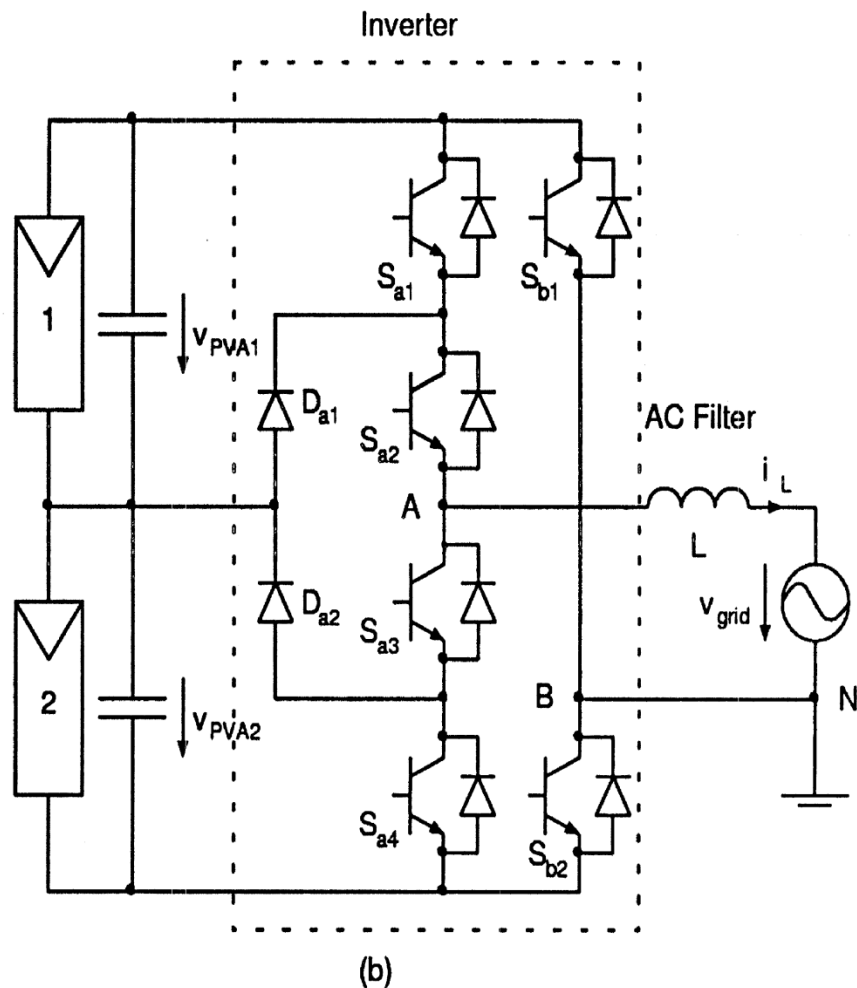


Full-bridge Single Leg Clamped

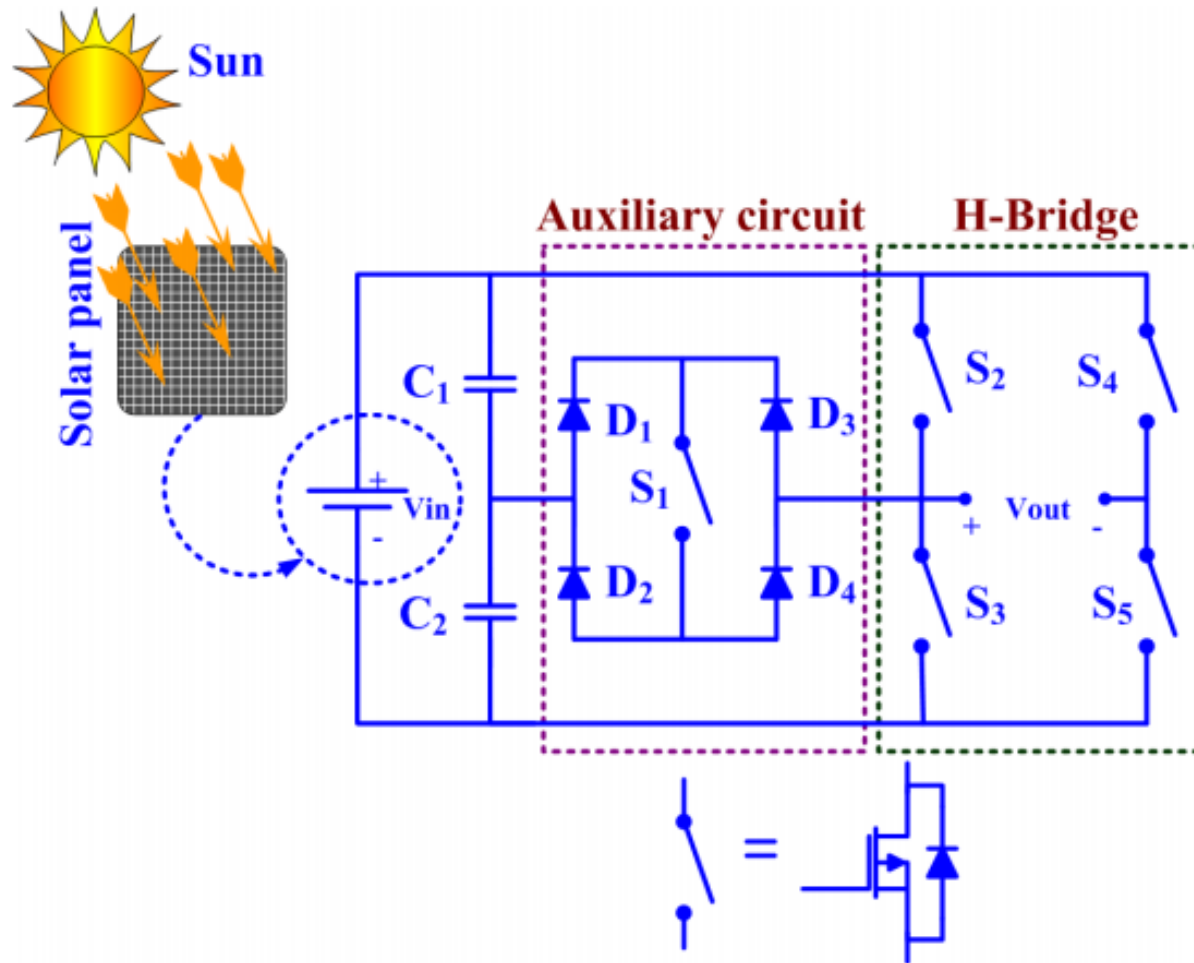
Full-bridge Single Leg Switch Clamped Inverter



