Power Electronics – The Key Technology for Renewable Energy System Integration

Frede Blaabjerg

Professor, IEEE Fellow
fbl@et.aau.dk

Aalborg University
Department of Energy Technology
Aalborg, Denmark

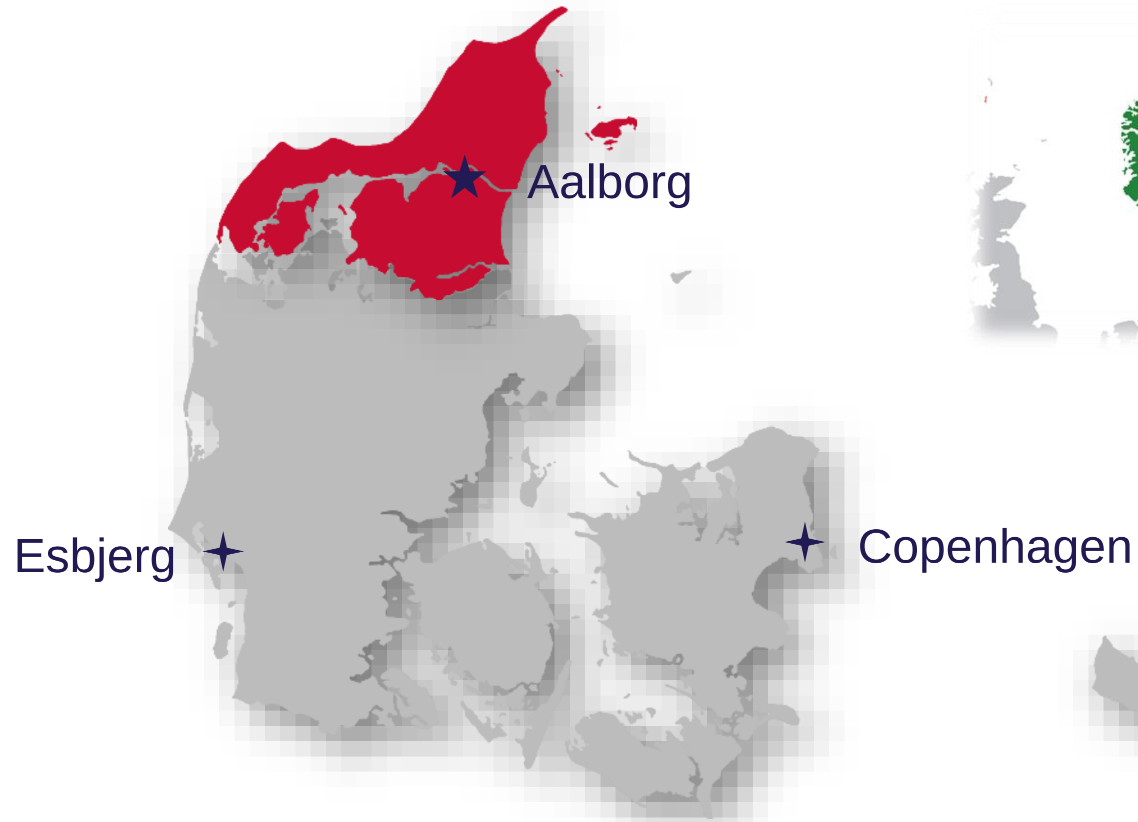
AALBORG UNIVERSITY
DENMARK

Outline

- **Overview of power electronics and renewable energy system**
  State-of-the-art; Technology overview, global impact
- **Demands for renewable energy systems**
  PV; Wind power; Cost of Energy; Reliability, Mission Profiles, Grid Codes
- **Power converters for renewables**
  PV inverters at different power; Wind power application; Power semiconductor devices
- **Control for renewable systems**
  PV application; Wind power application
- **Summary**

Aalborg University and Department of Energy Technology

Aalborg University



Inaugurated in 1974
22,000 students
2,300 faculty

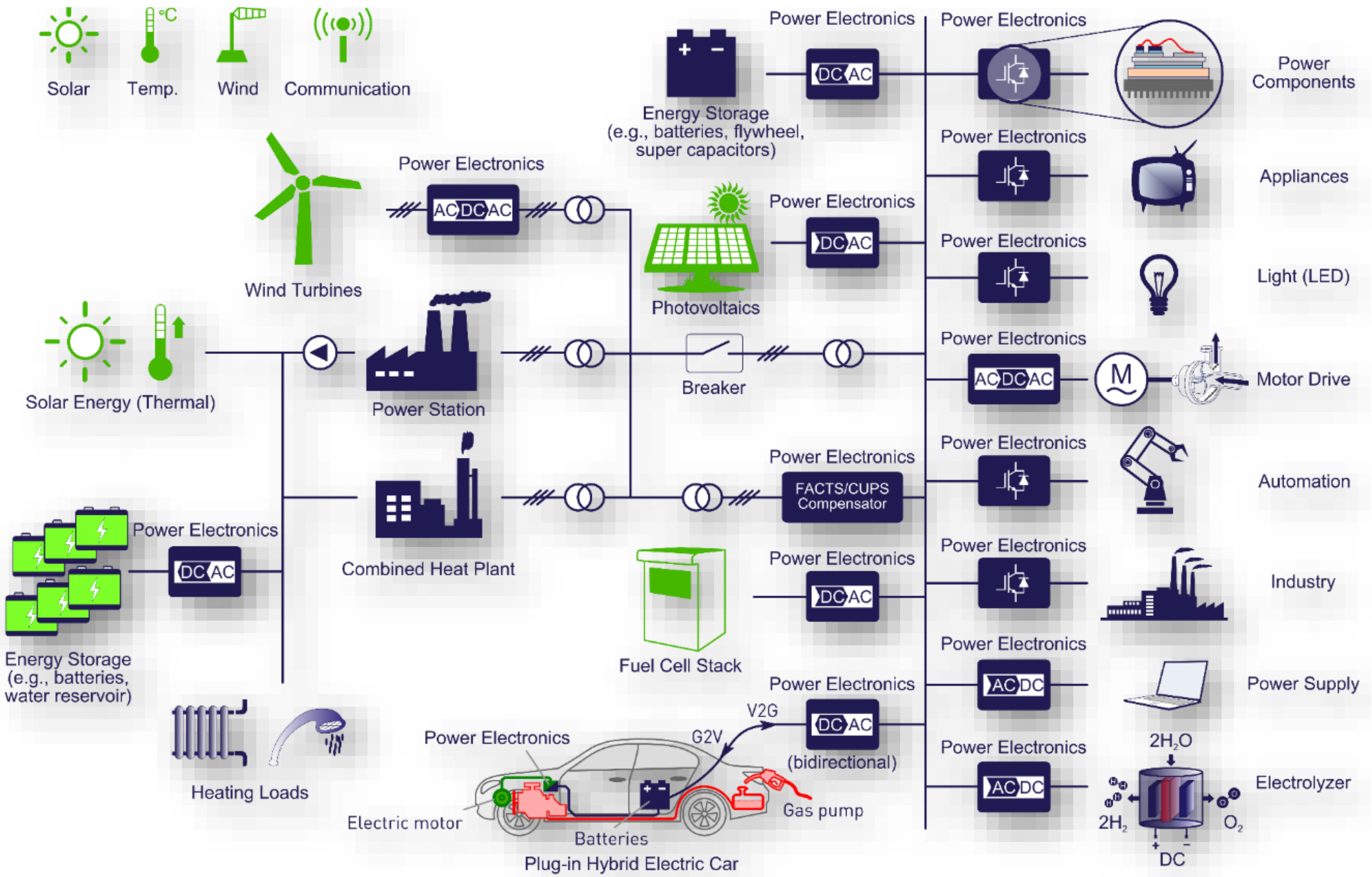
PBL-Aalborg Model
(Problem-based learning)

Adapted from Wikimedia Commons: https://commons.wikimedia.org/wiki/File:European_Union_(orthographic_projection).svg
https://upload.wikimedia.org/wikipedia/commons/c/c1/Denmark_regions.svg

Where Are We Located?

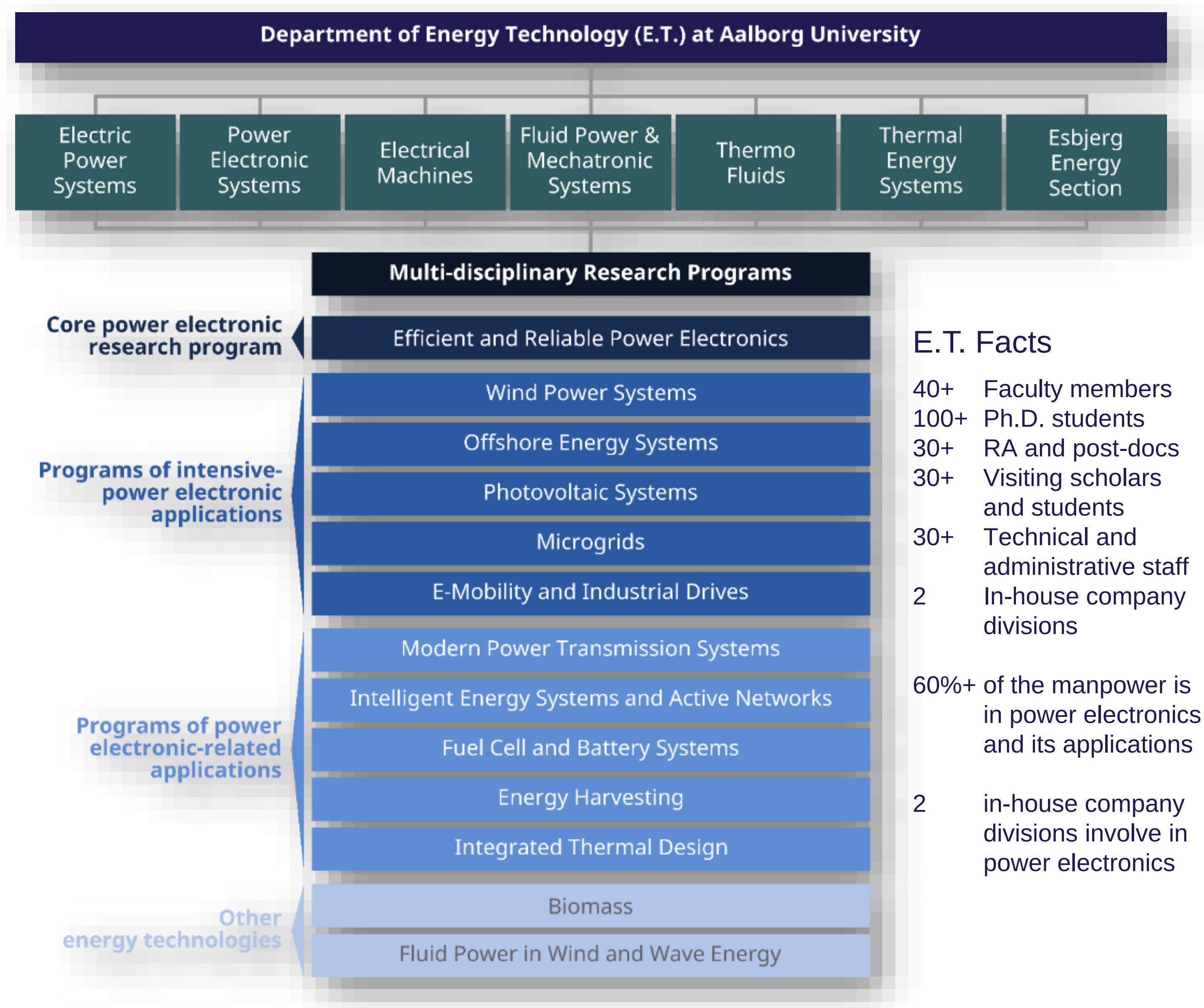
Aalborg University Campus

Power Electronics Centered



Energy Production | Distribution | Consumption | Control

Focuses at E.T.



