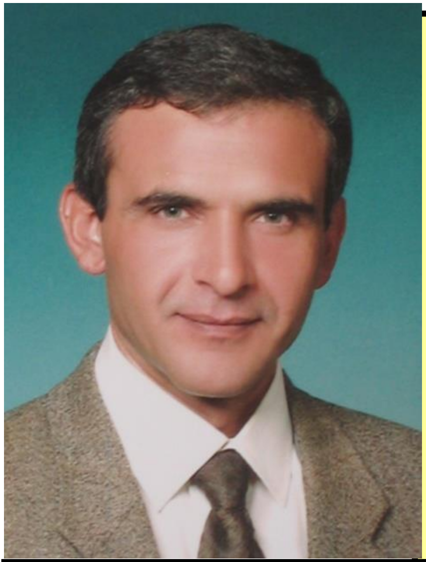
PHOTOVOLTAIC POWER PLANTS & INVERTERS

IBRAHIM SEFA

Gazi University, Faculty of Technology, Electrical & Electronics Engineering

Turkey

Assoc. Prof. Dr. Ibrahim SEFA



The paper is being presented
by

Dr.

Ibrahim SEFA

isefa@gazi.edu.tr

Ibrahim Sefa received the B.S. degree from the Department of Electrical and Electronics Education, Gazi University, Ankara, Turkey, in 1985, and the M.Sc. and Ph.D. degrees from the Department of Electrical and Electronics Engineering, Erciyes University, Kayseri, Turkey, in 1993 and 1997, respectively.

He is currently an Associate Professor in the Department of Electrical and Electronics Engineering, Faculty of Technology, Gazi University.

His current research interests include variable speed drives, power electronics, uninterruptible power supplies, control systems, and renewable energy sources.

Outline of the Presentation

- Components of the PV Power Plants
- MPPT
- Grid Interactive Inverters
- Basic Specifications of an Inverter
- International Standards of Grid Inverters
- Utility Disconnection Requirements
- Types of Grid Interactive Inverter
- The Evolution of the Inverters
- Conclusion

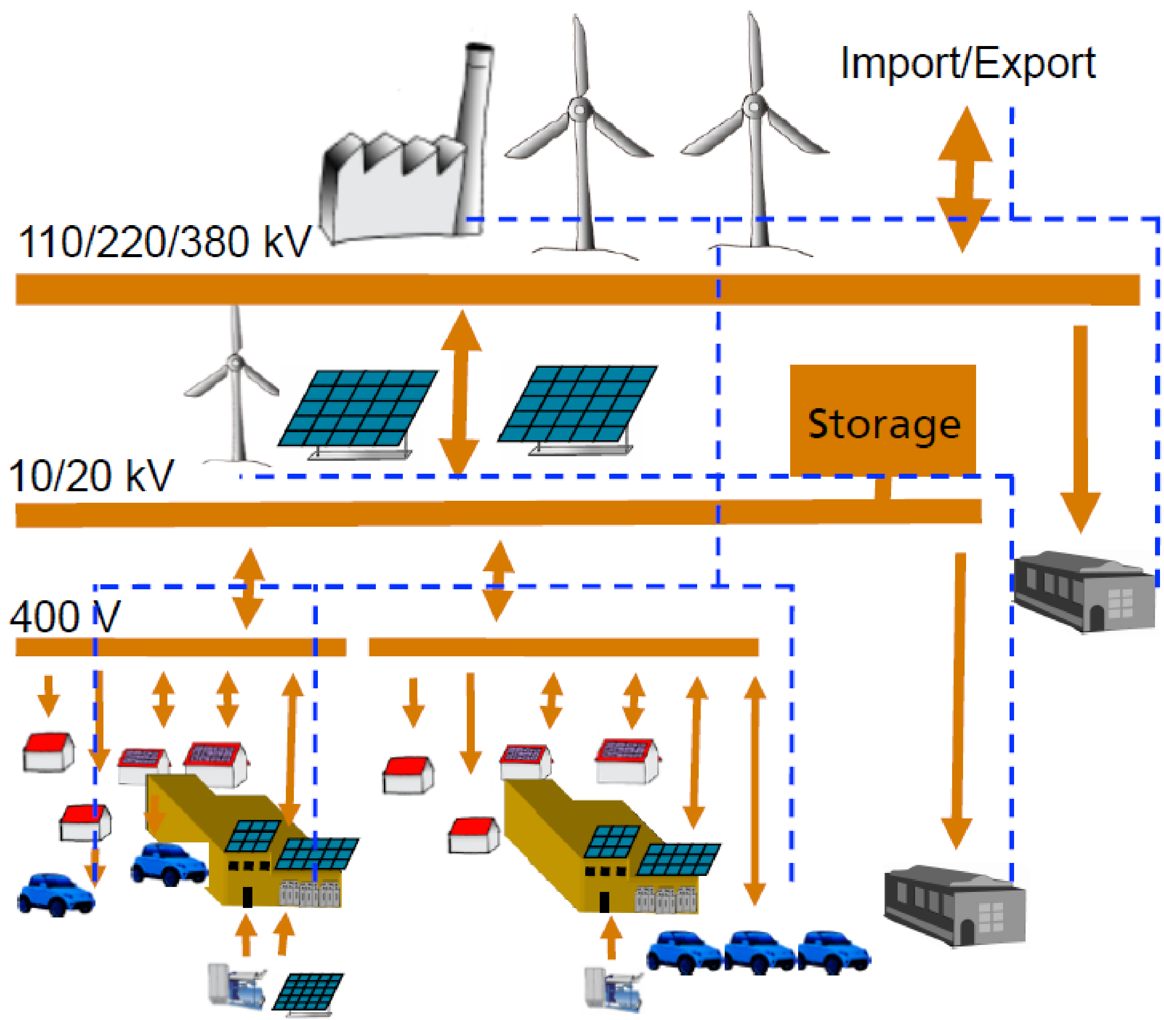
Renewable Energy Systems

- Renewable energy sources (RES) have become more important research area for the researchers due to increasing energy demand in the world.
- The most common renewable resources are Solar and Wind.
- Due to environment issues such as global warming and pollution, limited resources of fossil based fuels and energy crisis, renewable energy sources such as photovoltaic (PV) array, wind turbine, fuel cell, biomass system and the geothermal systems are becoming more and more popular in industrial and also residential applications

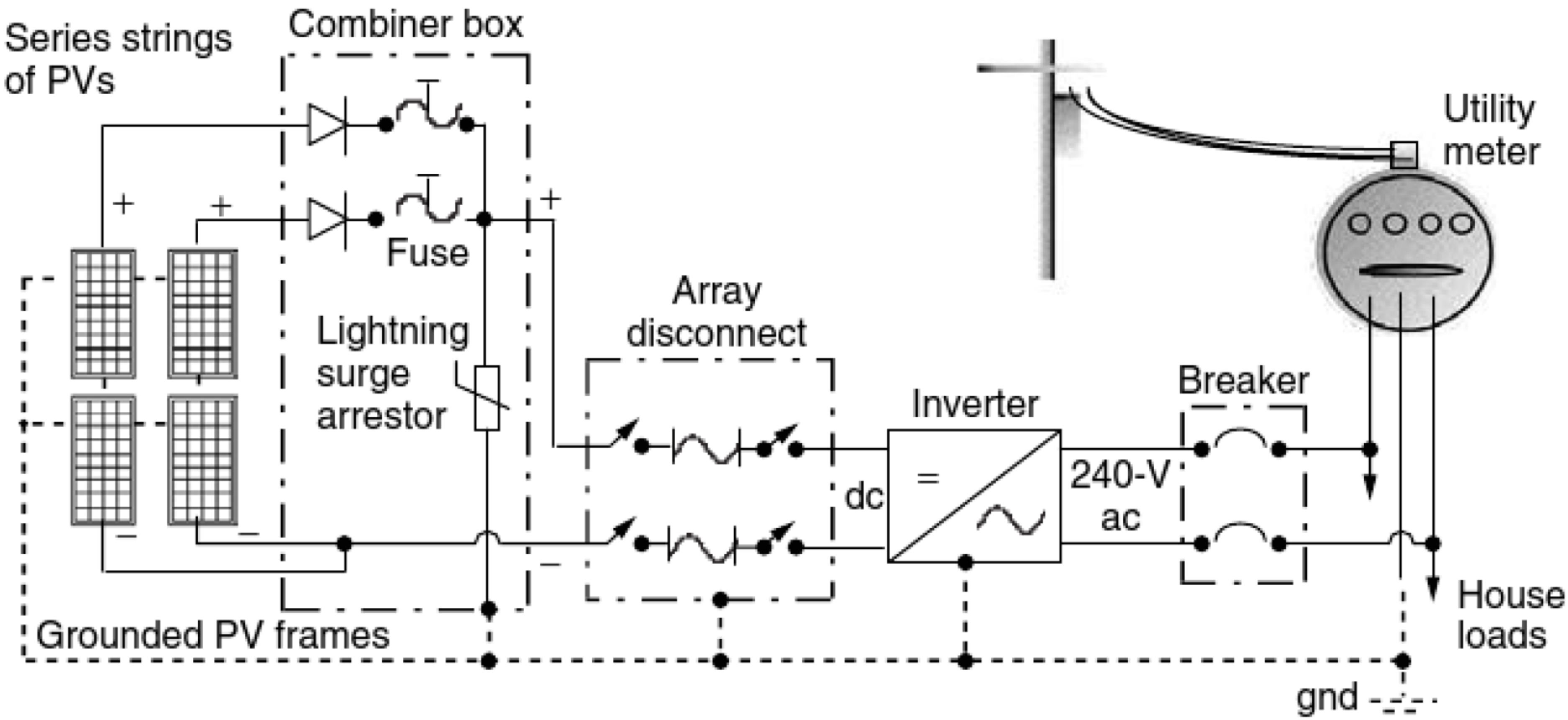
PHOTOVOLTAIC POWER PLANTS & INVERTERS

PHOTOVOLTAIC POWER PLANTS

Smart Grid Concept

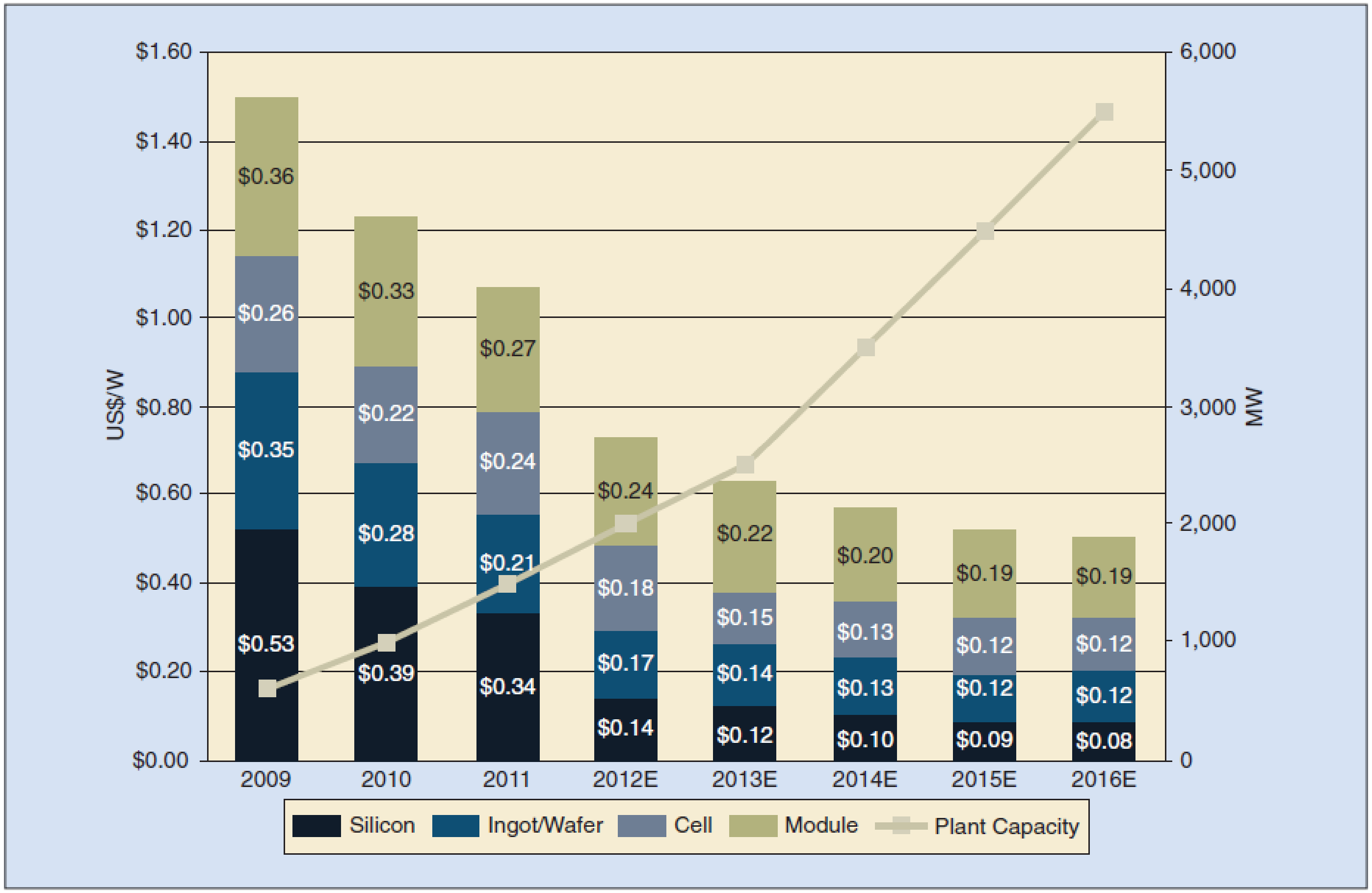


Components of the PV Power Plants



PHOTOVOLTAIC POWER PLANTS

PV modules



- All-in-module(US$/W) cost and plant capacity evolution (decreasing prices)