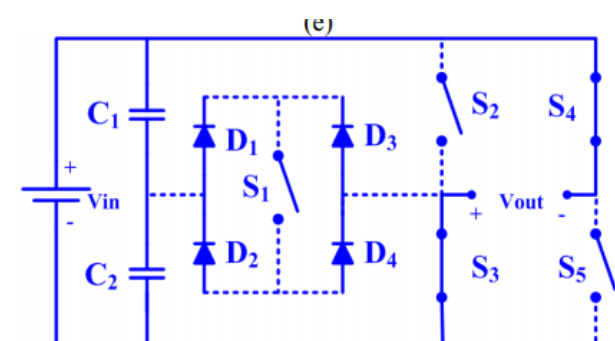
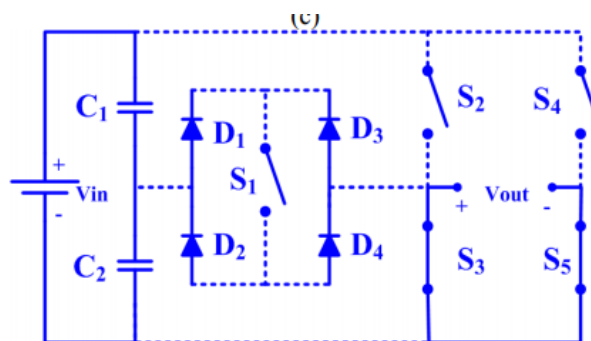
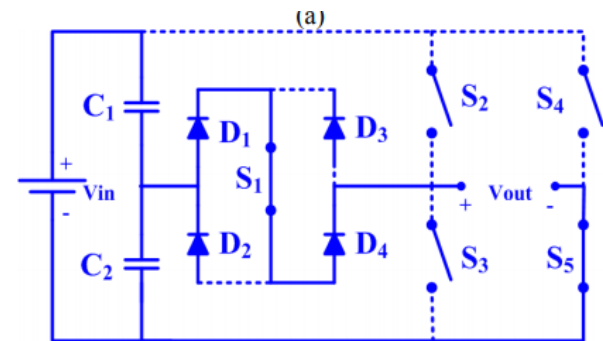
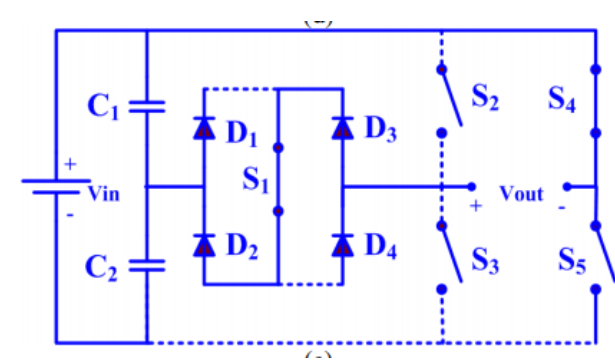
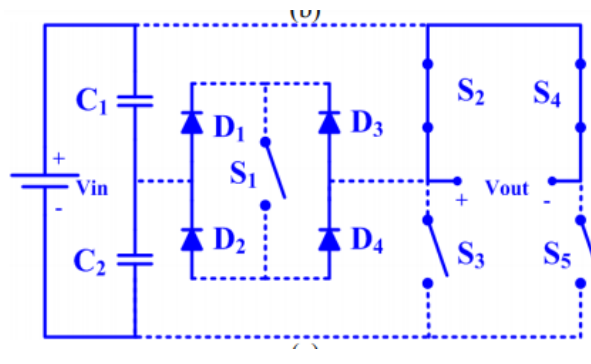
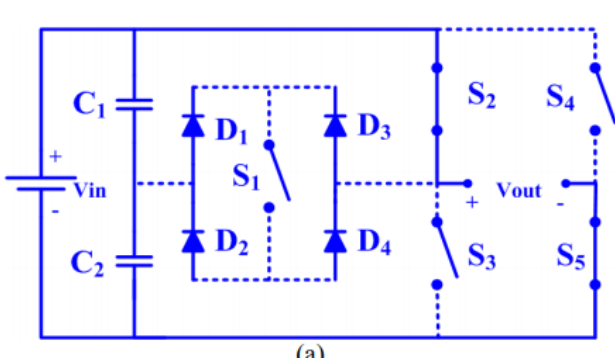
Full-bridge Single Leg Diode Clamped Inverter