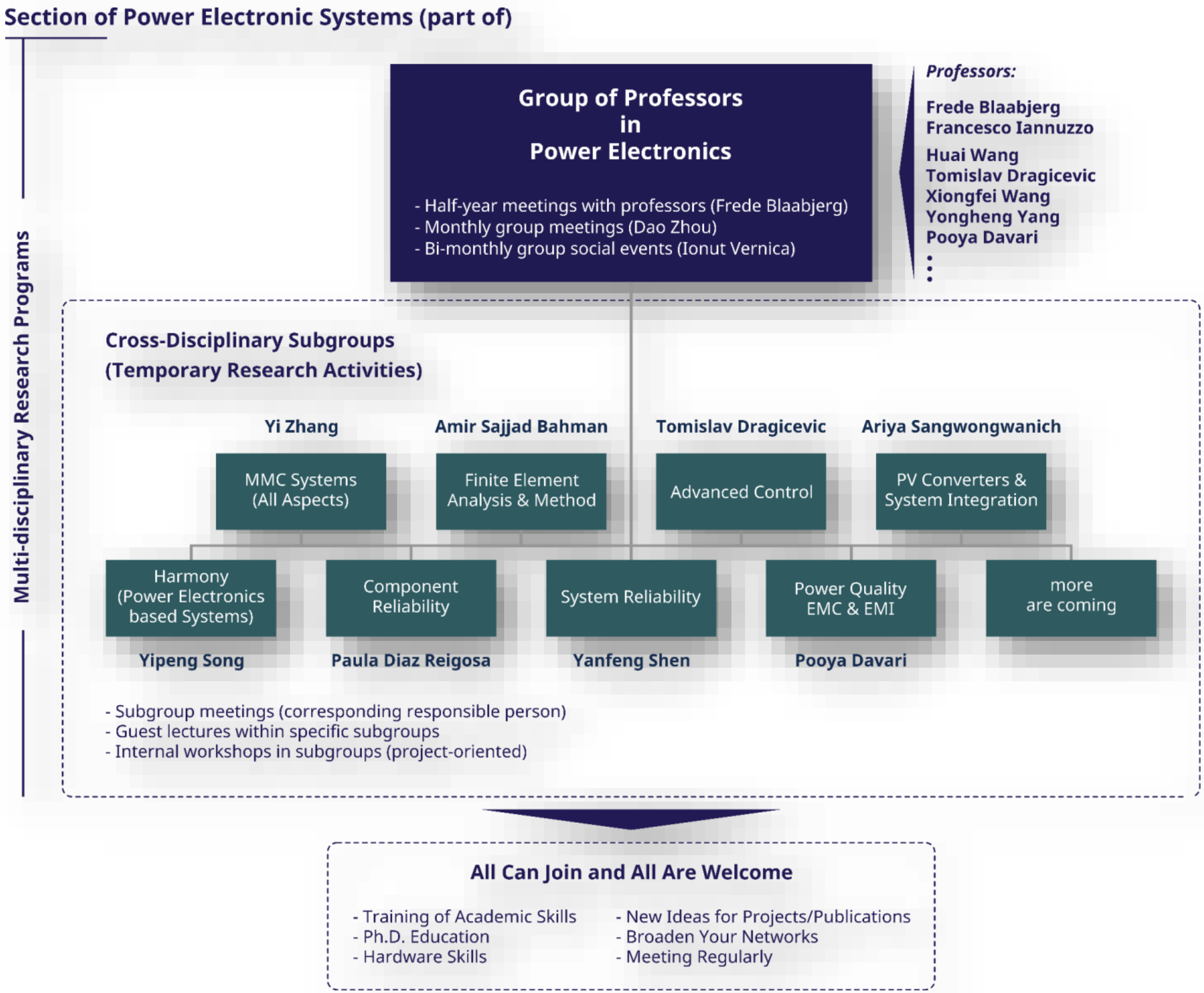
E.T. Facts

- 40+ Faculty members
- 100+ Ph.D. students
- 30+ RA and post-docs
- 30+ Visiting scholars and students
- 30+ Technical and administrative staff
- 2 In-house company divisions

60%+ of the manpower is in power electronics and its applications

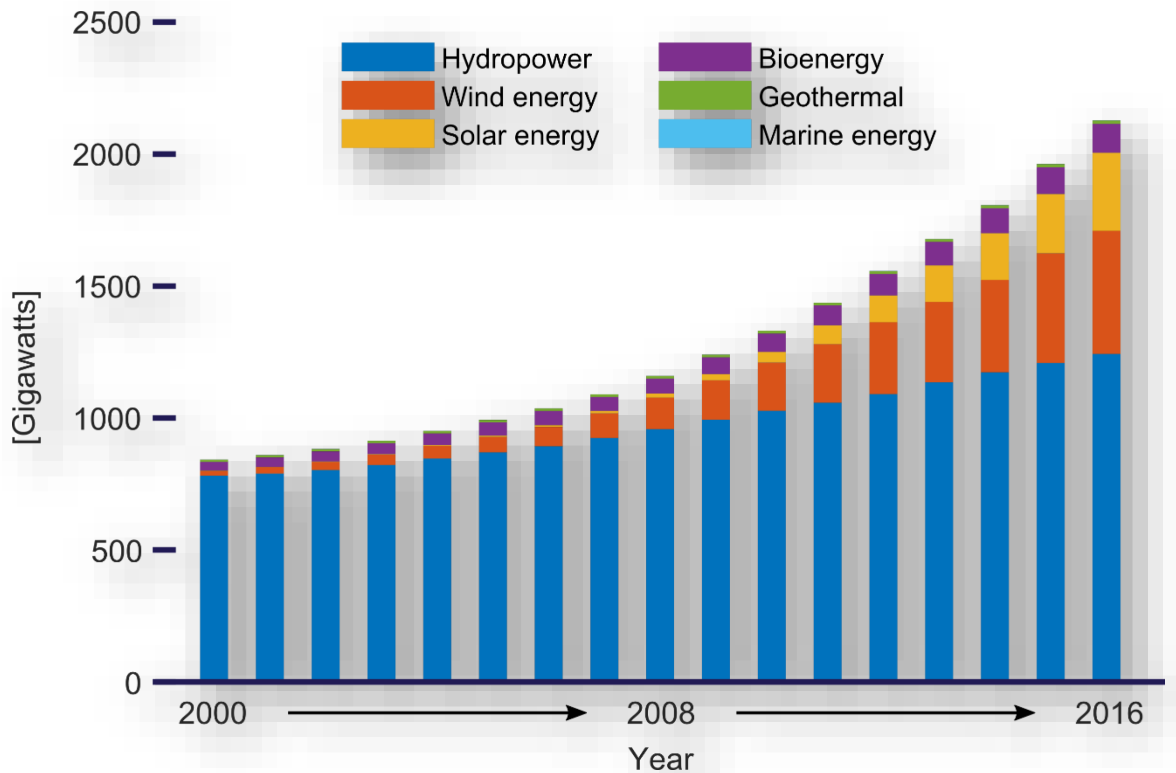
2 in-house company divisions involve in power electronics

Group Organization



Overview of power electronics technology and renewable energy systems

State of the Art – Renewable Evolution

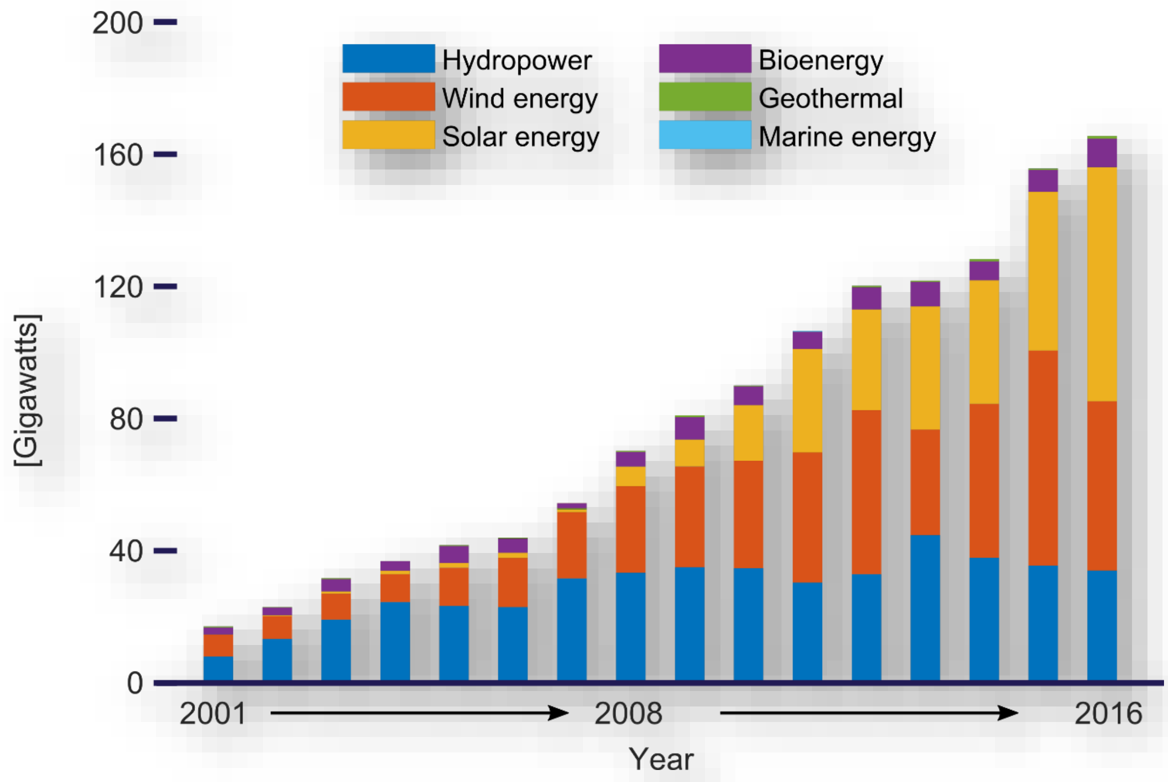


Worldwide Installed Renewable Energy Capacity (2000-2016)