PV modules

		1st Generation PV		2nd Generation PV			3rd Generation PV		
Technology	Units	Single crystalline silicon (sc-Si)	Polycrystalline silicon (pc-Si)	Amorphous silicon (a-Si)	Copper Indium Gallium Diselenide (CIS/CIGS)	Cadmium Telluride solar cells (CdTe)	III-V compound Multijunction, Concentrated PV (CPV)	Dye-sensitized (DSSC)	Organic or Polymer (OPV)
Best research solar cell efficiency at AM1.5*	%	24.7		10.4 Single junction 13.2 Tandem	20.3	16.5	43.5	11.1	11.1
Confirmed solar cell efficiency at AM1.5	%	20-24	14-18	6-8	10-12	8-10	36-41	8.8	8.3
Commercial PV Module efficiency at AM1.5	%	15-19	13-15	5-8	7-11	8-11	25-30	1-5	1
Confirmed maximum PV Module efficiency	%	23	16	7.1 / 10.0	12.1	11.2	25	-	-
Current PV module cost	USD/W	< 1.4	< 1.4	~ 0.8	~ 0.9	~ 0.9	-	-	-
Market share in 2009	%	83	3	1	13		-	-	-
Market share in 2010	%	87	2	2	9		-	-	-
Maximum PV module output power	W		320	300	120	120	120	-	-
PV module size	m²	2.0	1.4-2.5	1.4	0.6-1.0	0.72	-	-	-
Area needed per kW	m²	7	8	15	10	11	-	-	-
State of commercialisation		Mature with large-scale production	Mature with large-scale production	Early deployment phase, medium-scale production	Early deployment phase, medium-scale production	Early deployment phase, small-scale production	Just commercialised, small-scale production	R&D phase	R&D phase

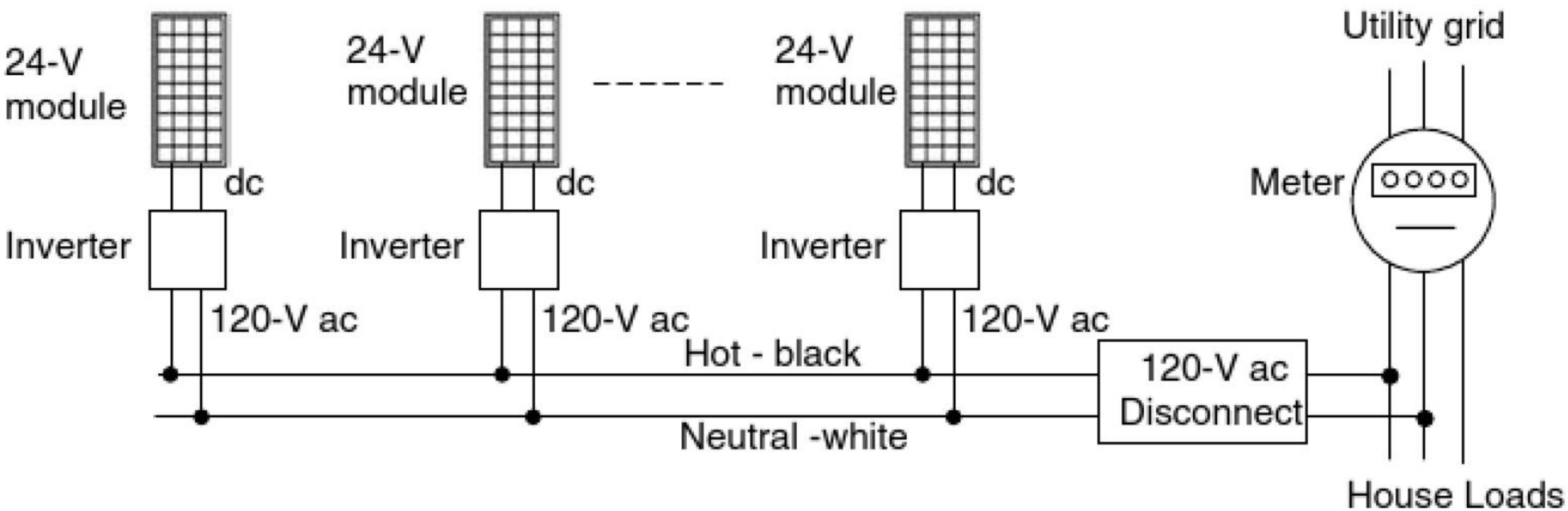
- Overview of major PV technologies

PV modules

Top Ten by Power		
Power	Description and Location	Commissioned
250 MW	Agua Caliente Solar Project, Yuma County, Arizona	2012
214 MW	Charanka Park, Patan District PV Power Plant, Charanka, India	2012
200 MWp	Golmud PV Power Plant, Golmud, China	2011
150 MW	Mesquite Solar I, Sonora Desert, Arizona	2011
145 MWp	Solarpark Neuhardenberg, Neuhardenberg, Germany	2012
128 MW	Solarpark Templin, Germany	2012
115 MW	Centrale Solaire de Toul-Rosières, France.	2012
106 MW	Perovo I-V PV Power Plant, Ukraine	2011
97 MW	Sarnia PV Power Plant, Canada	2009
91 MW	Solarpark Briest, Germany	2011

- Top large scale PV power plants

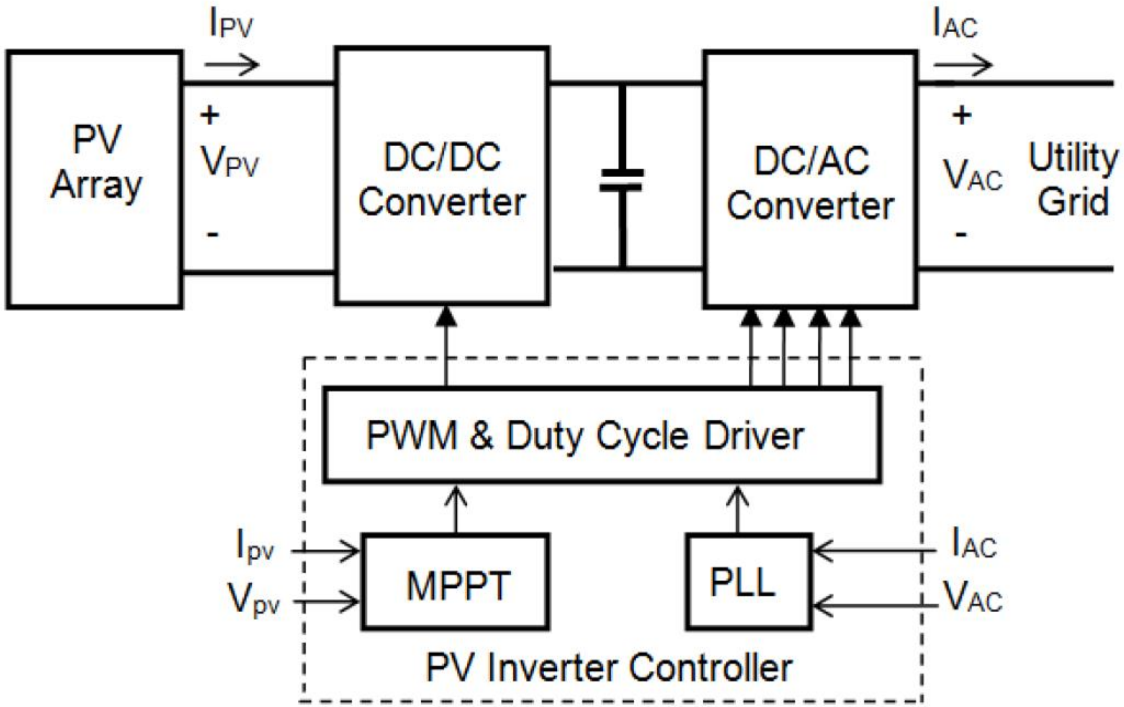
Components of the PV Power Plants-Micro-inverters



- An alternative approach is based on each PV module having its own small inverter (i.e., micro-inverter) mounted directly onto the backside of the panel.
- These ac modules allow simple expansion of the system, one module at a time, as the needs or budget dictate.

PHOTOVOLTAIC POWER PLANTS

Components of the PV Power Plants-Today's Grid-Tied PV Inverters

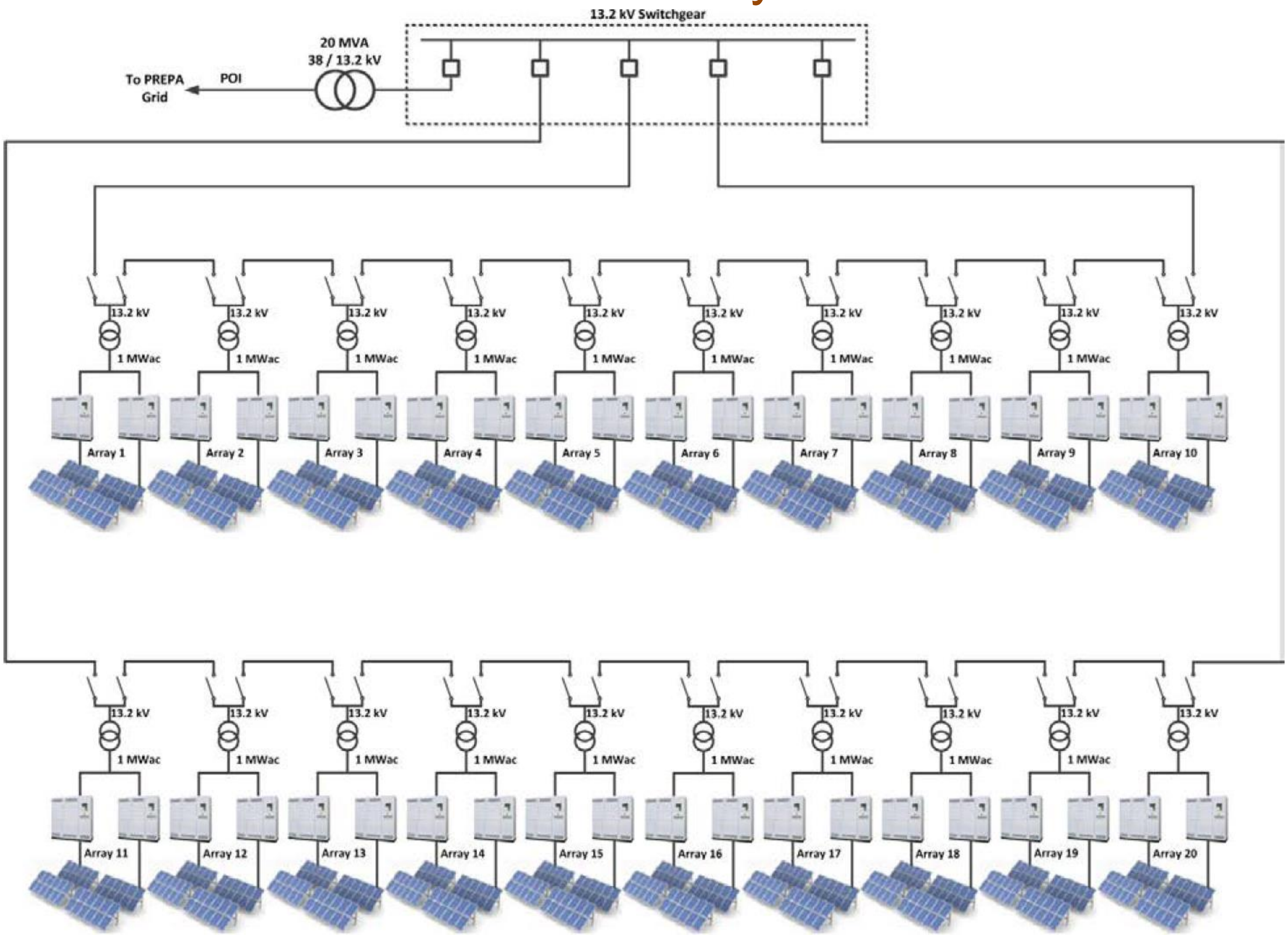


Today's inverters are already smart as they

- monitor the PV array, track the maximum power and operate at that point,
- sense the presence of the grid, synchronize to and inject a current in phase with the voltage,
- monitor the grid and disconnect in case of trouble (e.g., swings in voltage or frequency).