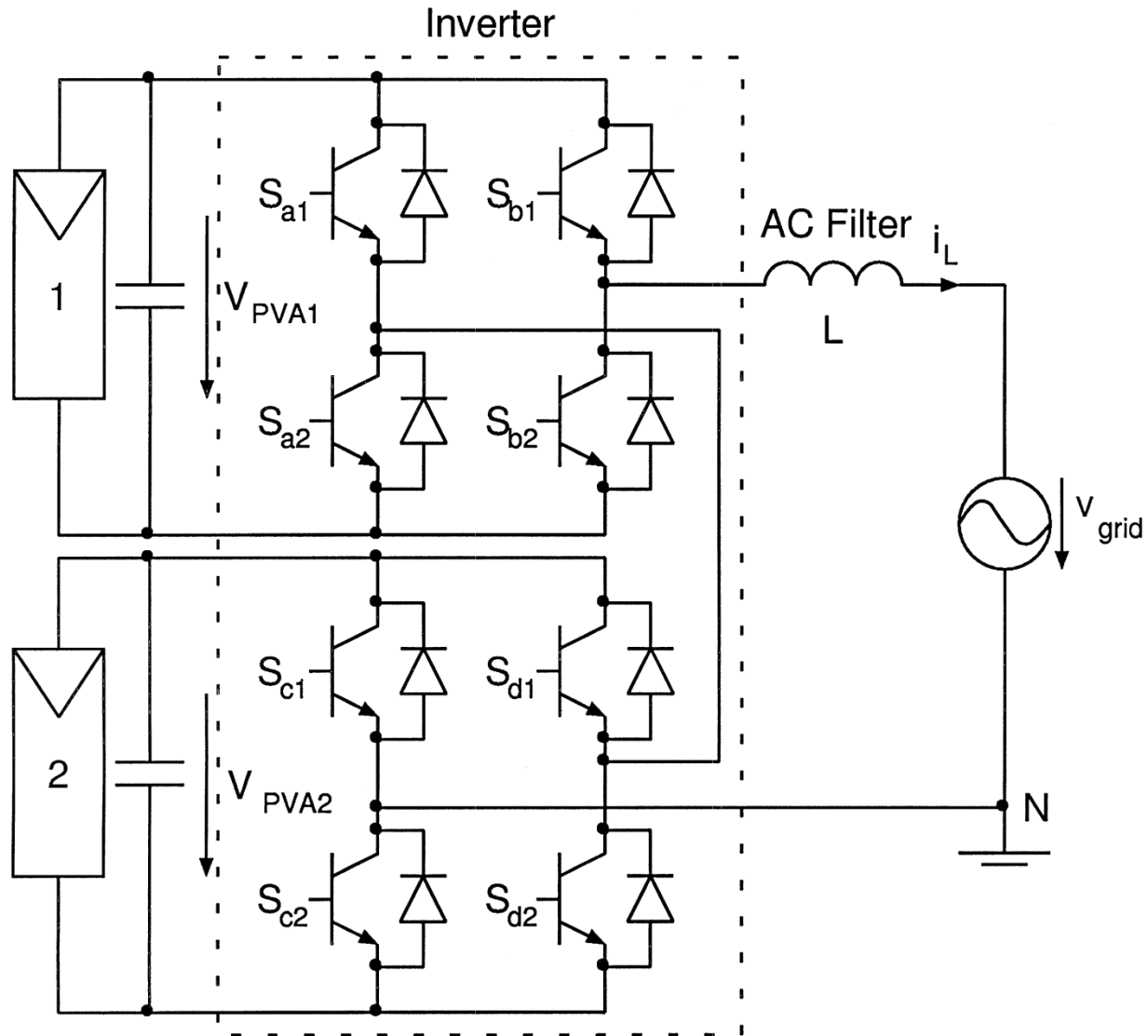
Full-bridge Single Leg Clamped



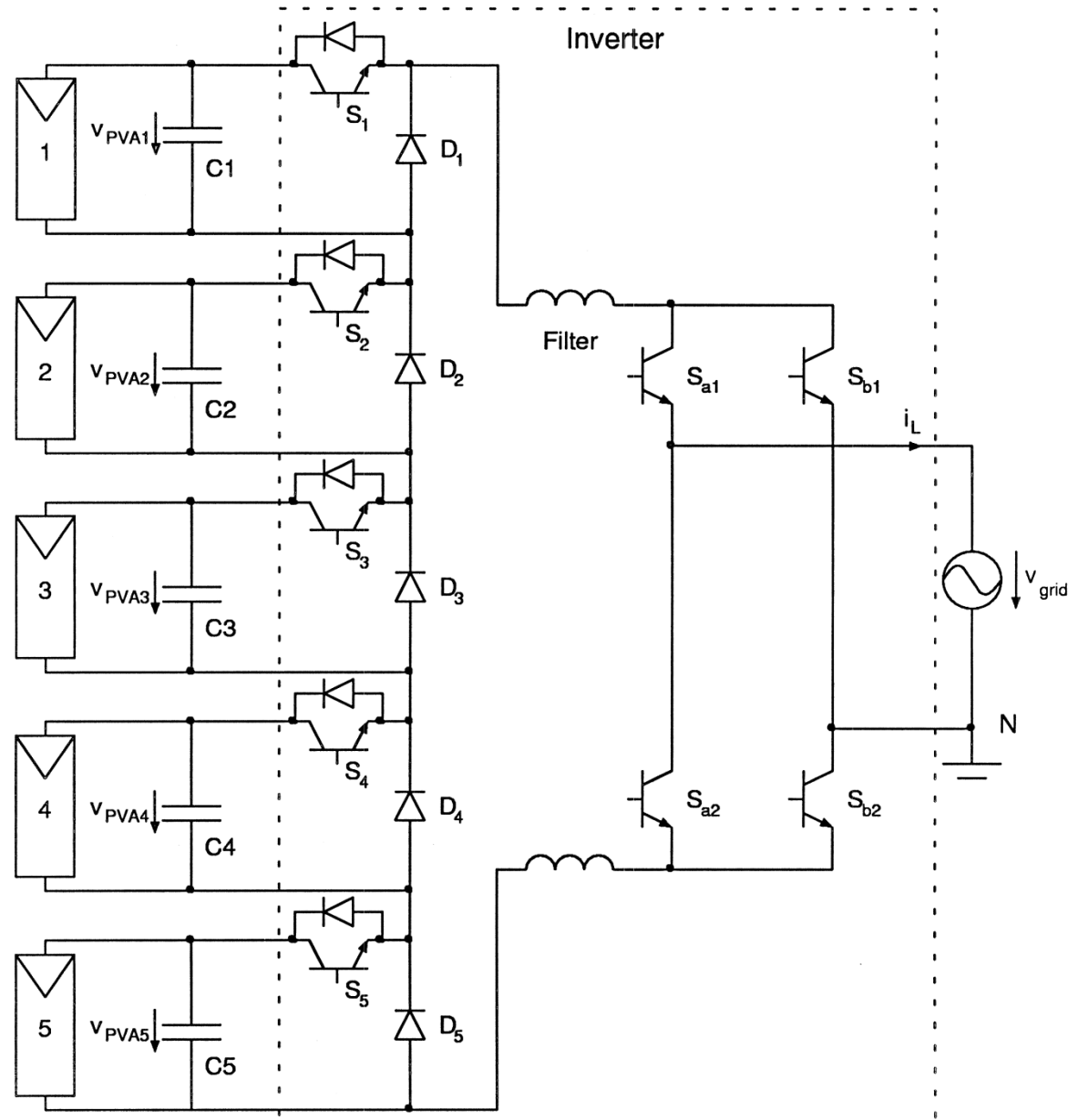