1. Hydropower also includes pumped storage and mixed plants;
2. Marine energy covers tide, wave, and ocean energy

(Source: IRENA, "Renewable energy capacity statistics 2017", http://www.irena.org/publications, July 2017)

Global RES Annual Changes

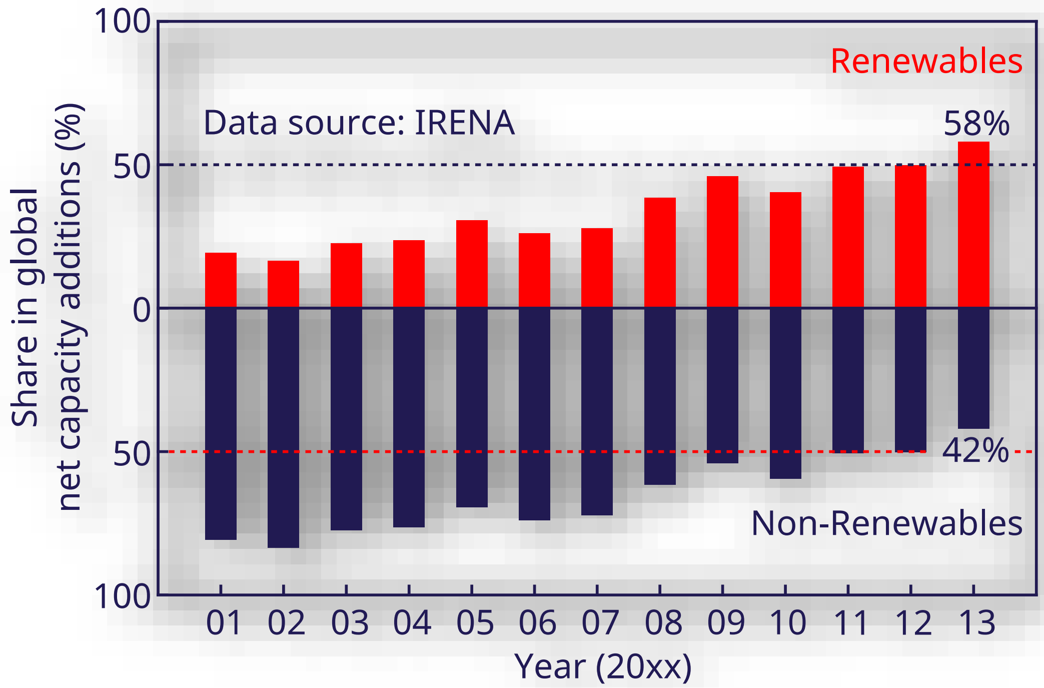


Global Renewable Energy Annual Changes in Gigawatt (2001-2016)

1. Hydropower also includes pumped storage and mixed plants;
2. Marine energy covers tide, wave, and ocean energy

(Source: IRENA, “Renewable energy capacity statistics 2017”, http://www.irena.org/publications, July 2017)

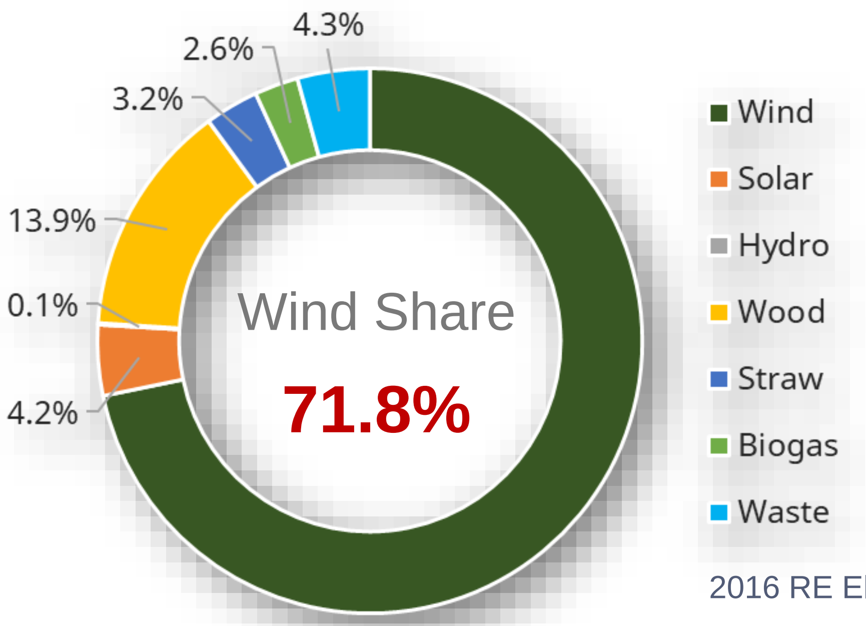
Share of the Net Total Annual Additions



RES and non-RES as a share of the net total annual additions

Chapter 01 in Renewable energy devices and systems with simulations in MATLAB and ANSYS, Editors: F. Blaabjerg and D.M. Ionel, CRC Press LLC, 2017

Renewable Electricity in Denmark



2016 RE Electricity Gener. in DK

Proportion of renewable electricity in Denmark (*target value)

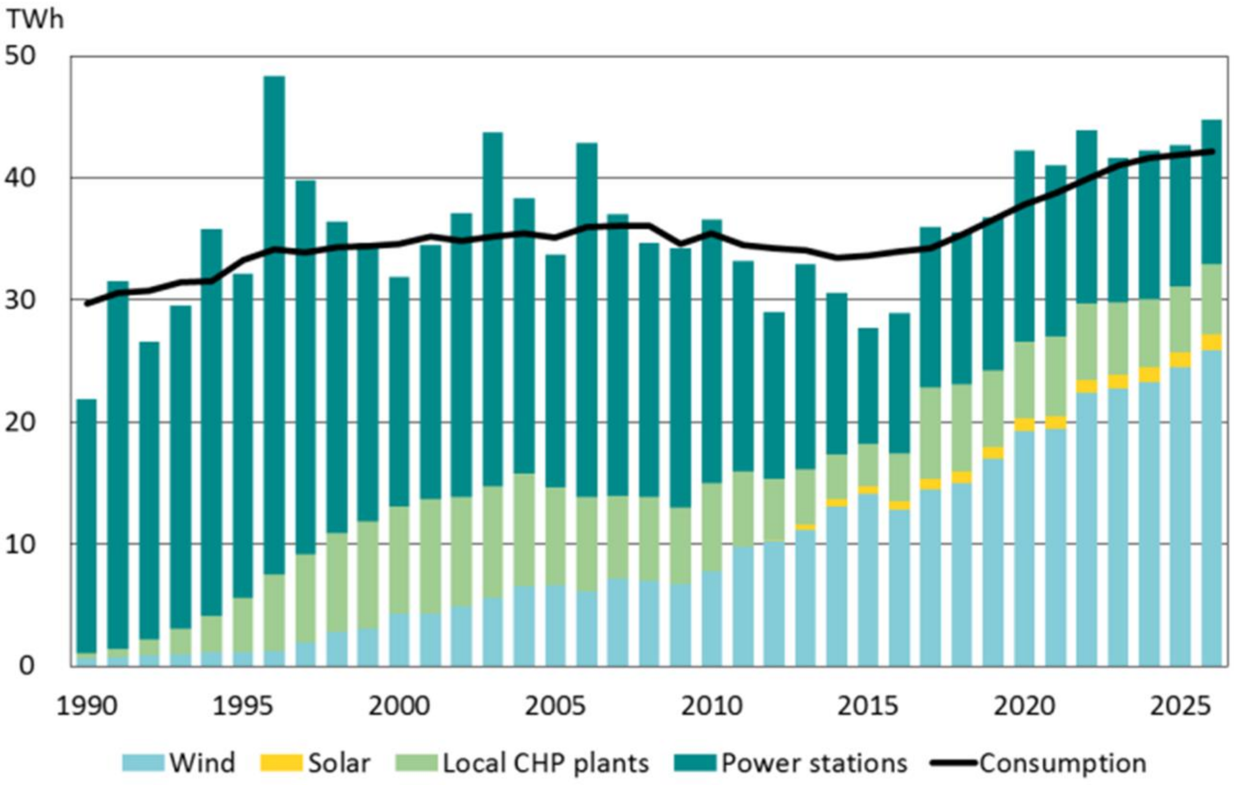
Key figures	2015	2016	2025	2035
Wind share of net generation in year	51.0%	44.2%	58%*	
Wind share of consumption in year	42.0%	37.6%		
RE share of net generation in year	66.9%	61.6%		100%*
RE share of net consumption in year	55.2%	52.4%	62%*	

https://en.energinet.dk/-/media/Energinet/El-RGD/Miljrapport-2017_EN.pdf

https://ens.dk/sites/ens.dk/files/Analyser/denmarks_energy_and_climate_outlook_2017.pdf