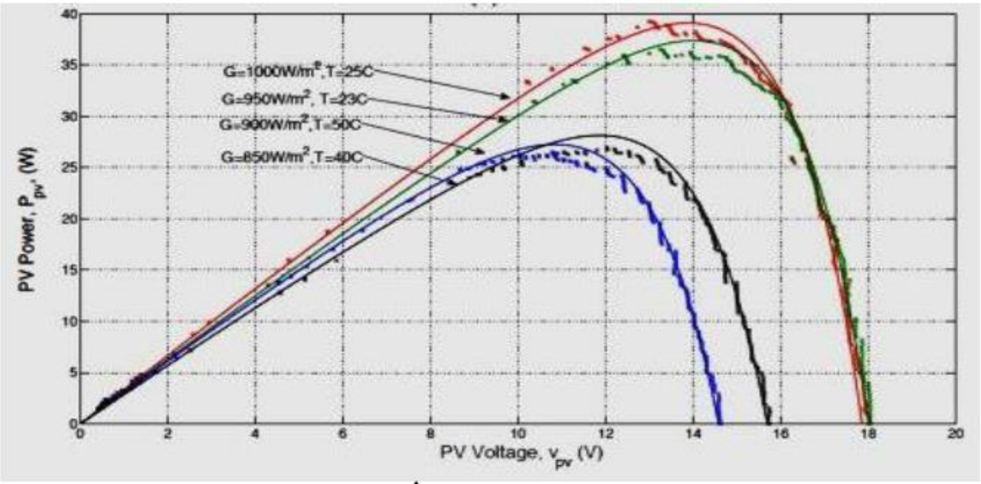
PHOTOVOLTAIC POWER PLANTS & INVERTERS

Components of PV Power Plants-Today's Grid-Tied PV Inverters



PHOTOVOLTAIC POWER PLANTS & INVERTERS

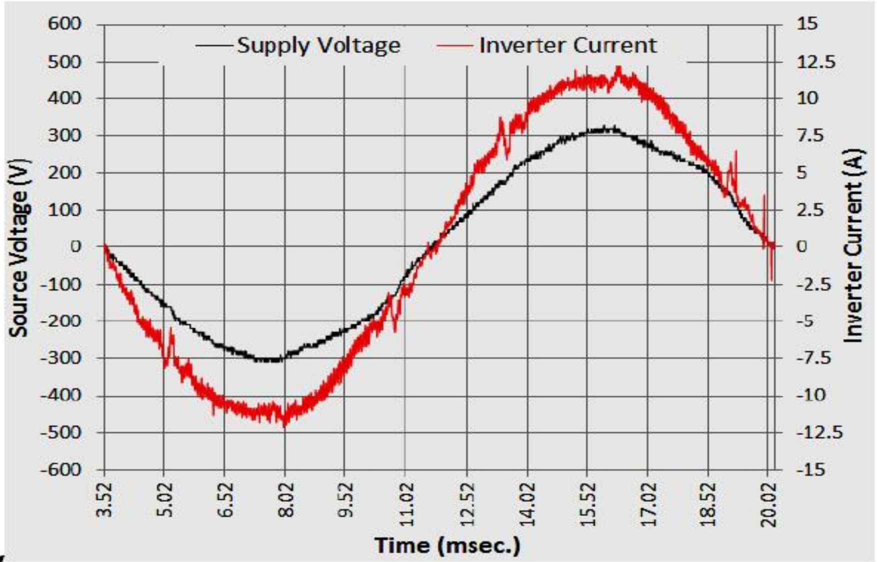
Components of PV Power Plants - Today's Grid-Tied PV Inverters

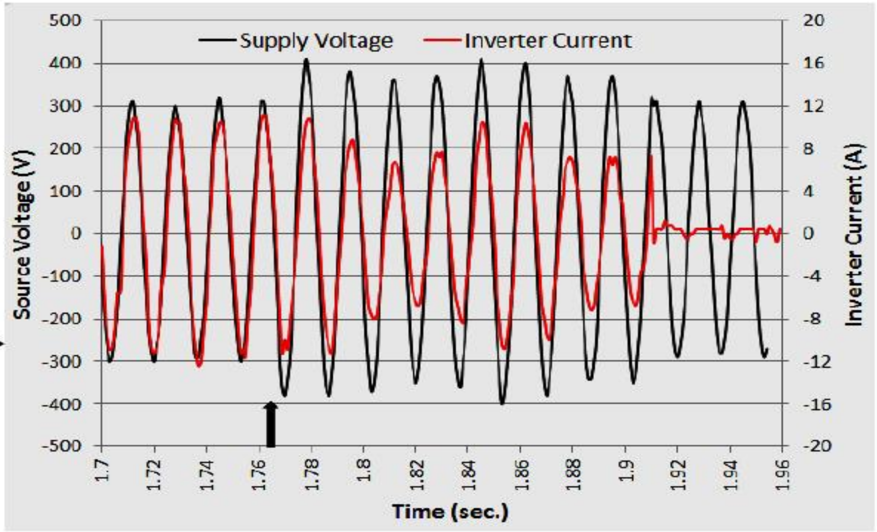


Maximum Power Tracking

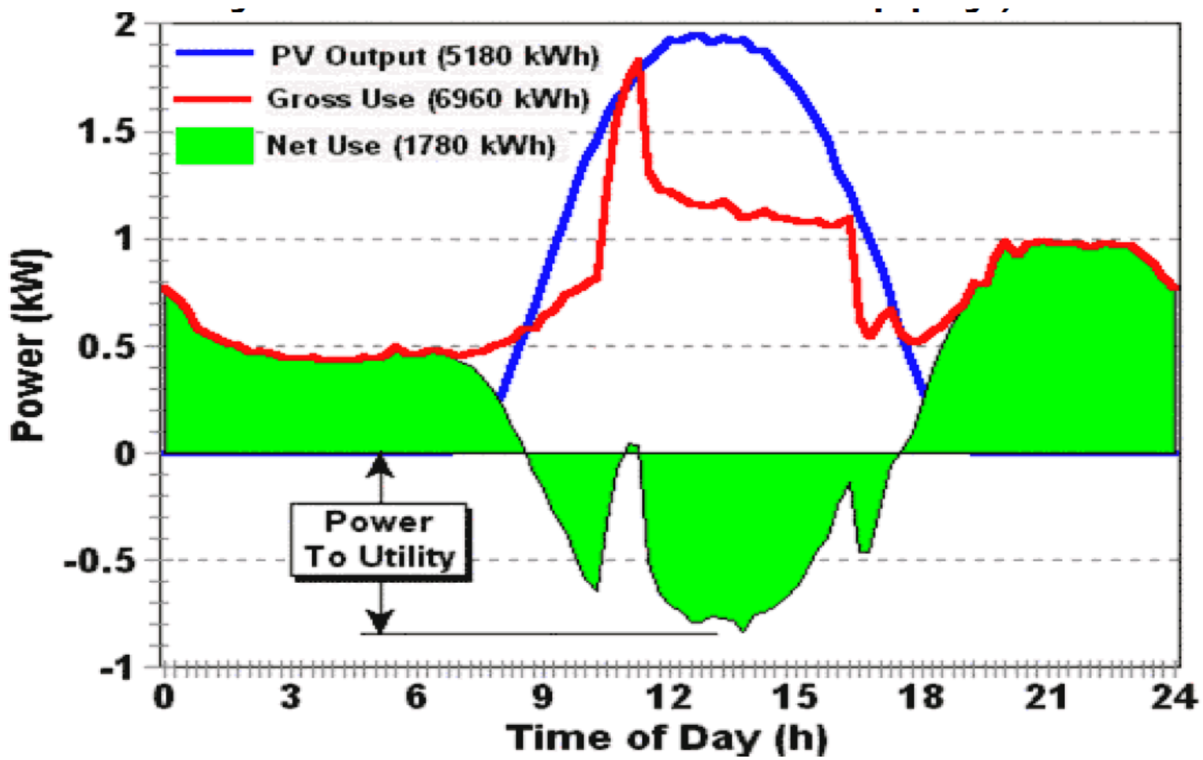
Grid synchronization

Grid Monitoring - Disconnect



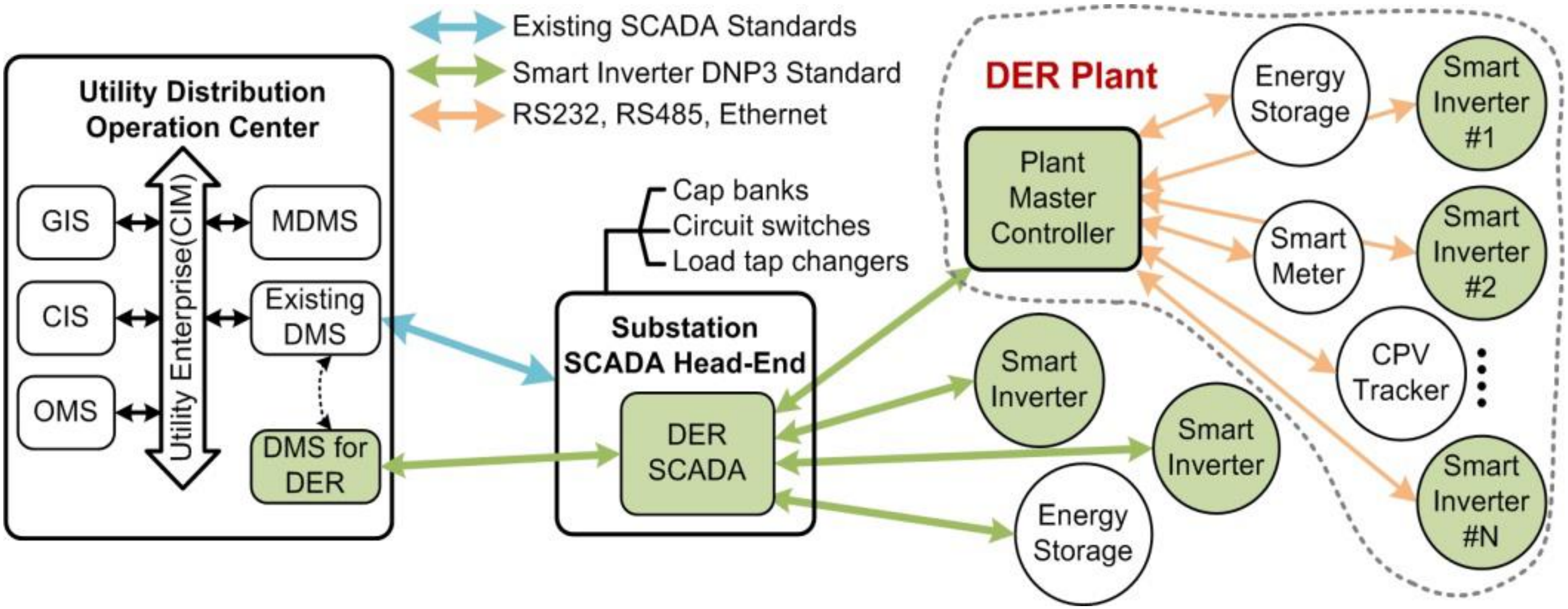


Components of PV Power Plants-Interfacing with the utility



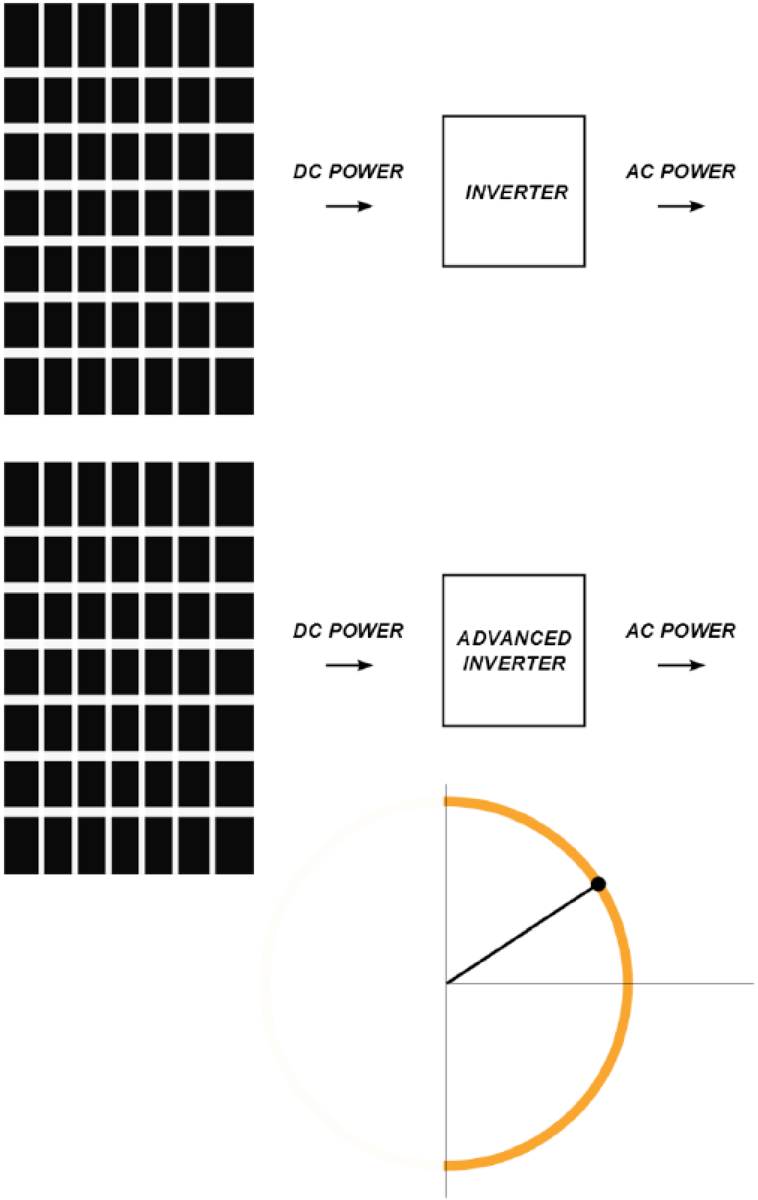
- Whenever the PV system delivers more power than the local demand, the electric meter runs backwards, building up a credit.
- When demand exceeds that supplied by the PV, the grid provides supplementary power. This arrangement is called *net metering* (the customer's monthly electric bill is only for that net amount of energy that the PV system is unable to supply).