Full-bridge Single Leg Clamped



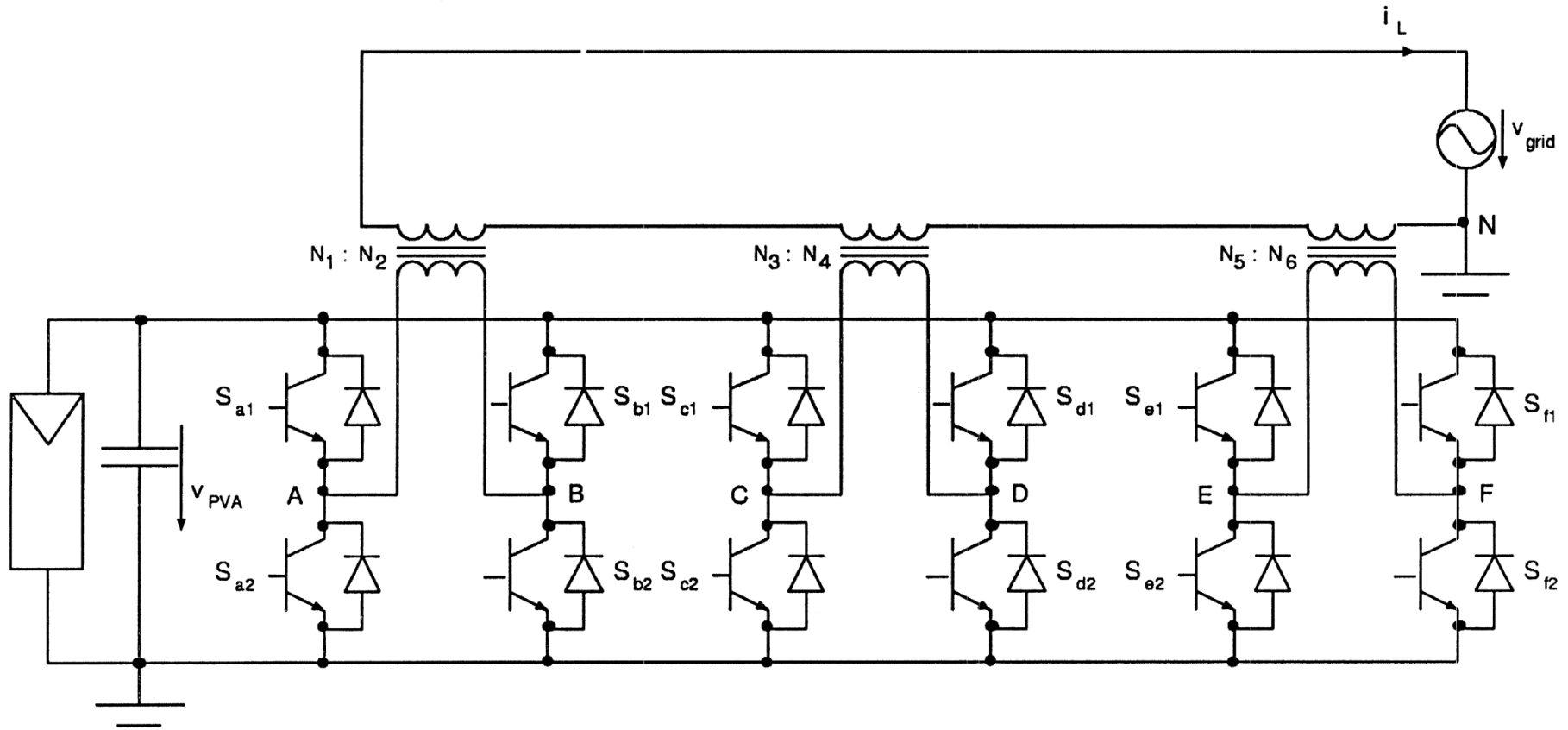
Grid Connected PV System With A Cascaded Inverter