Energy and Power Challenge in DK

Electricity consumption and generation in Denmark

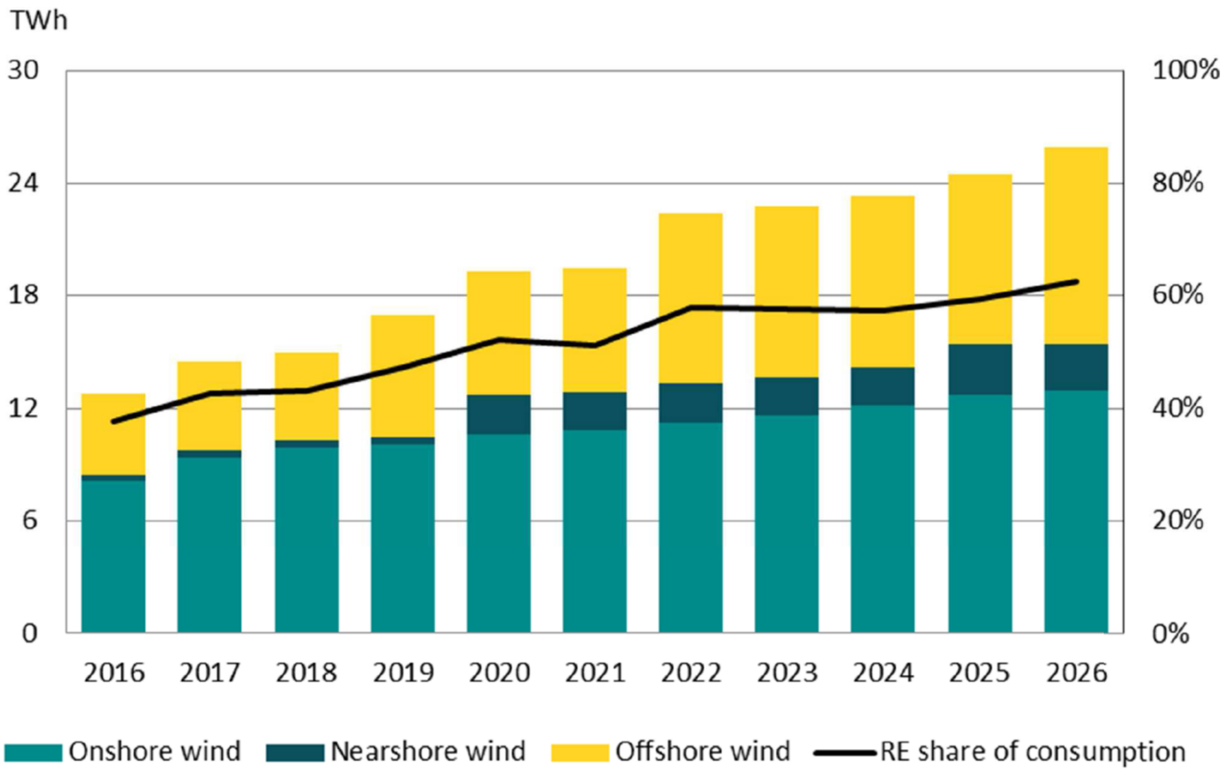


Very High Coverage of Distributed Generation

https://en.energinet.dk/-/media/Energinet/El-RGD/Miljrapport-2017_EN.pdf

Energy and Power Challenge in DK

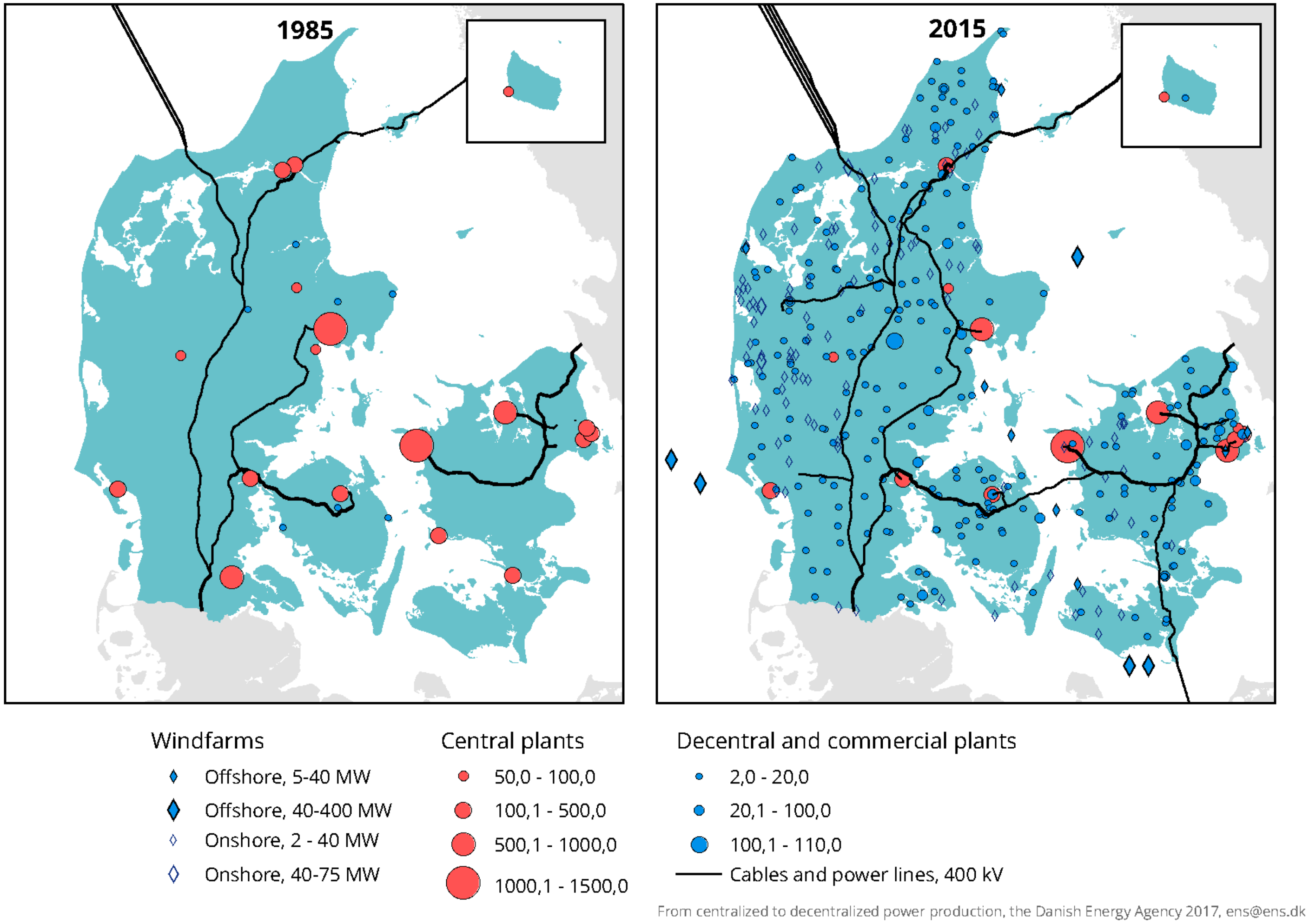
Wind power generation 2016-2026



Very High Penetration of Wind

https://en.energinet.dk/-/media/Energinet/El-RGD/Miljrapport-2017_EN.pdf

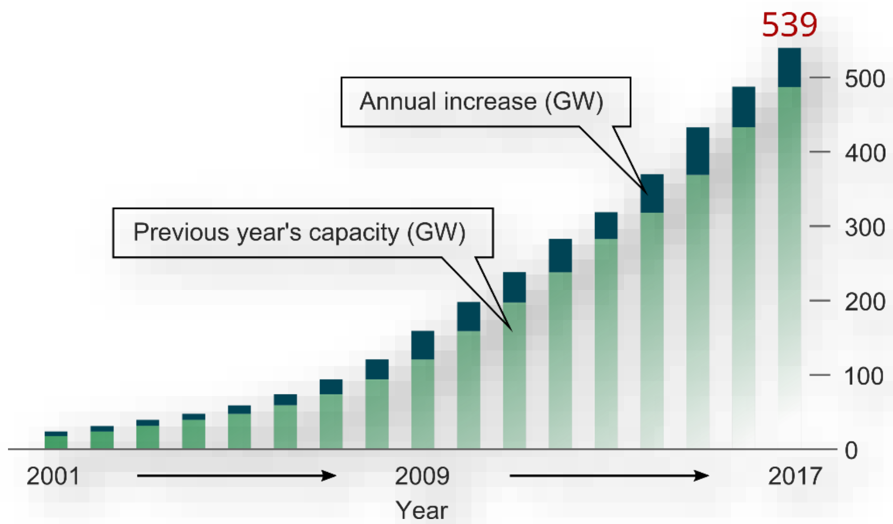
Development of Electric Power System in Denmark

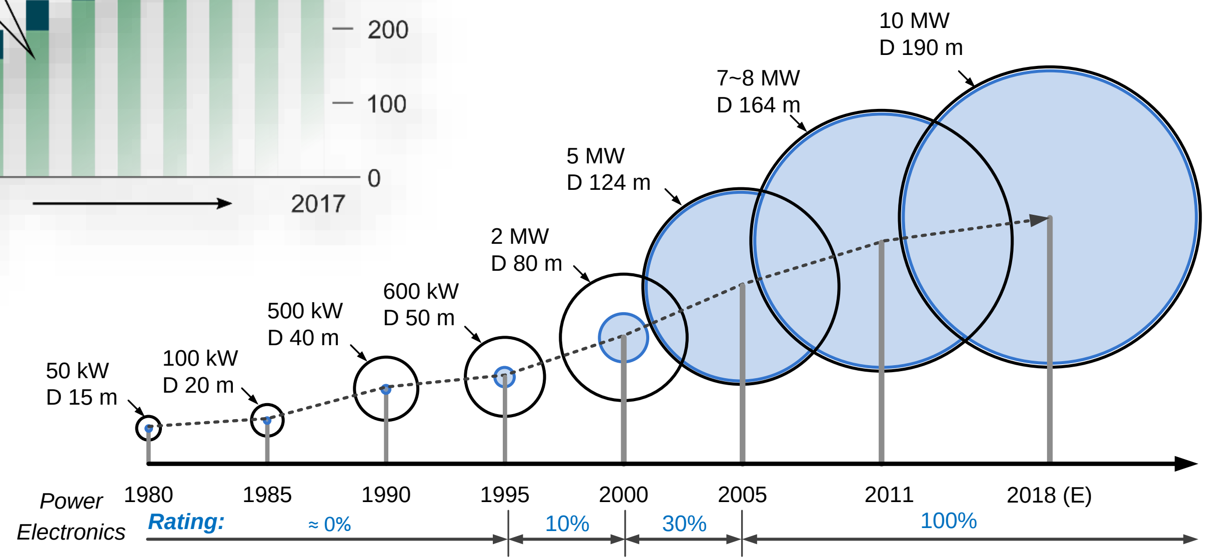


From **Central** to **De-central** Power Generation

Danish Energy Agency, https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/energy-infomaps

State of the Art Development – Wind Power





Global installed wind capacity (until 2017): 539 GW, 2017: 52.3 GW

- Higher total capacity (+50% non-hydro renewables).
- Larger individual size (average 1.8 MW, up to 6-8 MW, even 10 MW).
- More power electronics involved (up to 100 % rating coverage).

http://gwec.net/wp-content/uploads/vip/GWEC_PRstats2017_EN-003_FINAL.pdf

Top 5 Wind Turbine Manufacturers & Technologies

Manufacturer	Concept	Rotor Diameter	Power Range
Vestas (Denmark)	DFIG PMSG	80 m 100 m	2.0 MW 3.3-8.0 MW
Siemens Gamesa (Spain)	SCIG PMSG DFIG	120 m 128 – 154 m 90 m	3.6 MW 4.5 – 6.0 MW 2.0 MW
GE (USA)	DFIG PMSG	104 m 100 – 113 m	3.0 MW 2.5 – 4.1 MW
Goldwind (China)	PMSG	70 – 110 m	1.5 – 3.0 MW
Enercon (Germany)	WRSG	82 – 126 m	2.0 – 7.5 MW