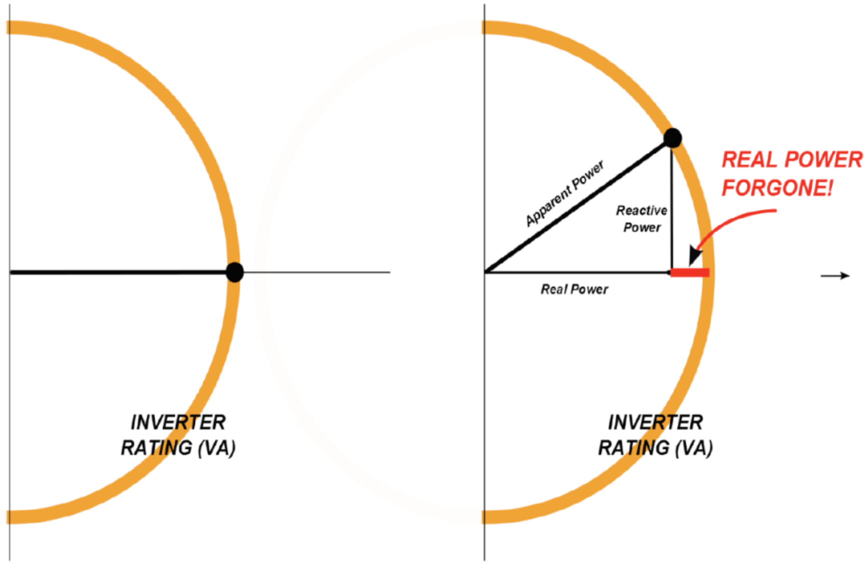
Components of PV Power Plants-Communications



PHOTOVOLTAIC POWER PLANTS & INVERTERS

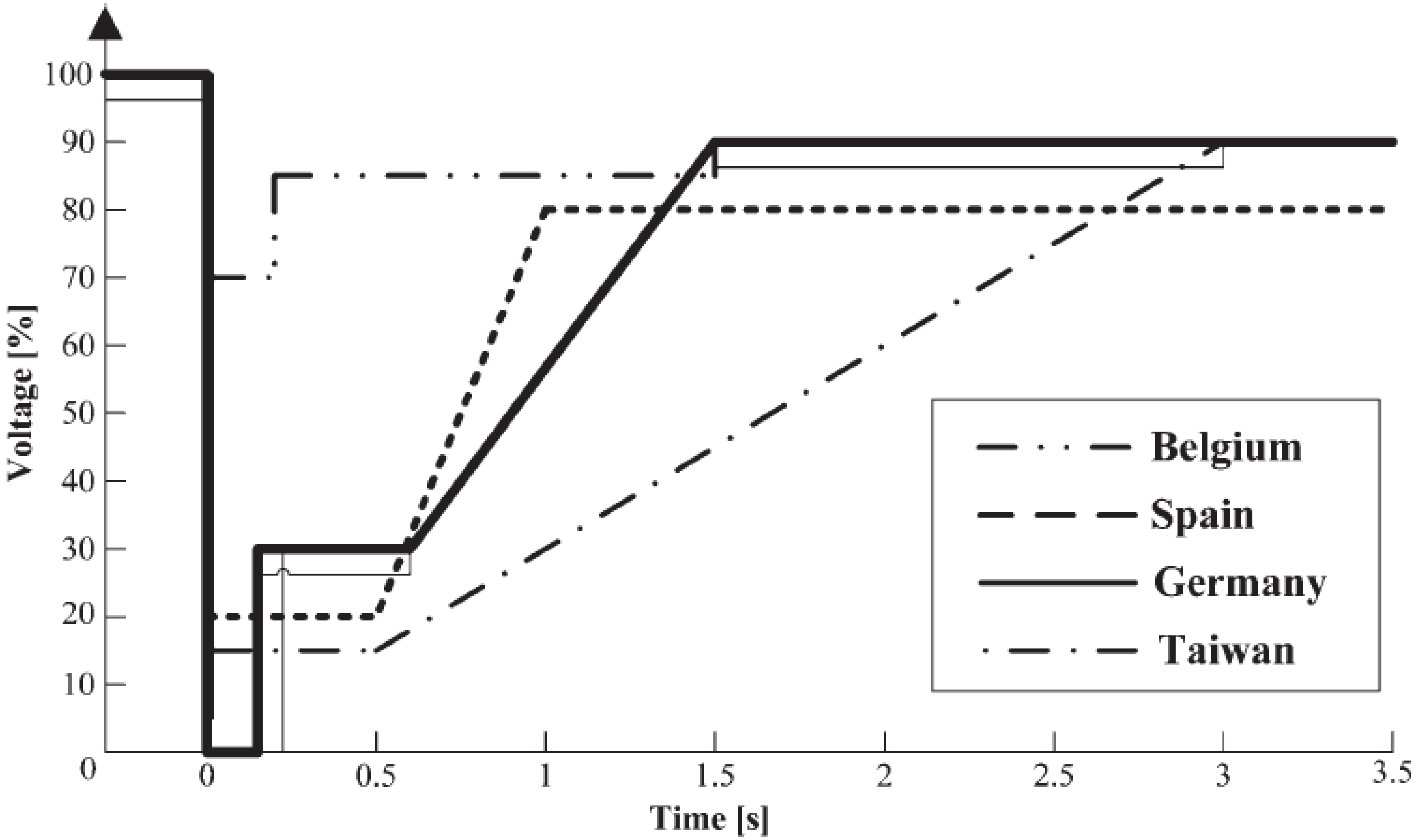
Components of PV Power Plants-Reactive power requirement



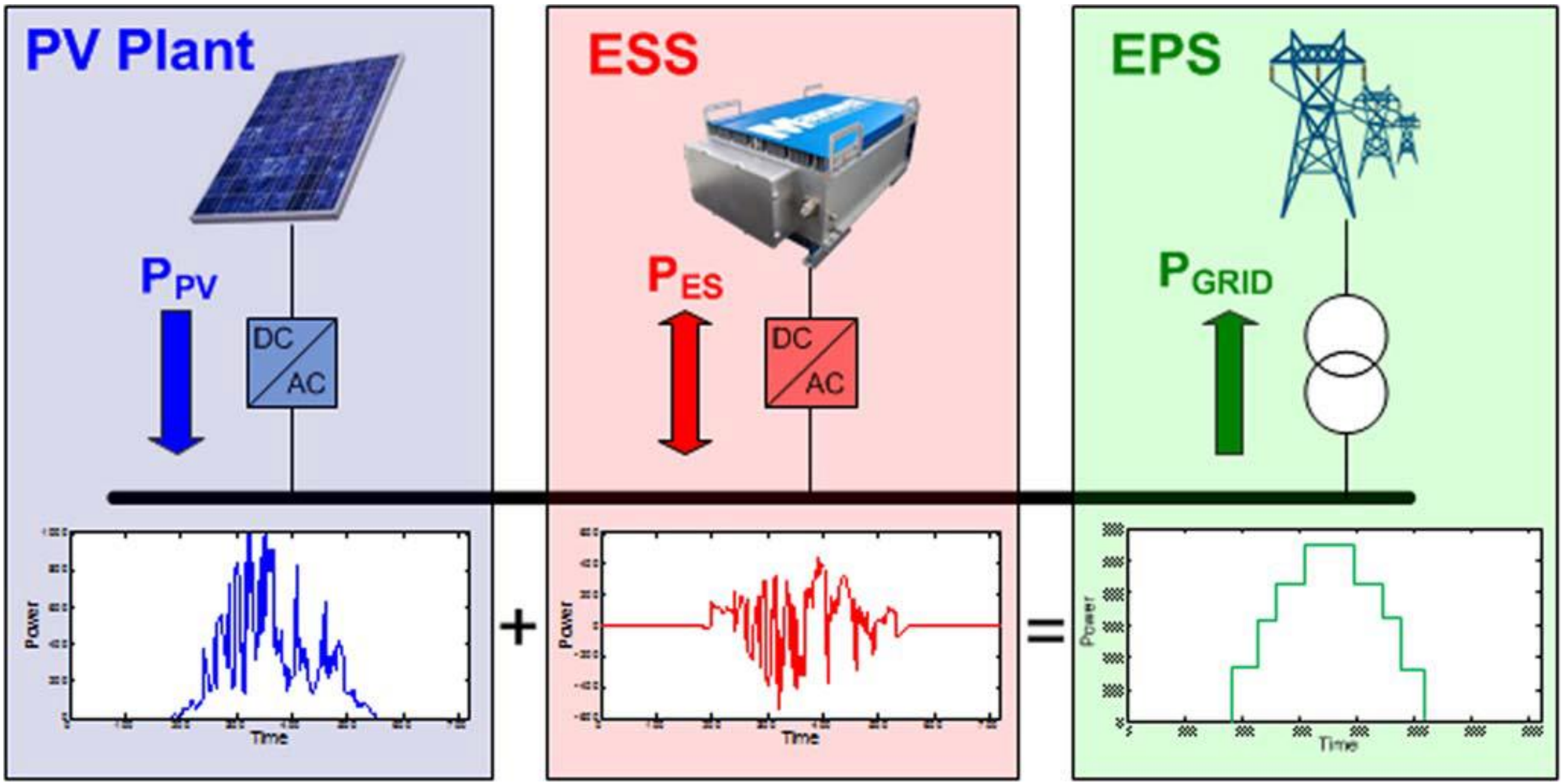


PHOTOVOLTAIC POWER PLANTS & INVERTERS

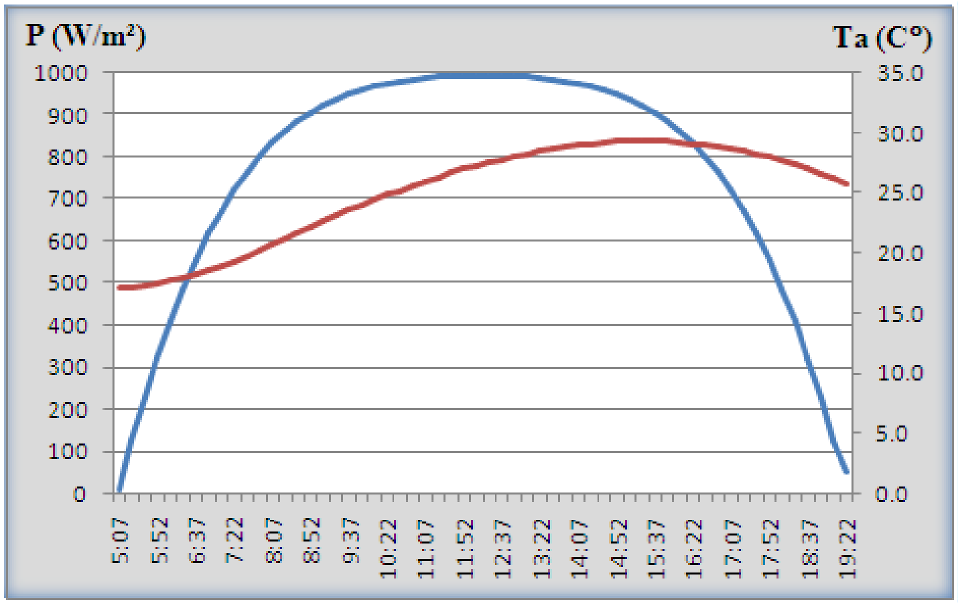
Low Voltage Ride Through Time of Different National Codes

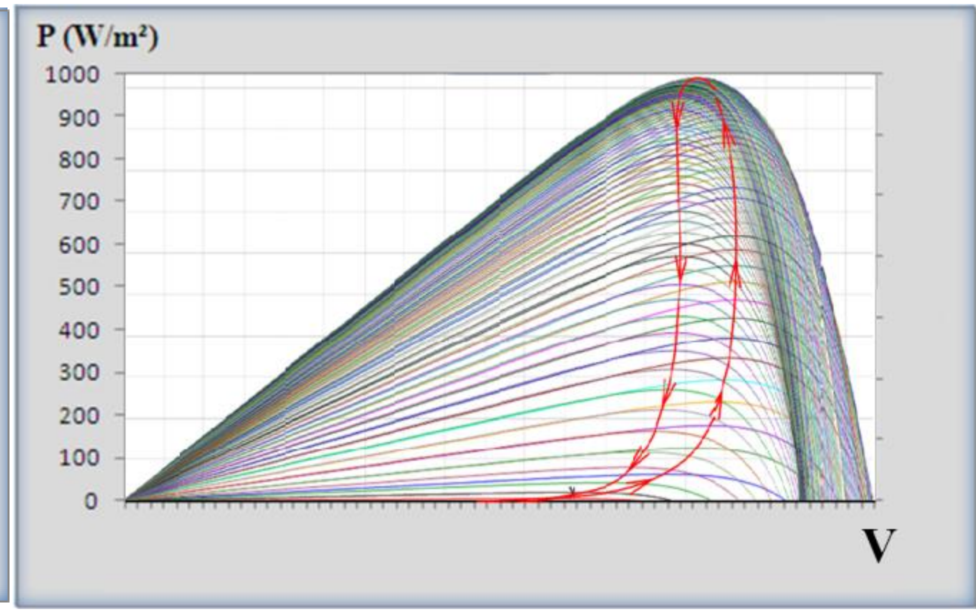


Components of PV Power Plants-Energy Storage



PV maximum power curves.