Grid Connected PV System With A Step Inverter



Grid connected PV systems with magnetic coupled inverter



System comparison

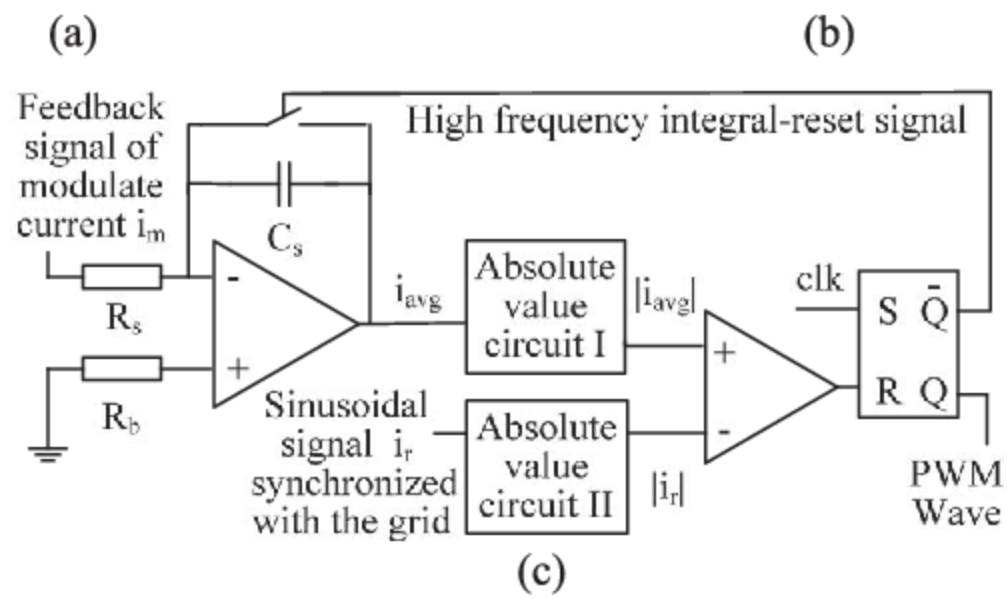
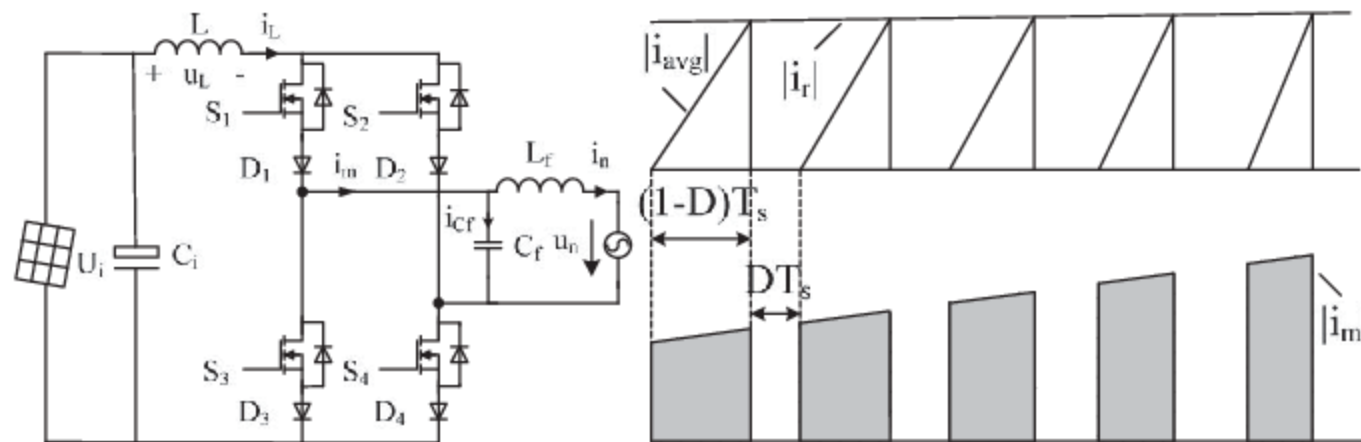
Table 2. System comparison