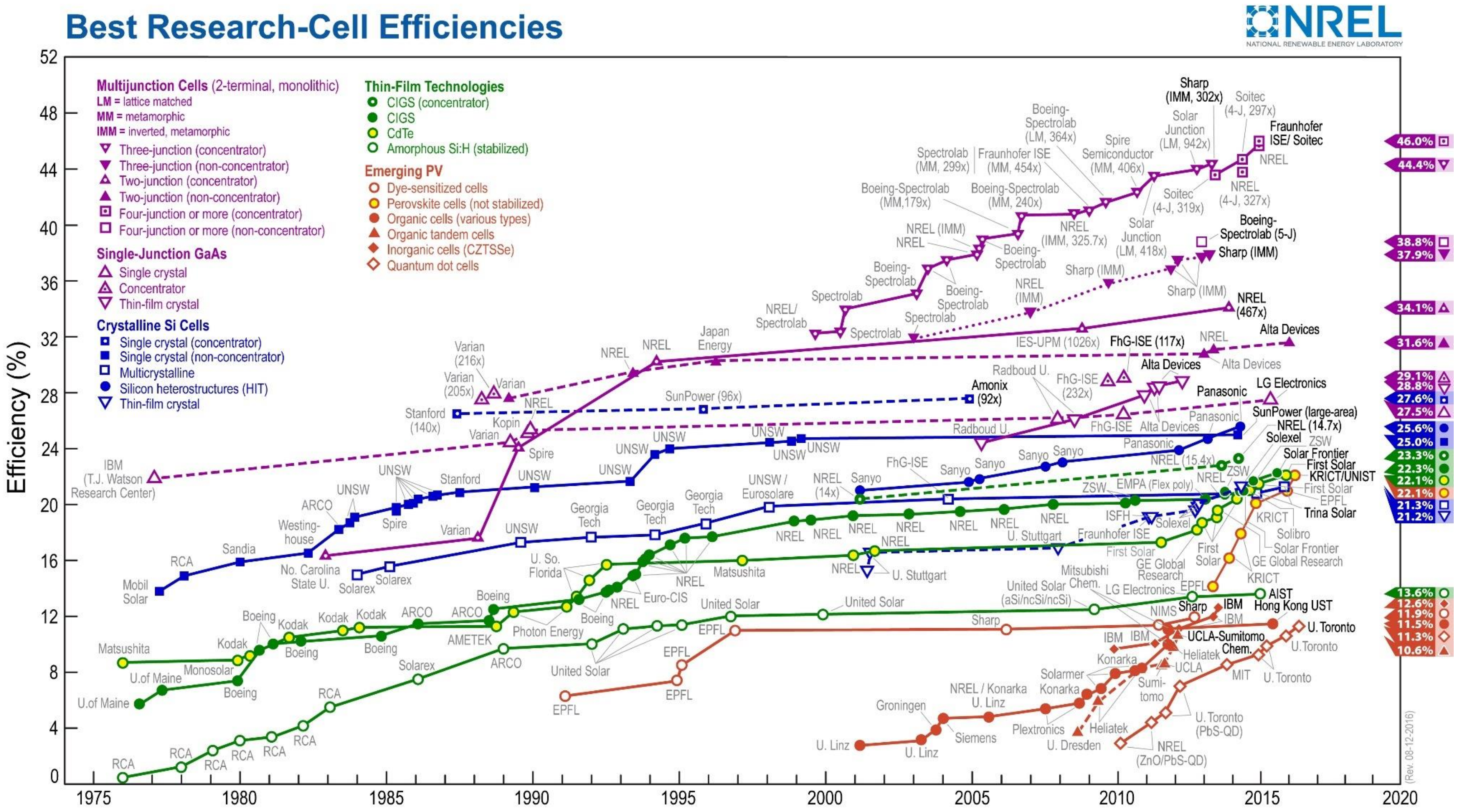
DFIG: Doubly-Fed Induction Generator

PMSG: Permanent Magnet Synchronous Generator

SCIG: Squirrel-Cage Induction Generator

WRSG: Wound Rotor Synchronous Generator

State of the Art – PV Cell Technologies



National Renewable Energy Laboratory, http://www.nrel.gov/pv/assets/images/efficiency_chart.jpg

Top 10 PV Cell Manufacturers & Technologies

Top Ten PV Cell Technology Focus and Module Assembly Capacity 2015

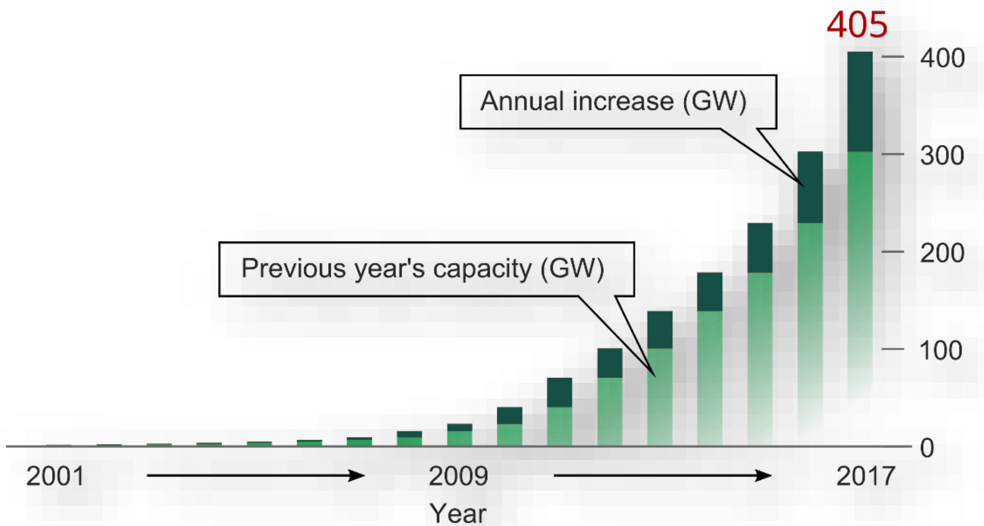
Manufacturer	Technology	Module Assembly Capacity (MW)
Trina (CN/NL)	c-Si	510
JA Solar (CN/MY)	c-Si	400
Hanwha Q-Cells (CN/DE/MY/KR)	c-Si	430
Canadian Solar (CN)	c-Si	430
First Solar (US/MY)	CdTe/c-Si	290
Jinko Solar (CN/MY)	c-Si	470
Yingli Solar (CN)	c-Si	245
Motech Solar (Taiwan/CN)	c-Si	140
NeoSolar (Taiwan/CN)	c-Si	50
Shunfeng-Suntech (CN/US)	c-Si	200

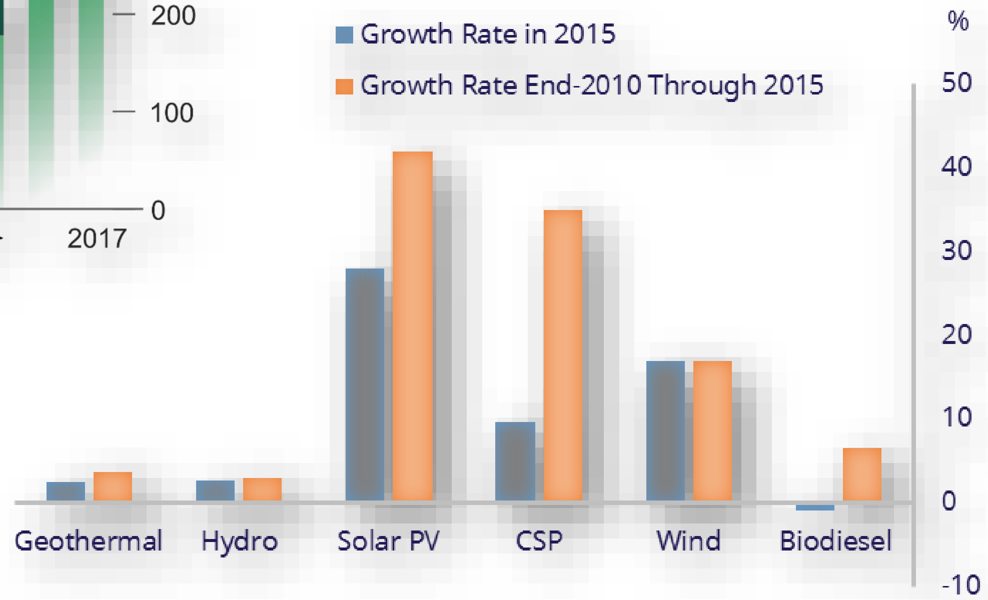
c-Si: Crystalline silicon

CdTe: Cadmium telluride

Paula Mints, 2015 Top Ten PV Cell Manufacturers, http://www.renewableenergyworld.com/articles/2016/04/2015-top-ten-pv-cell-manufacturers.html

State of the Art Development – Photovoltaic Power



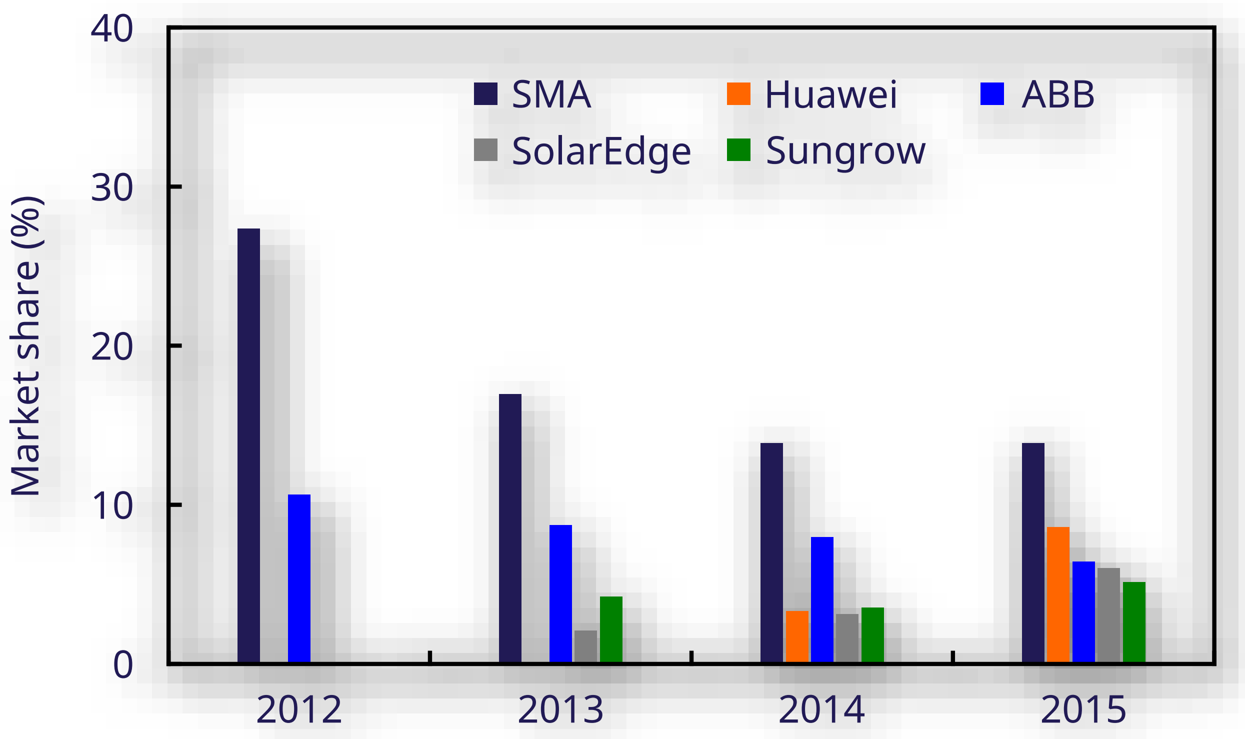


Global installed solar PV capacity (until 2017): 405 GW, 2017: 102 GW

- More significant total capacity (29 % non-hydro renewables).
- Fastest growth rate (42 % between 2010-2015).