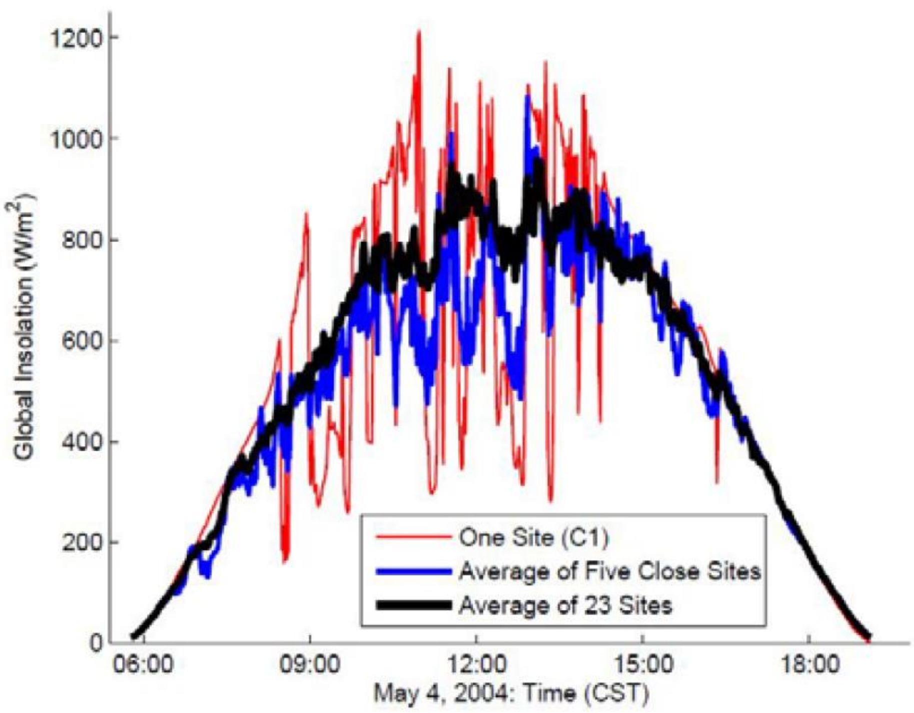


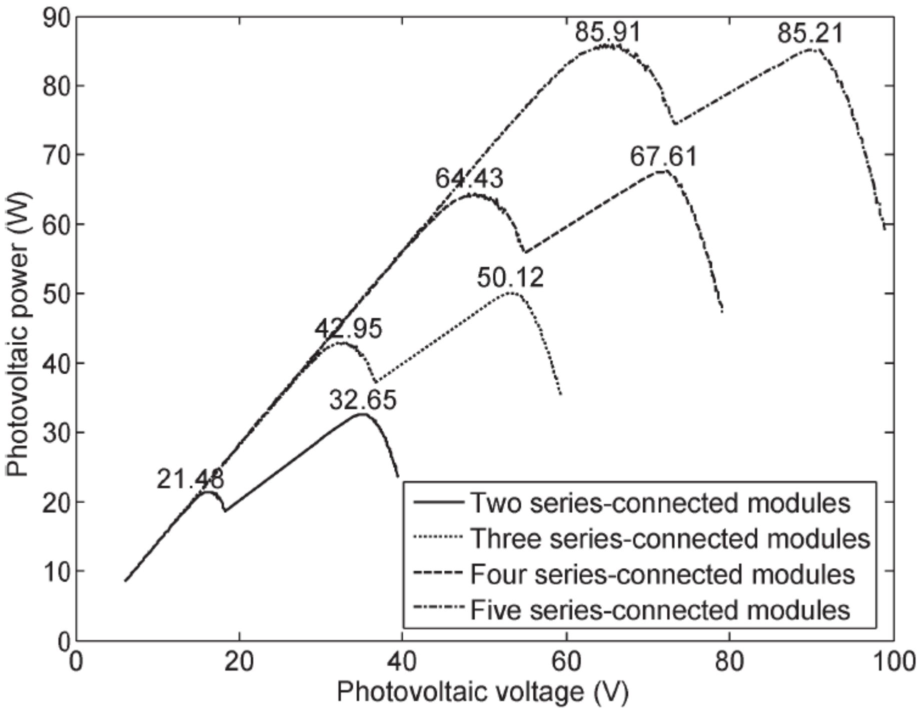
a) Daily irradiation level and temperature

b) Daily MPPT curve*

* Red line (MP traction line) shows clearly sky condition. It changes cloudy sky, temprature, PV pullation etc.

PV maximum power curves.

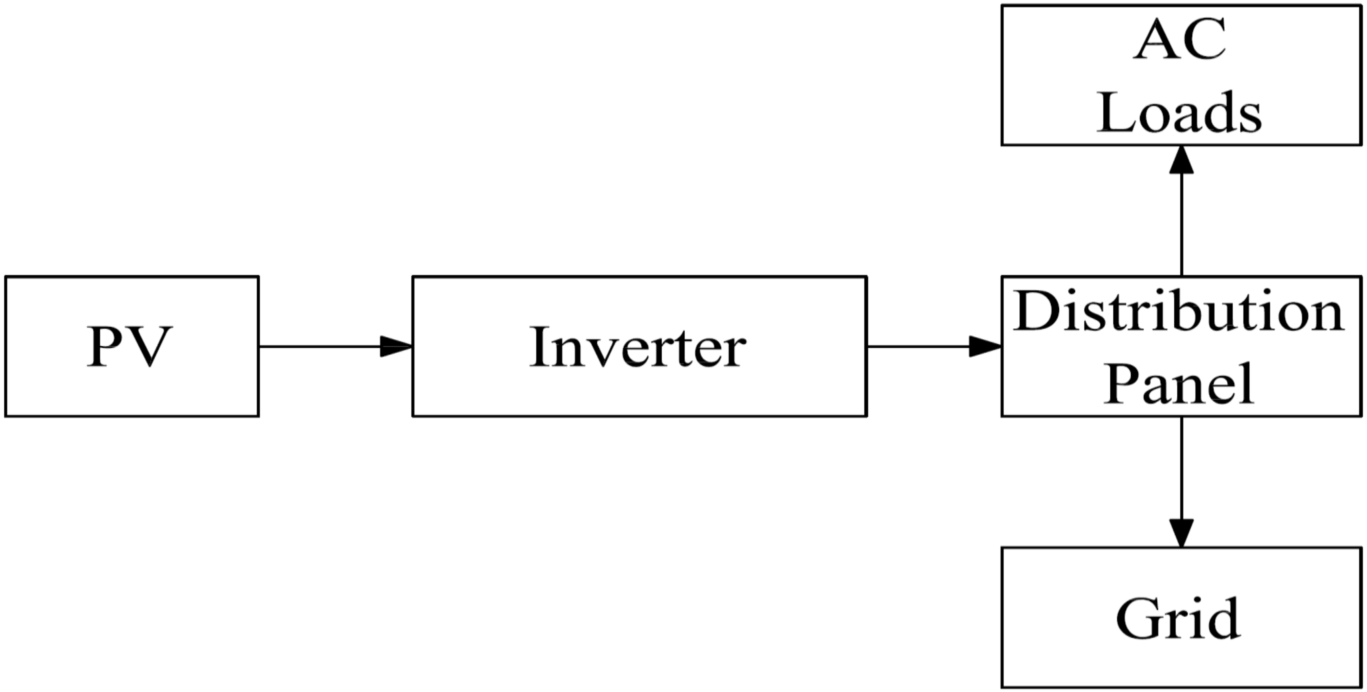




MPPT

- MPPT control methods can be grouped in two categories as off-line and on-line methods. This classification whether it is based on actual MPPT or not .
  - On-line methods obtain real MPPT independent from environmental and PV system conditions. Although response speeds of these on-line methods are variable depending on their structures and control methods, they are slower than the off-line methods.
  - Off-line methods, the output power of PV system is not read and calculated. MPPT process is obtained by using PV values (Isc, Voc, temperature and irradiation). Although off-line methods are simple, low cost and useful, switching off loads to determine the MPP is a problem.

Grid Interactive Inverter



Structure of grid interactive system.

- The grid interactive inverter consists of a PV power supply, a power conditioning unit, distribution panels and a inverter stage.

Basic Specifications of an Inverter

Typical specifications required for a grid of interactive inverter is determined as follows;

- The current injected to the grid must be in sinusoidal waveform and its harmonics have to be within the limits specified in the regulations.
- The power factor of the grid interactive inverter must be unity.

Basic Specifications of an Inverter

Typical specifications required for a grid of interactive inverter is determined as follows (continue);

- The radio interference due to the high-frequency switching of power components in the inverter must be under control.
- The grid interactive inverter has to be separated from the grid when the grid fails.
- In order to keep the highest RES efficiency, the withdrawal of maximum power must always be provided.

International Standards on Grid Inverters

- There are some rules and constraints about the rectifying AC voltage generated by RES, inverting DC voltage, exporting energy to the grid.
- A typical grid interactive inverter injects a sinusoidal current to the line, and must meet the international standards like IEC61727, IEEE1547 and EN61000-3-2, and radio frequency interference due to high frequency switching should be under control.

PHOTOVOLTAIC POWER PLANTS & INVERTERS

Summary of the most interesting standards dealing with grid interactive systems

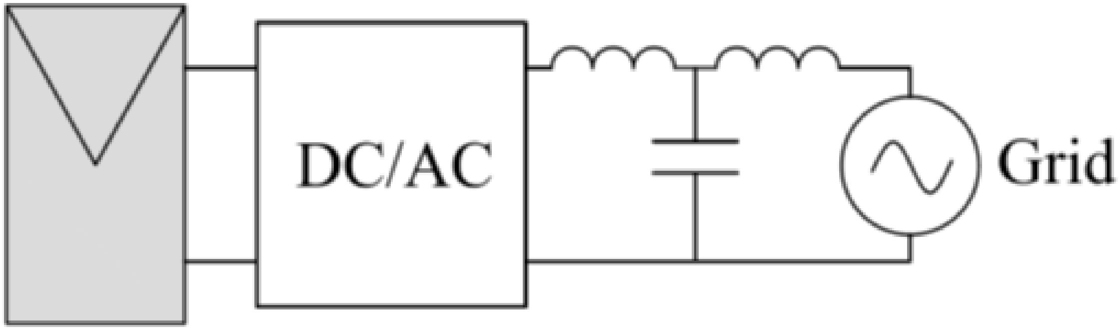
Subject	IEC61727	IEEE1547	EN61000-3-2
Rated Power	10 kW	30 kW	16A X 230V = 3,7 kW
Indivudial Harmonic Limits	(3-9) %4,0	(2-10) %4.0	(3) 2,30 A
	(11-15) %2,0	(11-16) %2,0	(5) 1,14 A
	(17-21) %1,5	(17-22) %1,5	(7) 0,77 A
	(23-33) %0,6	(23-34) %0,6	(9) 0,40 A
		(>35) %0,3	(11) 0,33 A
			(13) 0,21 A
			(15-39) 2,25/h
	Even harmonics should be %25 less then Odd harmonics in this range		Approximately Equal or less then %30 of Odd harmonics
Maximum Total Harmonic Distortion	5.00%	5.00%	-
Power Factor at %50 Rated Power	0,9	-	-
DA Current Injection	Less then %1 of rated current	Less then % 0.5 of rated current	<0.22A - 50W Suitable for half wave rectifier
Nominal Working Voltage Range	%85 - %110	%88 - %110	-
	(196V - 253V)	(97V - 121V)	
Nominal Working Frequency Range	50±1 Hz	59.3 Hz – 60.5 Hz	-

IEEE 929 Utility disconnect requirements

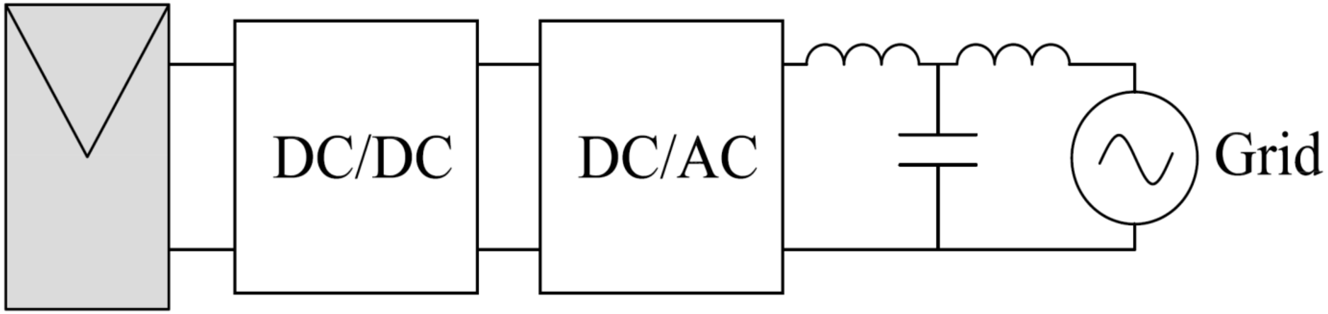
Voltage and Frequency Limits for Grid Interactive Condition			
State	Voltage	Frequency	**Max. Off Time**
A	0.5 ≤ Vnom	fnom	**6 cycle**
B	0.5 Vnom<V<0.88 Vnom	fnom	**2 second**
C	0.88 Vnom- V 1.10 Vnom	fnom	**-**
D	1.10 Vnom<V<1.37 Vnom	fnom	**2 second**
E	1.37 Vnom V	fnom	**2 second**
F	Vnom	f<fnom-0.7 Hz	**6 cycle**
G	**Vnom**	**f >fnom+0.5 Hz**	**6 cycle**

Types of Grid Interactive Inverter

- There can be one or two or more power processing stages in the grid interactive inverters. Single-stage inverter carries out all tasks such as MPPT, grid current control and, if necessary, like voltage step up.