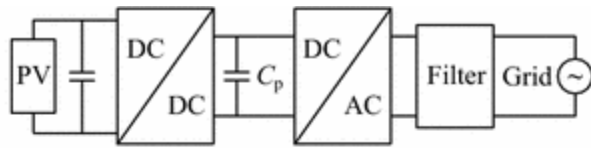
	FB	SLSC	SLDC	CC	FC	HBDC	HB
$P_{r,min}/kWp$	1.5	1.5	1.5	1.5	3	3	3
No. of PV modules	28	28	28	28	54	54	54
No. of PV subarrays	1	2	2	2	2	2	2
No. of Capacitors	1	2	2	2	3	2	2
No. of Switches	4	6	6	8	4	4	2
No. of Diodes	0	2	2	0	0	2	0
$V_{block,max}/kV$	0.7	0.7 or 0.35	0.7 or 0.35	0.35	0.7	0.7	1.4
I_{max}/A	9	9	9	9	18	18	18
AC voltage levels	3	5	5	5	3	3	2
Capacitive Earth Currents	Yes	Yes	Yes	Yes	No	No	No

Table 3. Number of switches

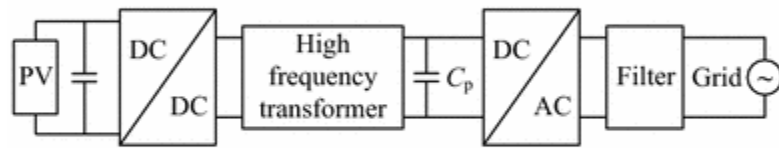
Topology	$V_{block,max} = 700\text{ V}$ $I_{max} = 9\text{ A}$	$V_{block,max} = 350\text{ V}$ $I_{max} = 9\text{ A}$
SLSC	4	2
SLDC	2	4
CC	0	8