SolarPower Europe, http://www.solarpowereurope.org/home/
REN21, Renewables 2016, http://www.ren21.net/wp-content/uploads/2016/10/REN21_GSR2016_FullReport_en_11.pdf
https://en.wikipedia.org/wiki/Growth_of_photovoltaics

Top 5 Global Photovoltaic Inverter Supplier



Global Market Share (% of $M) of Top Five PV Inverter Suppliers (2012-2015)

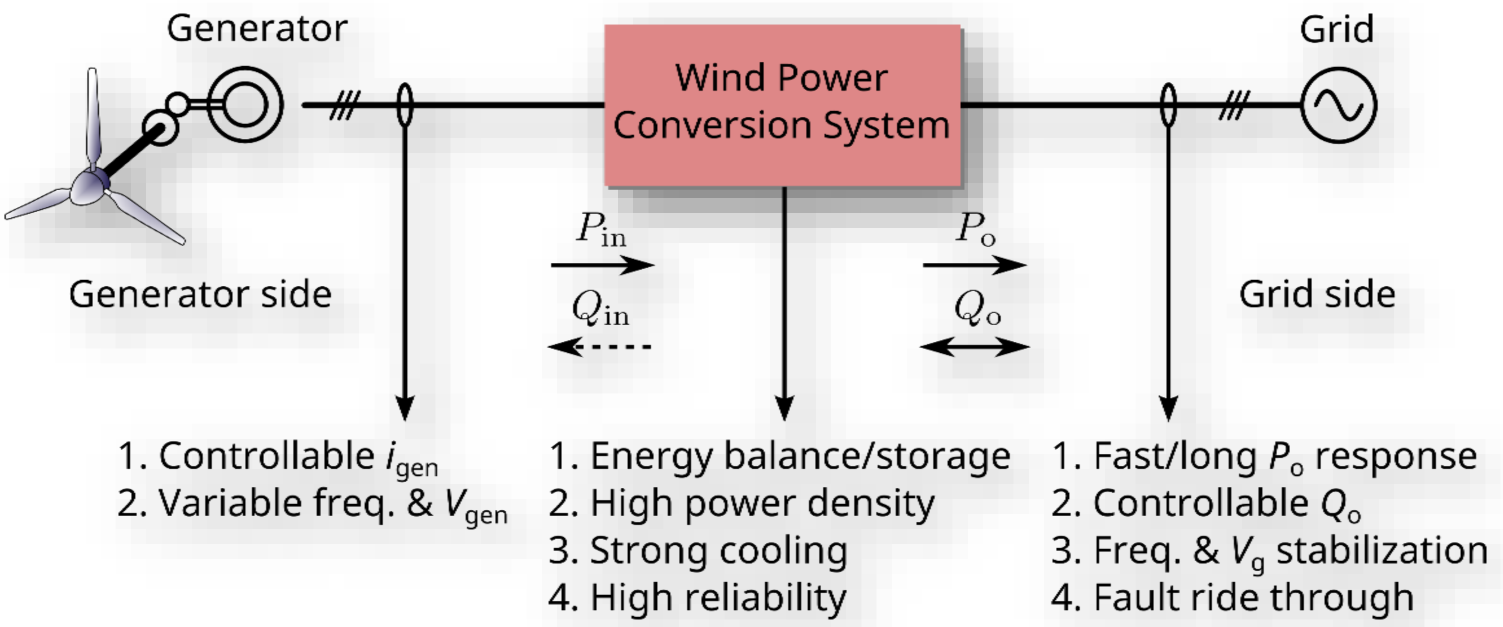
1. Market share is not shown when less than 2%;
2. Suppliers shown are top five in 2015.

Figure Adapted according to the report by IHS

IHS, *SMA Retains Top Ranking in Global PV Inverter Market, but Competitors are Gaining*, http://press.ihs.com/press-release/technology/sma-retains-top-ranking-global-pv-inverter-market-competitors-are-gaining-i

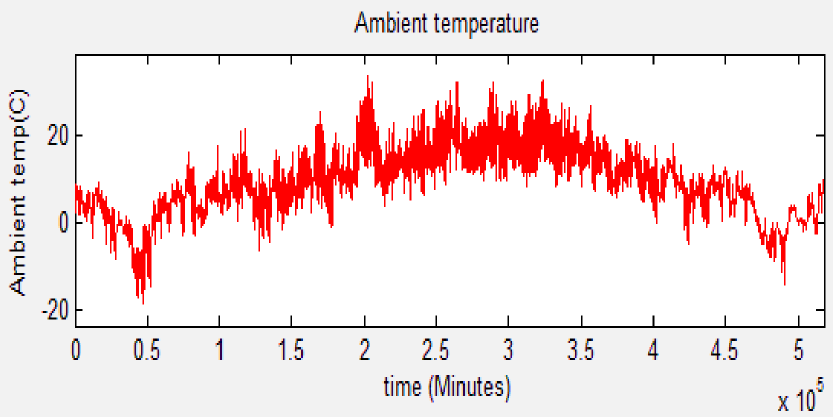
Demands for renewable energy systems

Requirements for Wind Turbine Systems

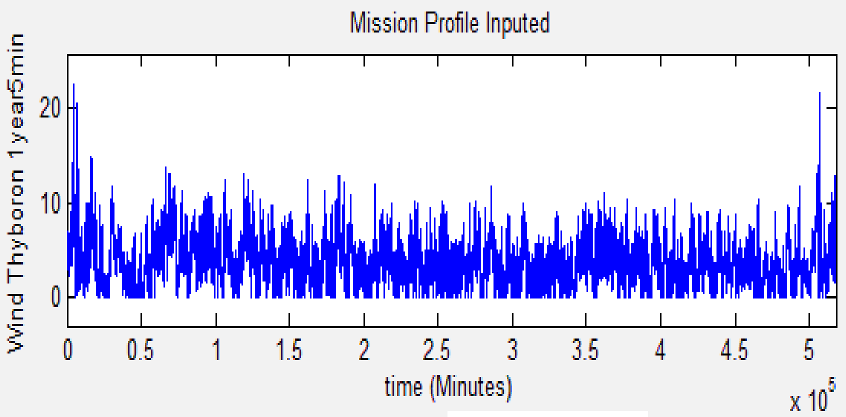


General Requirements & Specific Requirements

Input mission profiles for wind power application



Ambient temperature



Wind speed

Mission profile for wind turbines in Thyboron wind farm

- Highly variable wind speed
- Different wind classes are defined - turbulence and avg. speed
- Large power inertia to wind speed variation – stored energy in rotor.
- Large temperature inertia to ambient temp. variation – large nacelle capacity

Grid Codes for Wind Turbines

Conventional power plants provide active and reactive power, inertia response, synchronizing power, oscillation damping, short-circuit capability and voltage backup during faults.

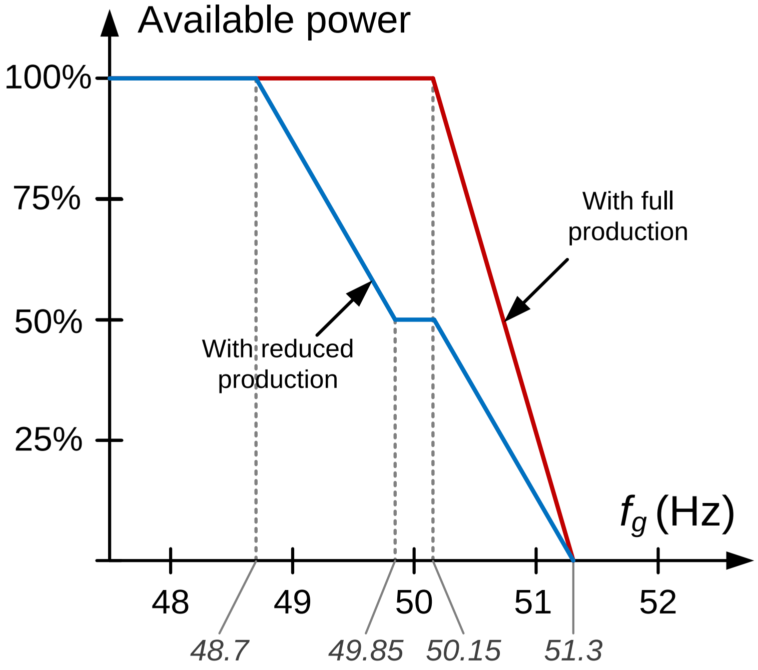
Wind turbine technology differs from conventional power plants regarding the converter-based grid interface and asynchronous operation

Grid code requirements today

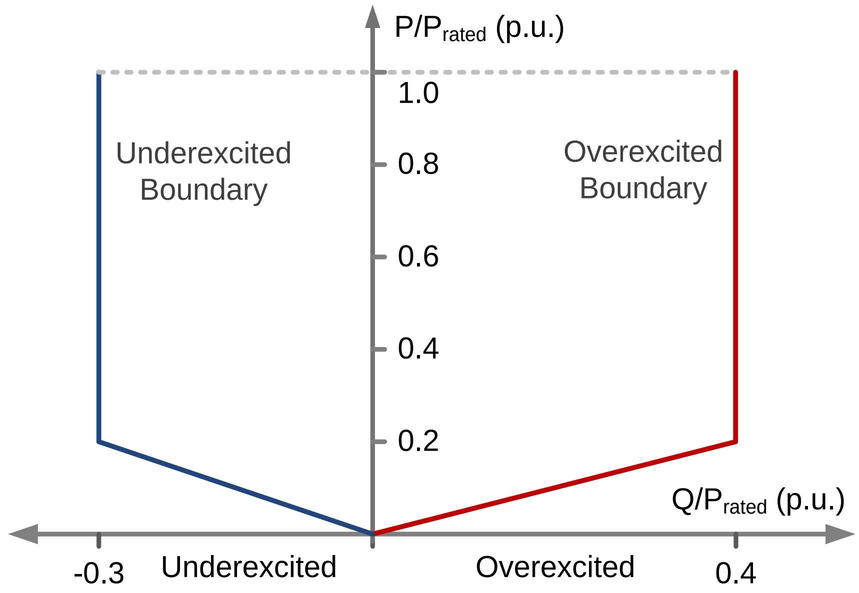
- Active power control
- Reactive power control
- Frequency control
- Steady-state operating range
- Fault ride-through capability

Wind turbines are active power plants.