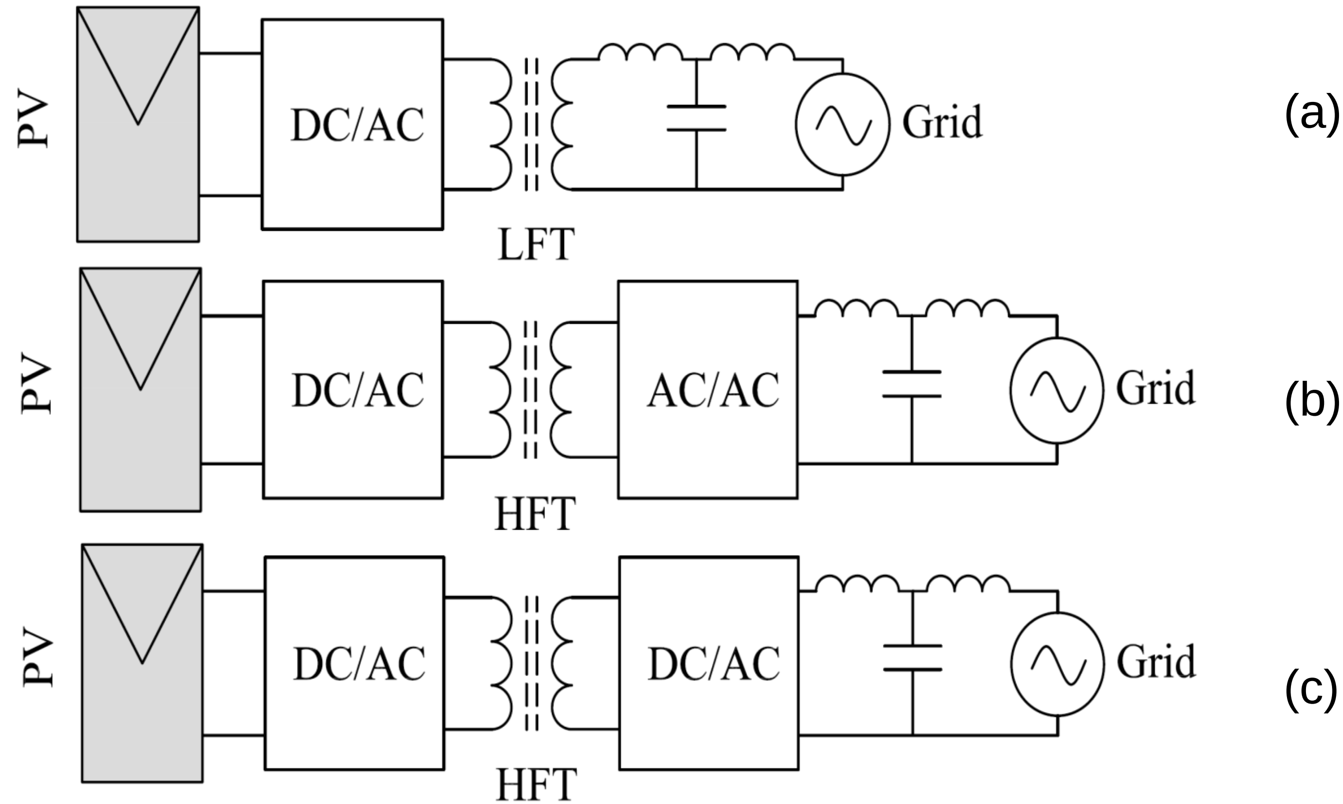
Single stage power processing



Two stage power processing

Types of Grid Interactive Inverter

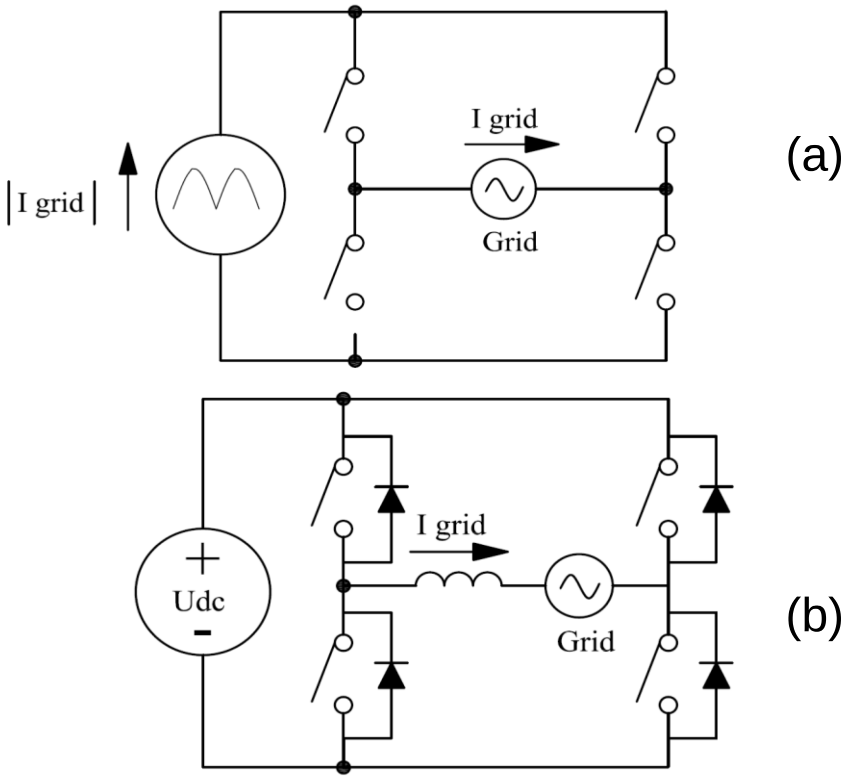
- Transformer-included inverter examples.



a) Line frequency transformer is connected between the line and the inverter.
b) High-frequency transformer is embedded in an HF-link inverter.
c) High-frequency transformer is embedded in DC-DC converter.

Types of Grid Interactive Inverter

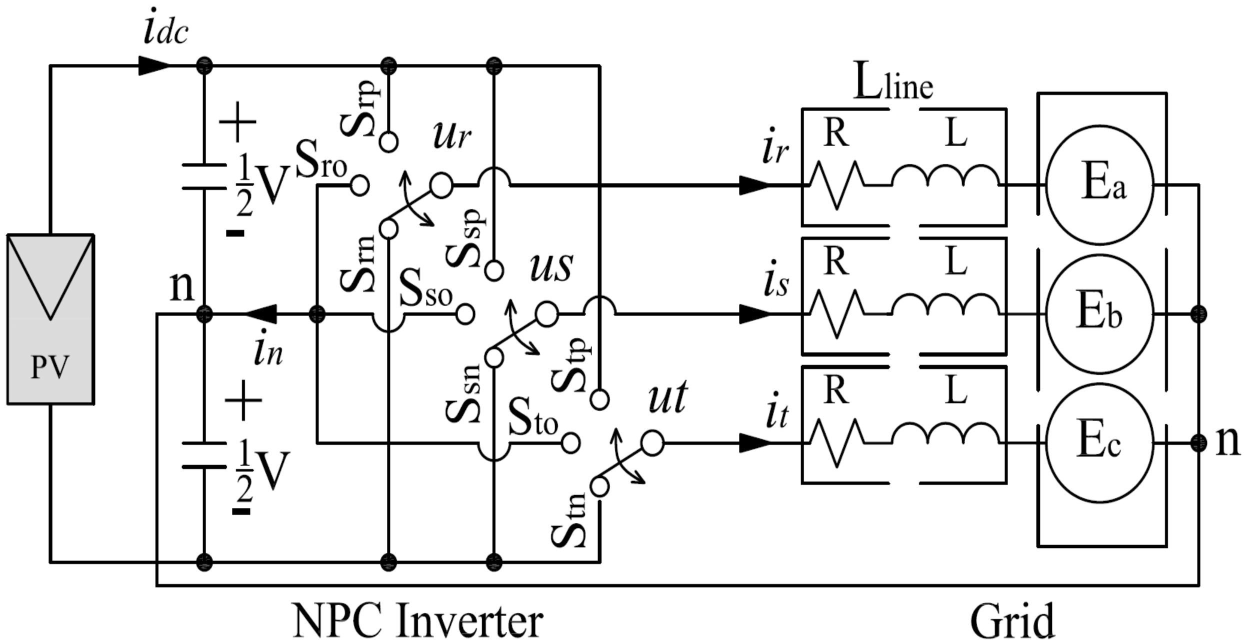
- Current and voltage fed grid interactive inverters.



a) Current fed grid commutated inverter switching at twice the grid frequency.
b) Voltage fed, self commutated inverter at high frequency.

Types of Grid Interactive Inverter

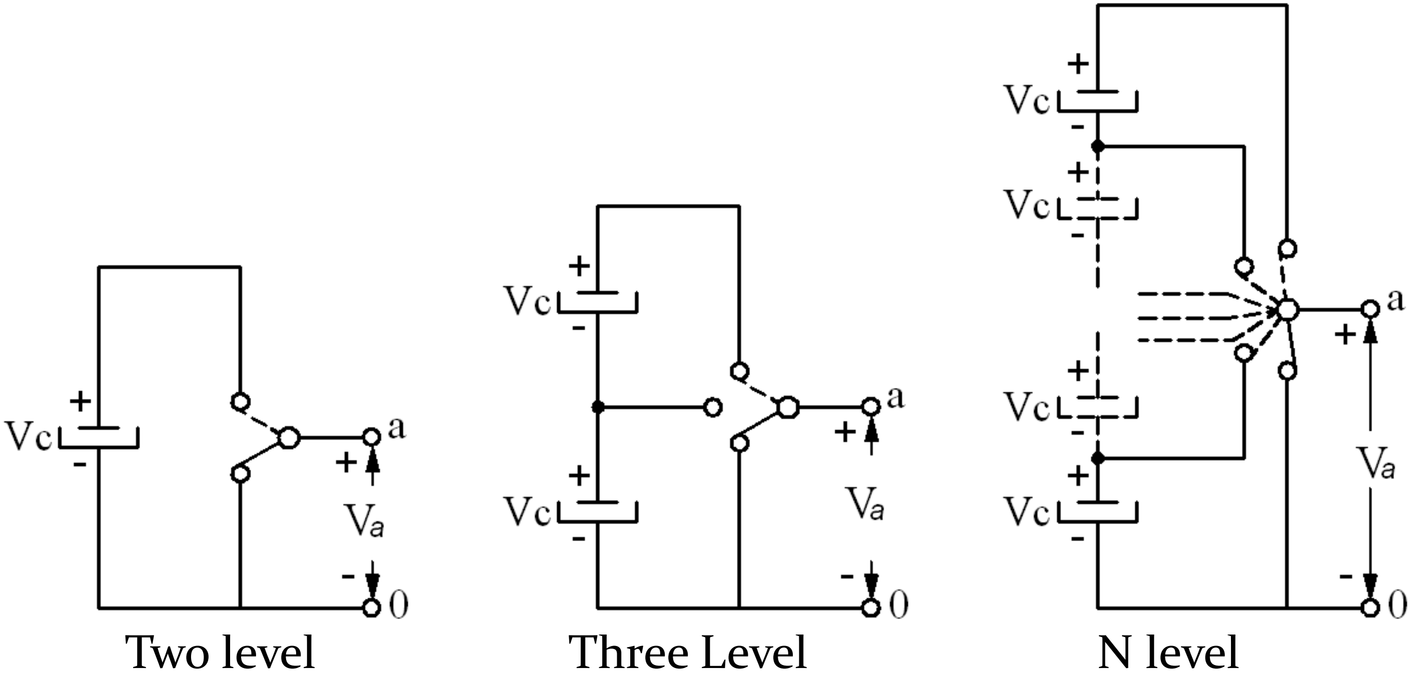
- Multilevel grid interactive inverter.



Three Level NPC Grid interactive inverter.

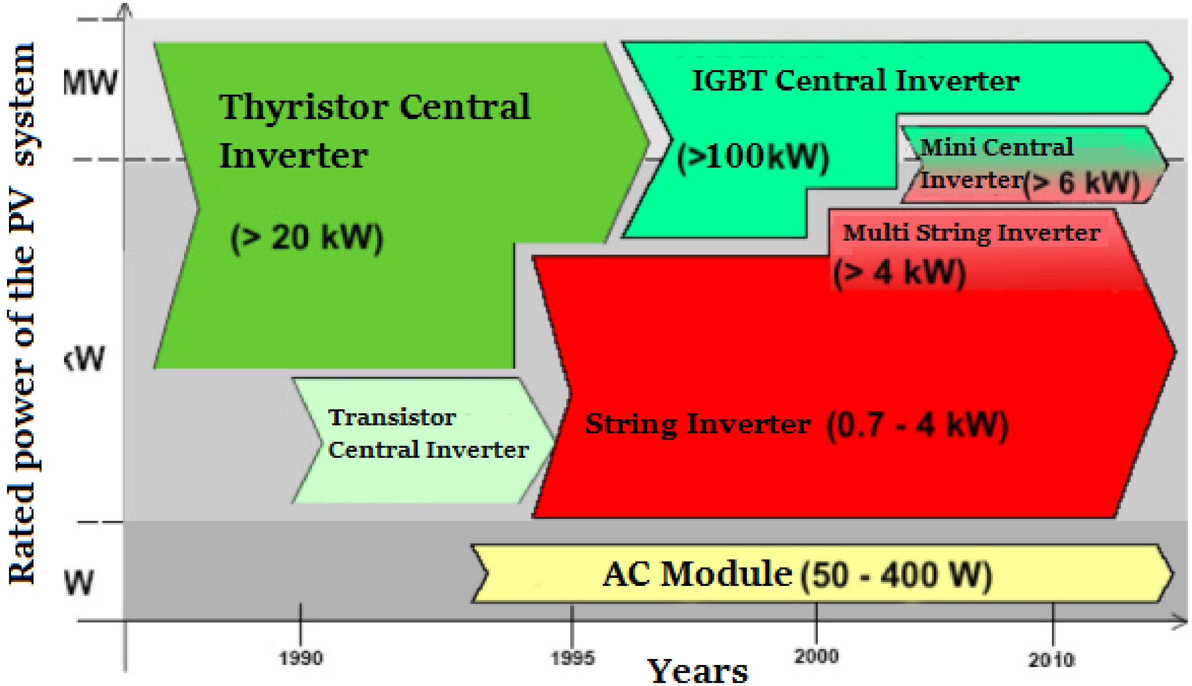
Types of Grid Interactive Inverter

- These topologies synthesize voltage waveform with a number of semiconductor devices connected in a special arrangement, rated at a fraction of the dc bus voltage.