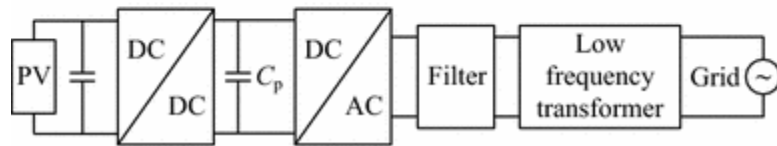




(a) A transformer-less inverter



(b) A high frequency transformer



(c) A low frequency transformer

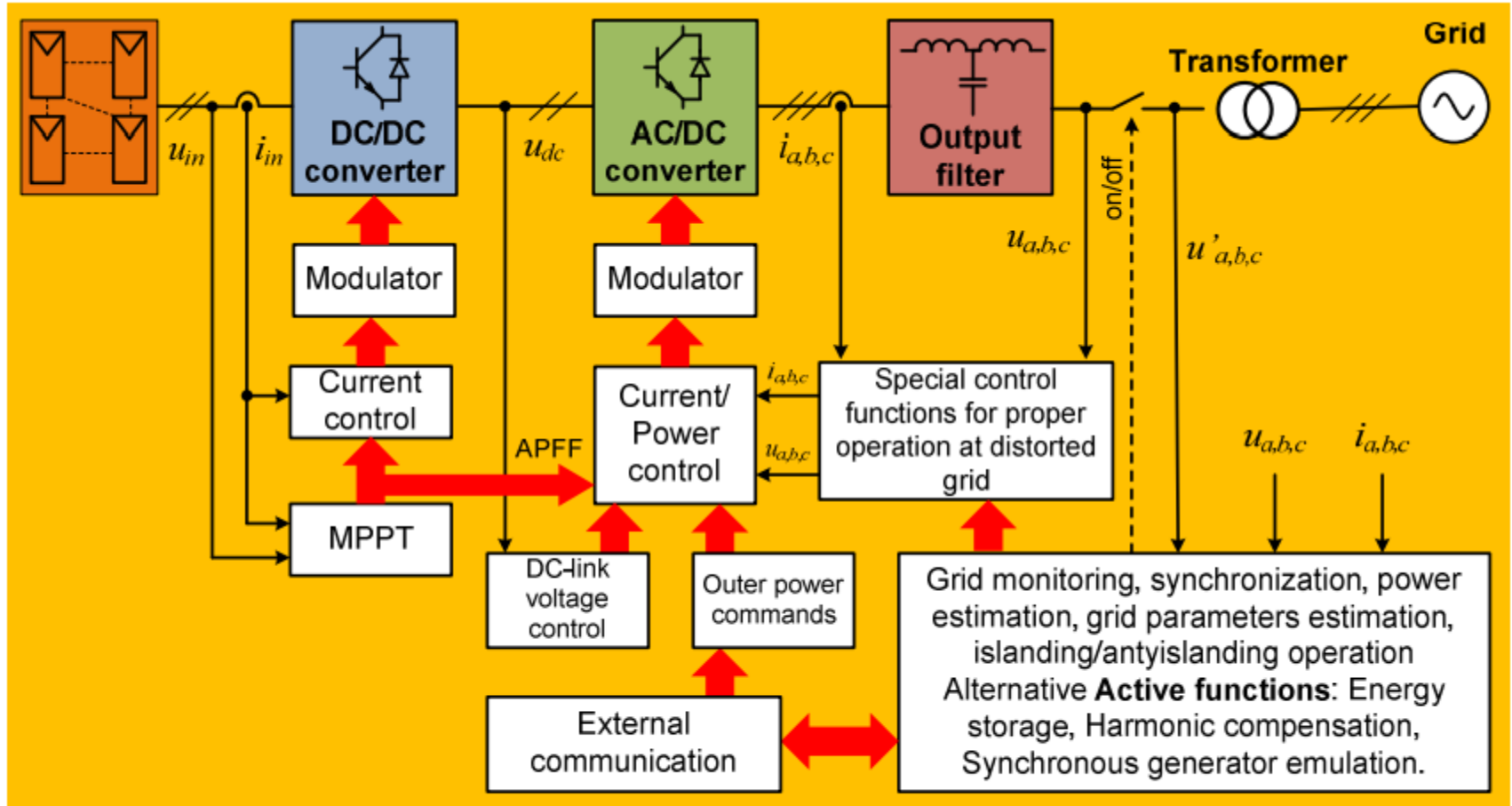


Fig. 4. General control structure of grid-connected PV plant.

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

End of Solar Energy—Semiconductor Part 5

Course Work