Power Grid Standards – Frequency/Voltage Support



Freq. – *P* control

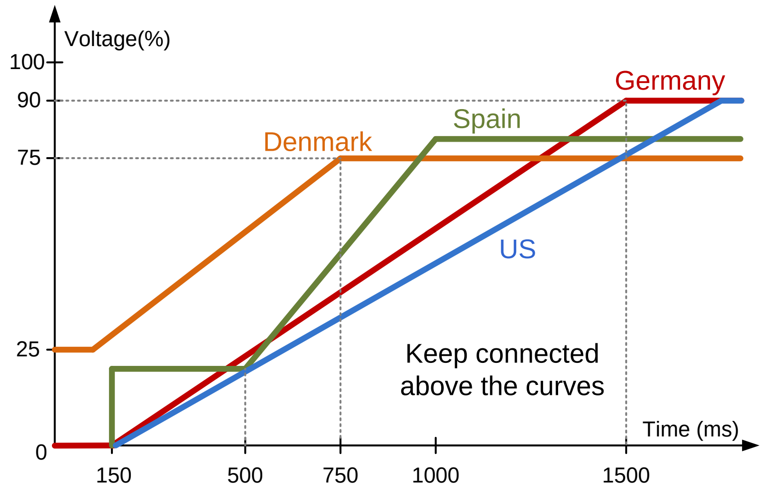


Q ranges under different generating *P*

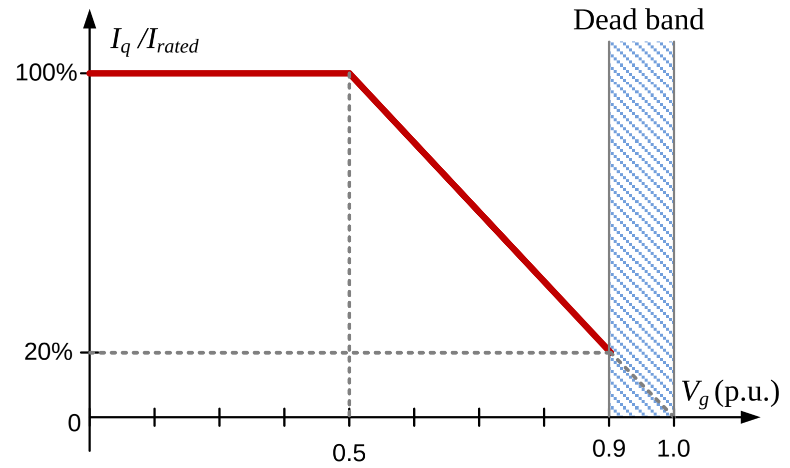
- Frequency control through active power regulation.
- Reactive power control according to active power generation.
- Voltage support through reactive power control.

Power Grid Standards – Ride-Through Operation

Requirements during grid faults



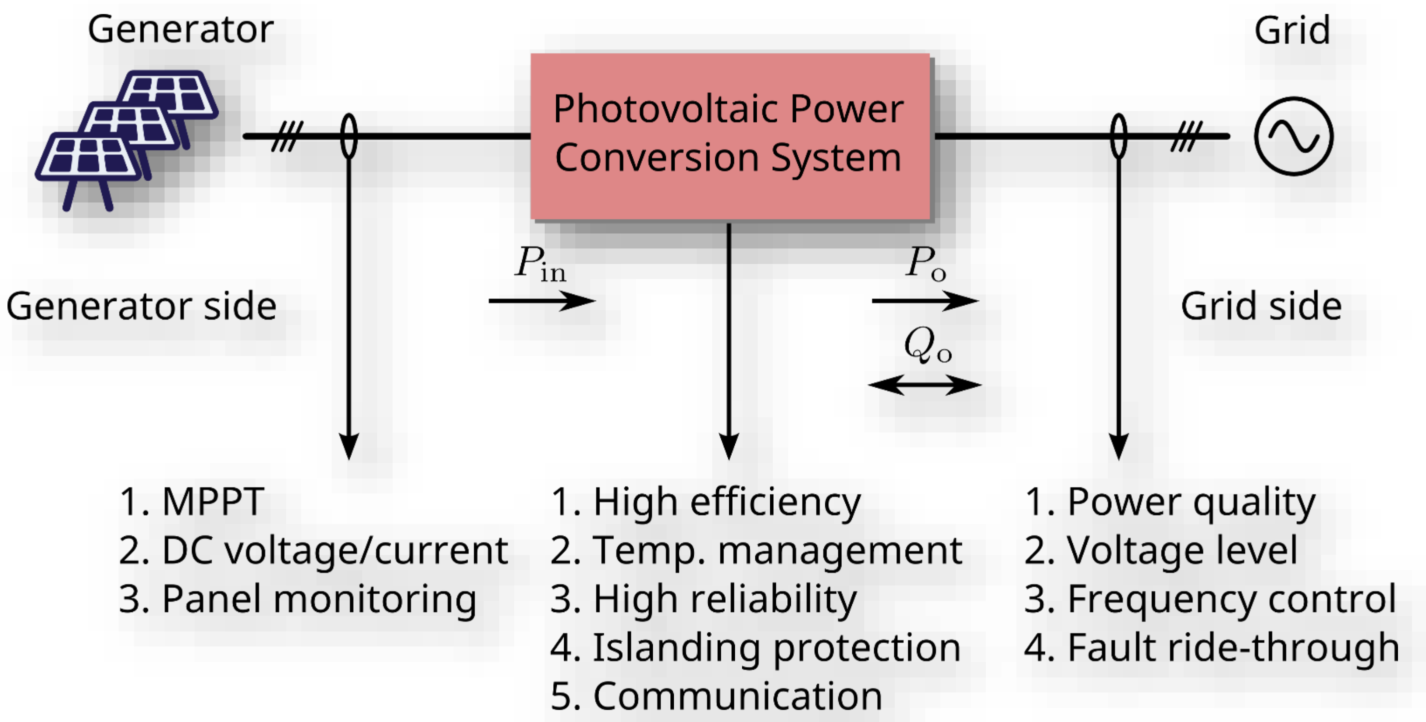
Grid voltage dips vs. withstand time



Reactive current vs. Grid voltage dips

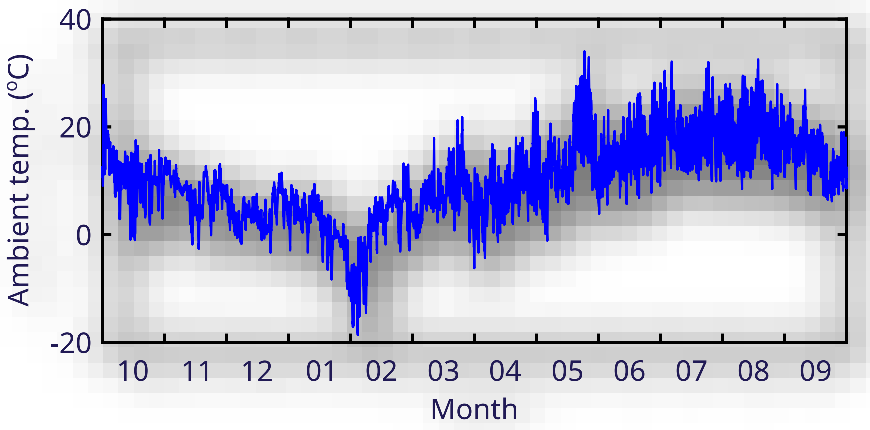
- Withstand extreme grid voltage dips.
- Contribute to grid recovery by injecting I_q.
- Higher power controllability of converter.

Requirements for Photovoltaic Systems

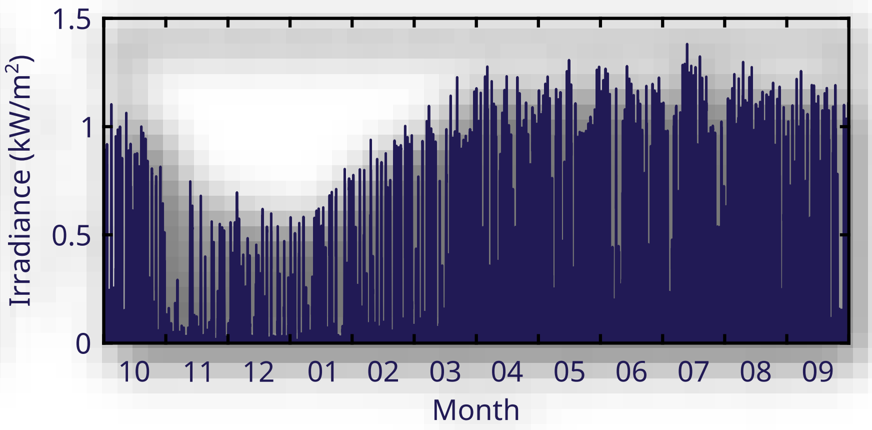


General Requirements & Specific Requirements

Input mission profiles for PV power application



Ambient temperature



Solar irradiance

Mission Profile for PV Systems Measured at AAU (201110-201209)

- Highly variable solar irradiance
- Small power inertia to solar variation – quick response of PV panel.
- Small temperature inertia to ambient temp. variation – small case capacity.
- Temperature sensitive for the PV panel and power electronics.

Grid Codes for Photovoltaic Systems

Grid-connected PV systems ranging from several kWs to even a few MWs are being developed very fast and will soon take a major part of electricity generation in some areas. PV systems have to comply with much tougher requirements than ever before.