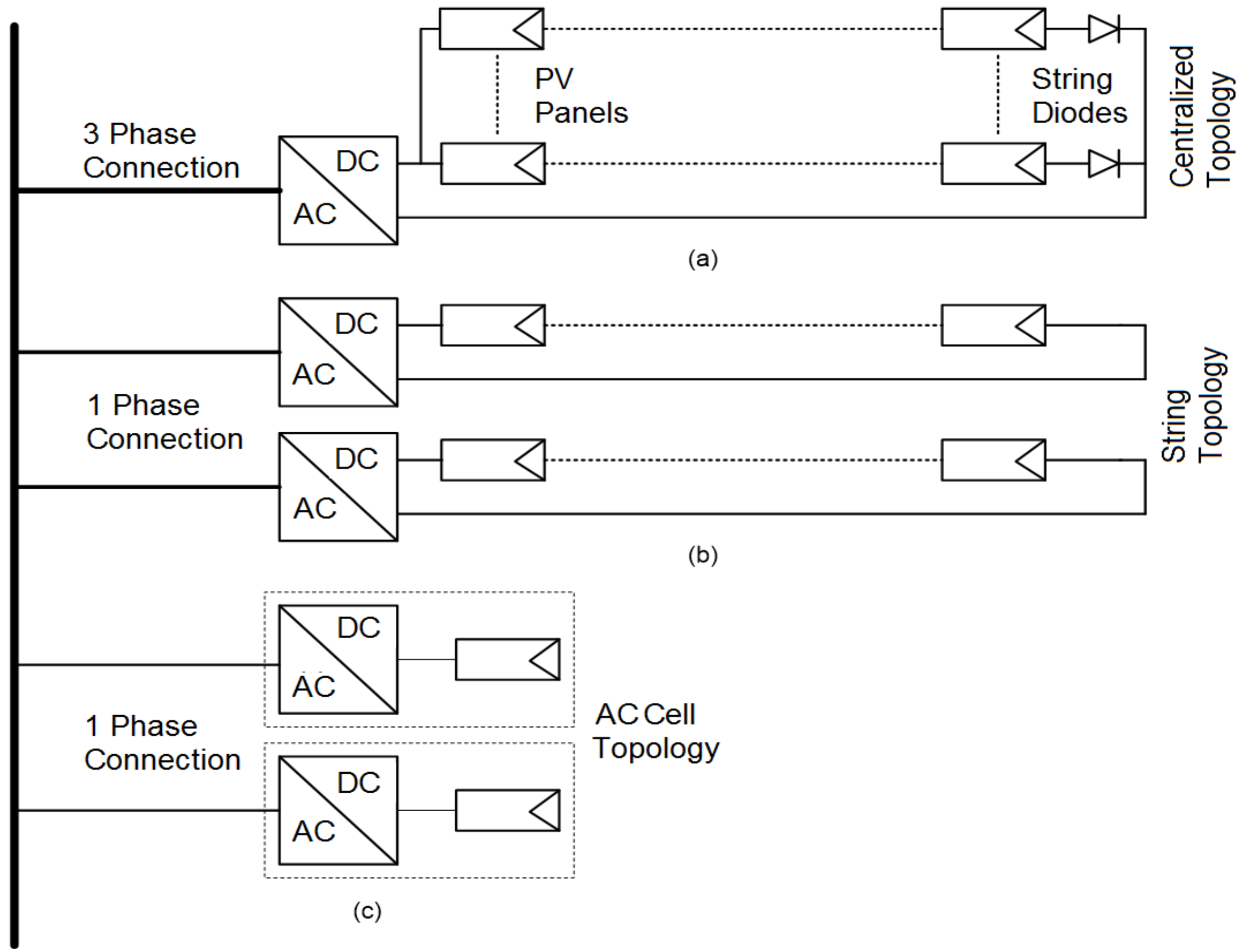
Description of Multilevel Inverter

The Evolution of the Inverters



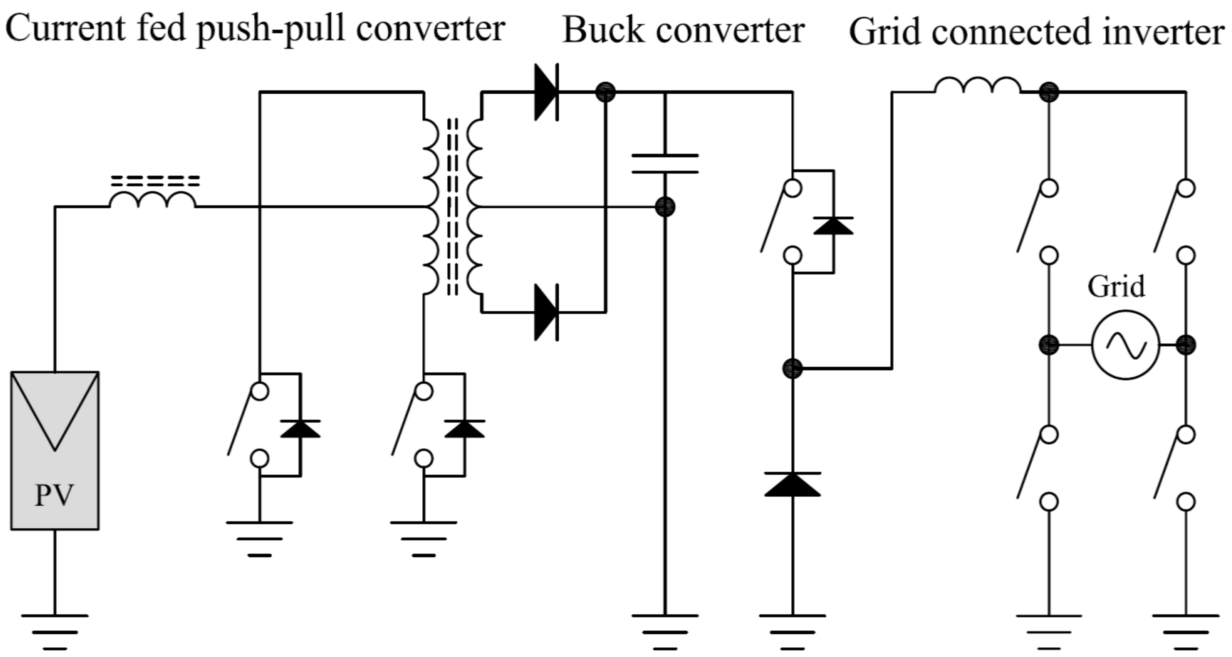
- Advances of the semiconductor power switching devices and the developed new high frequency low loss core materials give idea to the designers investigate of new topologies.
- High performance dedicated processors help to the designers for the realization of the digital control.
- Increasing demand of the grid interactive inverter also tends the manufacturers and researchers to find lower cost and higher efficiency products.

The Evolution of the Inverters



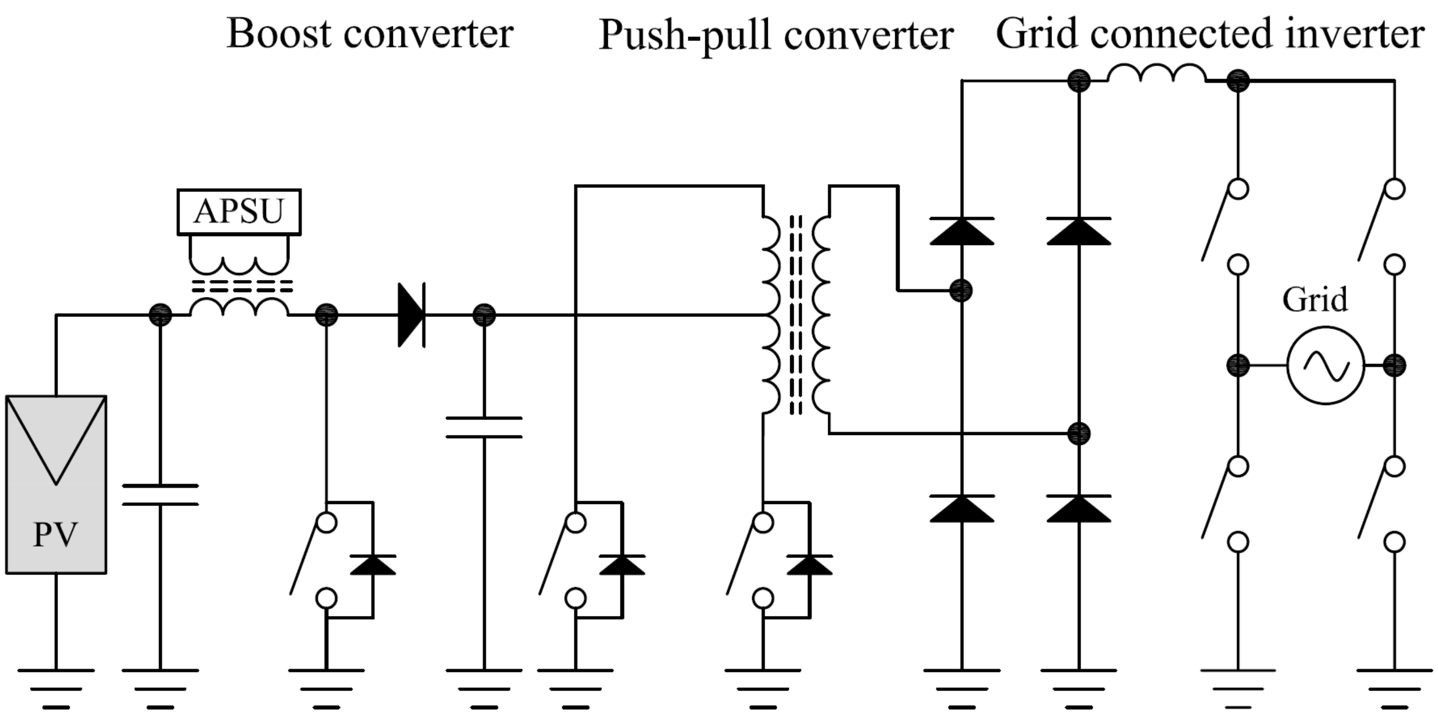
Historical overview of PV inverters (a) Past centralized (b) Present string (c) Present and future AC-module and AC cell technologies.

The Evolution of the Inverters



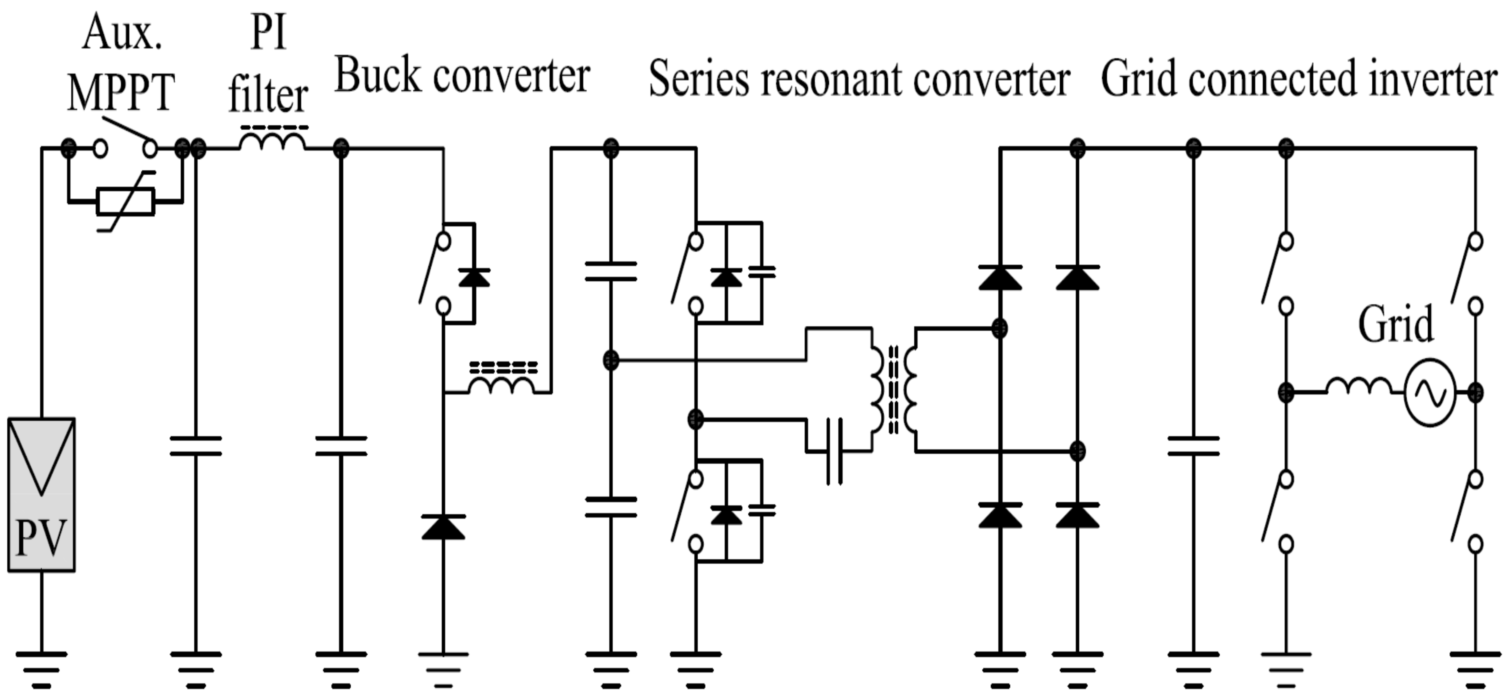
Different AC module topologies.

The Evolution of the Inverters



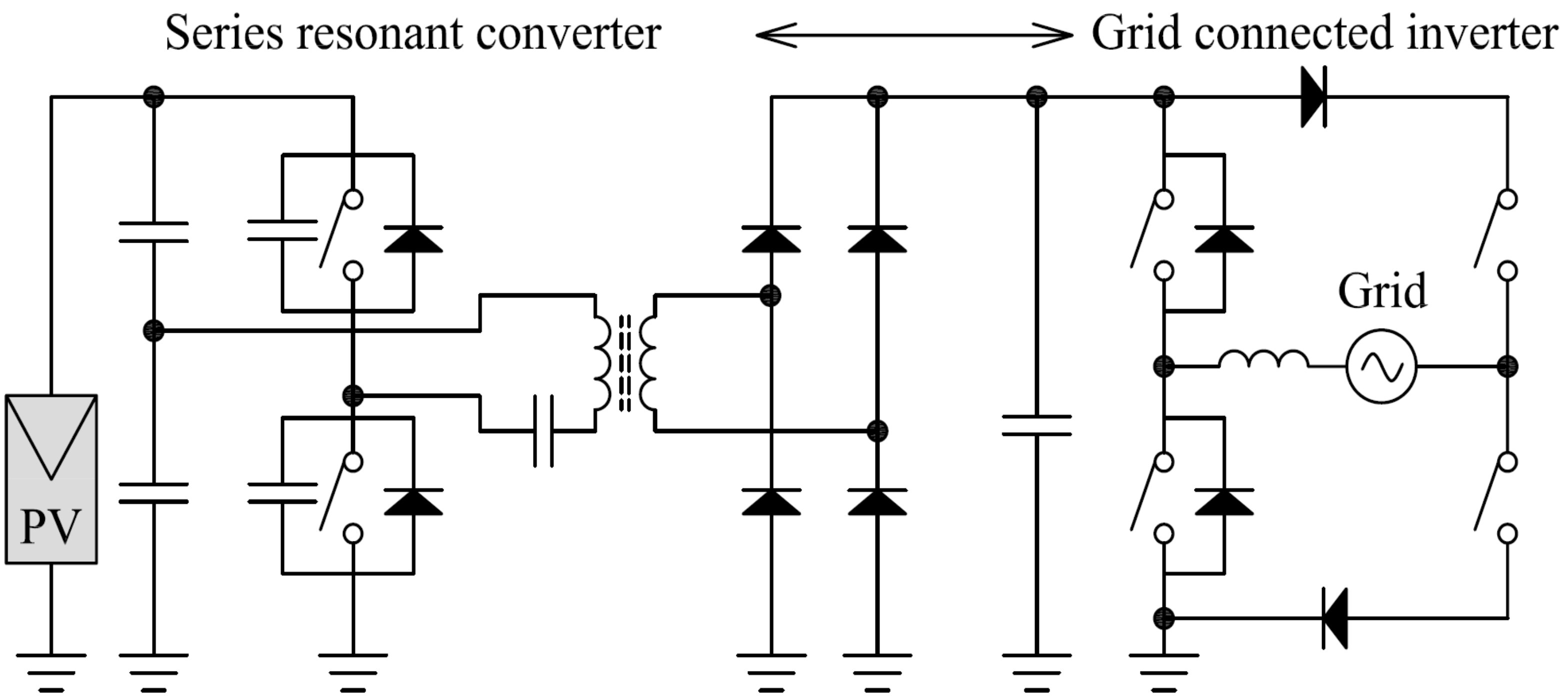
Different AC module topologies.

The Evolution of the Inverters



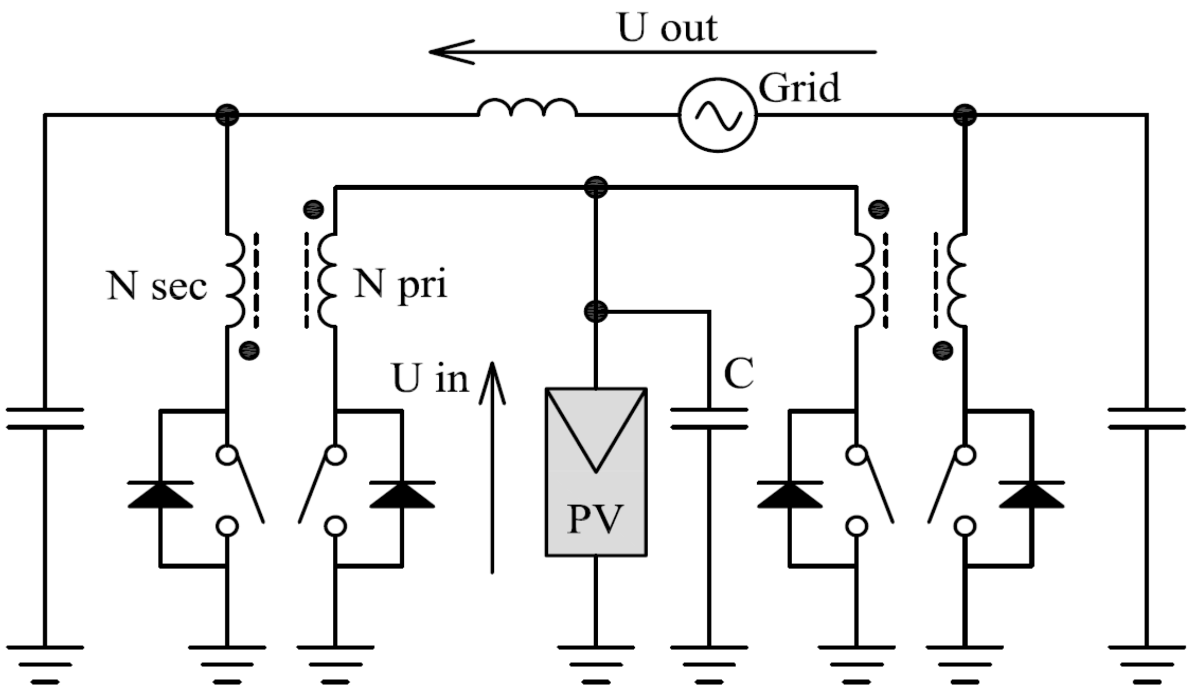
Different AC module topologies.

The Evolution of the Inverters



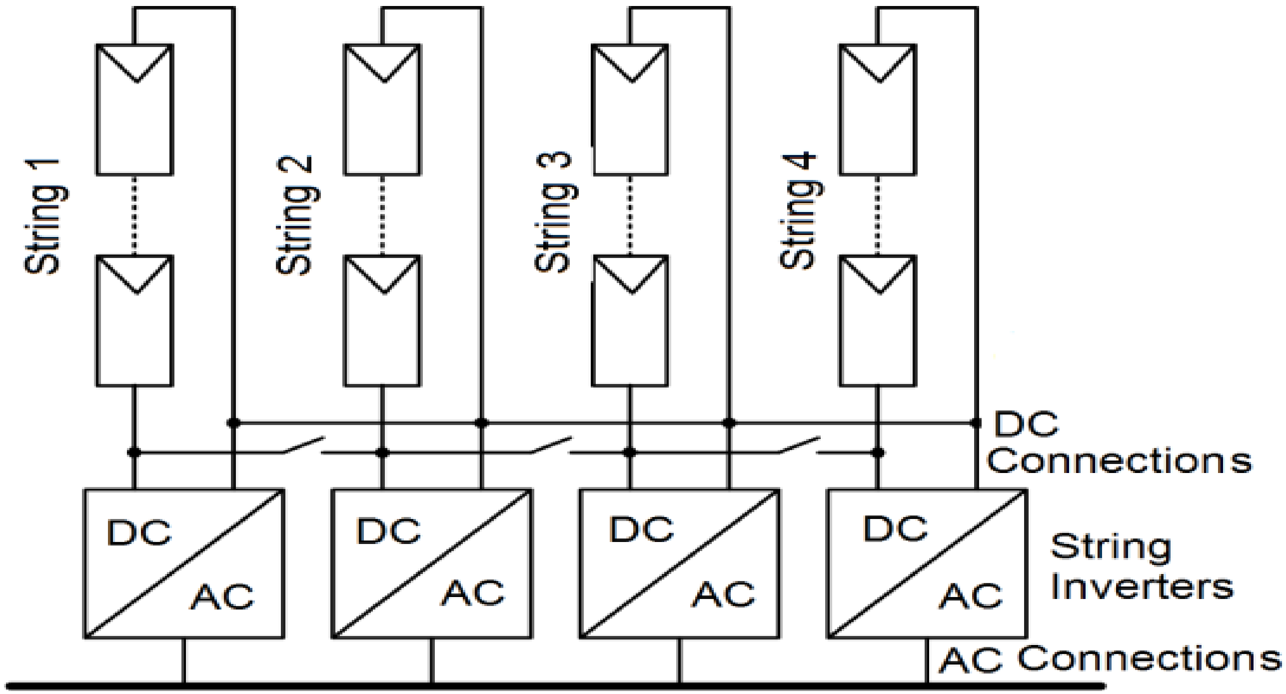
Different AC module topologies.

The Evolution of the Inverters



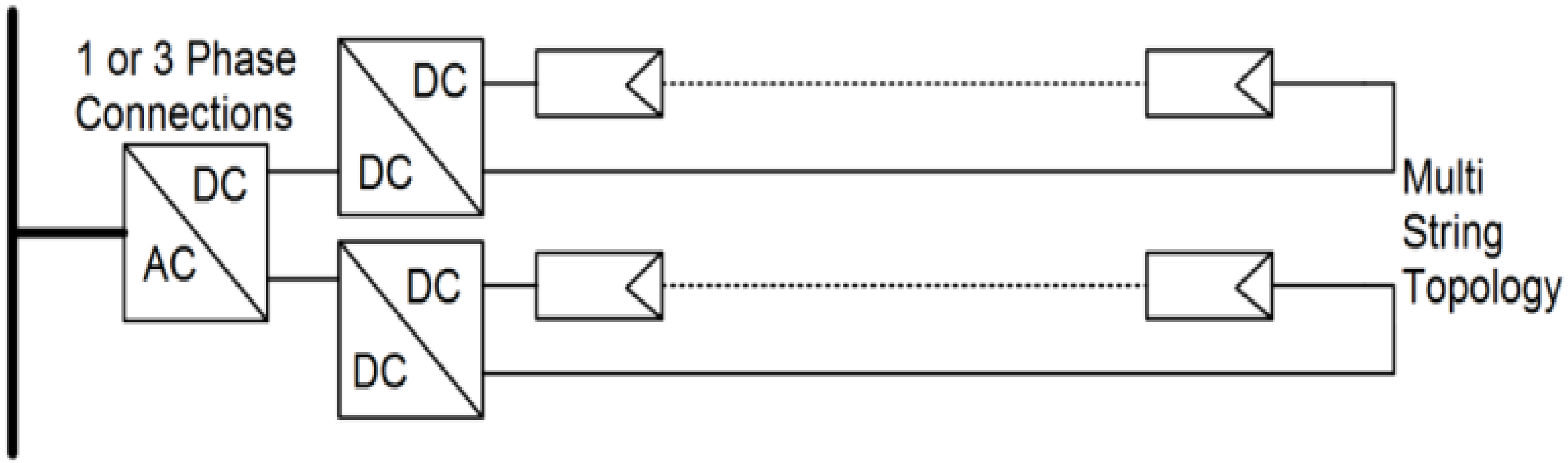
Different AC module topologies.

The Evolution of the Inverters



- Team concept is the notion of another PV system.
- Combining the string technology with the master-slave technology increases the system efficiency compared to the separately operated inverters in the PV systems which has multi inverters.

The Evolution of the Inverters



- The multi-string concept shown in figure is designed to combine the low cost feature of the central inverters with the high efficiency feature of the string inverters. In less-powerful DC-DC converters are connected to the PV strings individually.
- Each PV string has own MPPT which optimizes the power output by operating independently from the other strings.

Conclusion

- In this study, an extensive research on the grid interactive inverters used in PV applications has been presented.
- The operation modes of the grid interactive inverter and the basic features of the inverter required to be possess has been explained.
- Also the international standards on issues like the power quality, the detection of island mode and the grid impedance changes are noted.
- In addition, the historical development of the grid interactive inverters used in PV applications summarized and the future expectations are given.
- As a result, the research activities continue in order to develop the inverters which are low-cost, easy to install, long life and operable with high efficiency even though the input voltage and the power change in a wide range due to the natural conditions.

THANK YOU

QUESTIONS