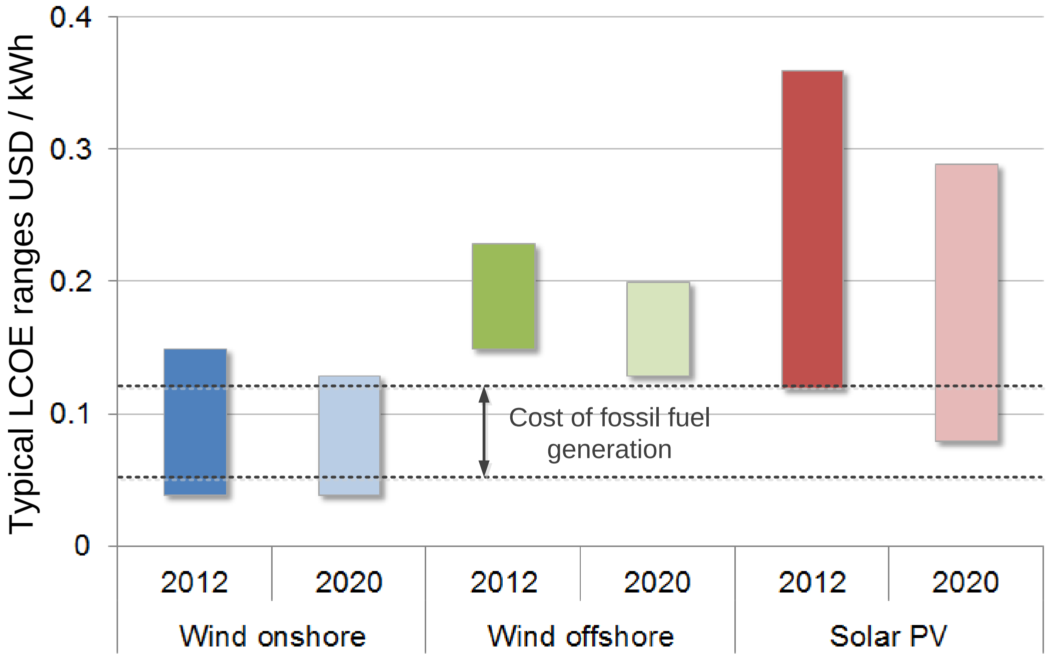
Requirements today

- Maximize active power capture (MPPT)
- Power quality issue
- Ancillary services for grid stability
- Communications
- High efficiency

In case of large-scale adoption of PV systems

- Reactive power control
- Frequency control
- Fault ride-through capability
- …

Cost of Energy (COE)



$$COE = \frac{C_{Cap} + C_{O\&M}}{E_{Annual}}$$

C_{Cap} – Capital cost
$C_{O\&M}$ – Operation and main. cost
E_{Annual} – Annual energy production

Determining factors for renewables
- Capacity growth
- Technology development

Approaches to Reduce Cost of Energy

$$COE = \frac{C_{Cap} + C_{O\&M}}{E_{Annual}}$$

C_{Cap} – Capital cost

$C_{O\&M}$ – Operation and main. cost

E_{Annual} – Annual energy production

Approaches	*Important and related factors*	*Potential*
Lower C_{Cap}	Production / Policy	+
Lower $C_{O\&M}$	Reliability / Design / Labor	++
Higher E_{annual}	Reliability / Capacity / Efficiency / Location	+++

Reliability is an efficient way to reduce COE – lower $C_{O\&M}$ & higher E_{Annual}

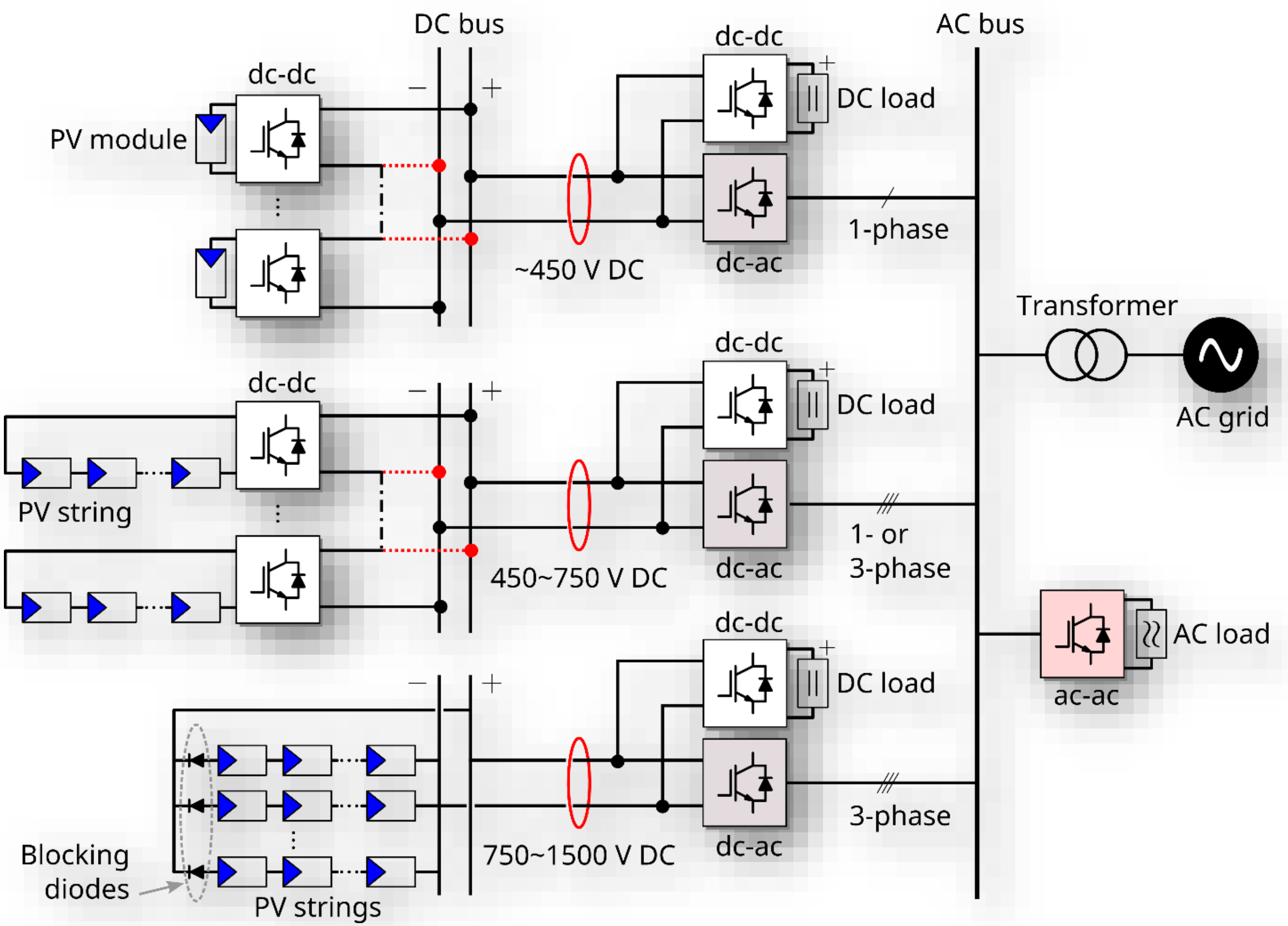
Typical Lifetime Target in PE Applications

Applications	Typical design target of Lifetime
Aircraft	24 years (100,000 hours flight operation)
Automotive	15 years (10,000 operating hours, 300,000 km)
Industry motor drives	5-20 years (40,000 hours in at full load)
Railway	20-30 years (10 hours operation per day)
Wind turbines	20 years (18-24 hours operation per day) 100000 hours
Photovoltaic plants	20-30 years (12 hours per day) 100000 hours

Different O&M programs

Power converters for renewables application

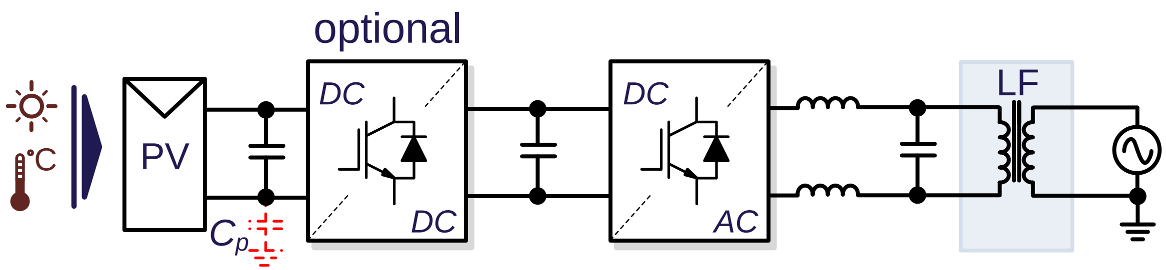
PV Inverter System Configurations

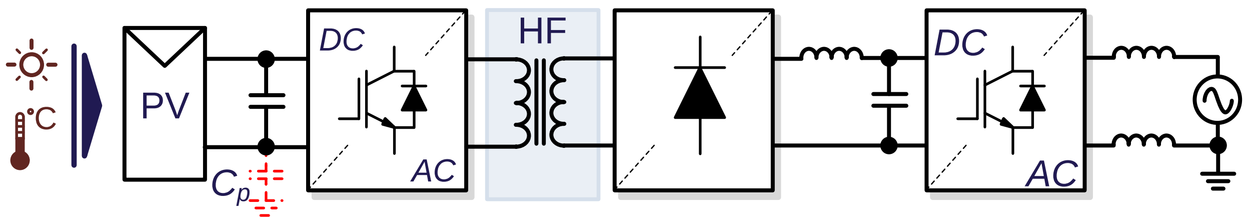


Module Converters | String Inverter | Multi-String Inverters | Central Inverters

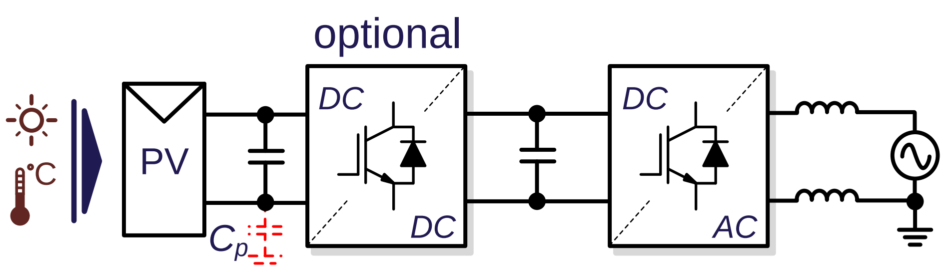
Grid-Connection Configurations

Transformer-based grid-connection





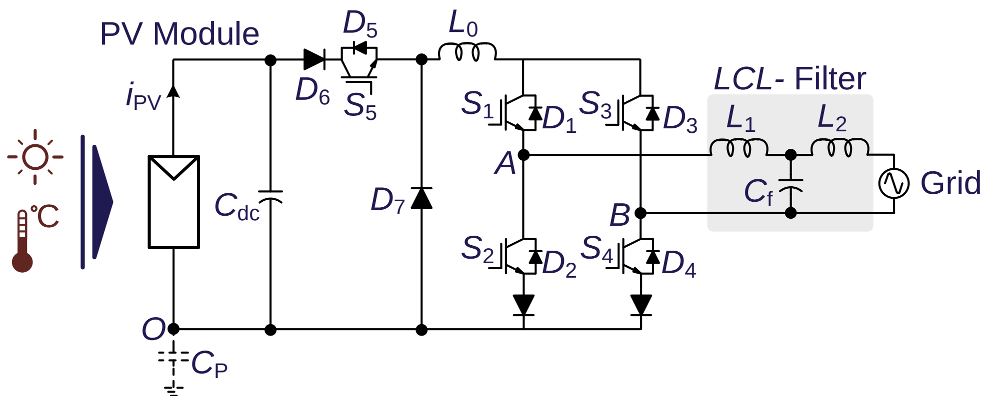
Transformerless grid-connection → Higher efficiency, Smaller volume



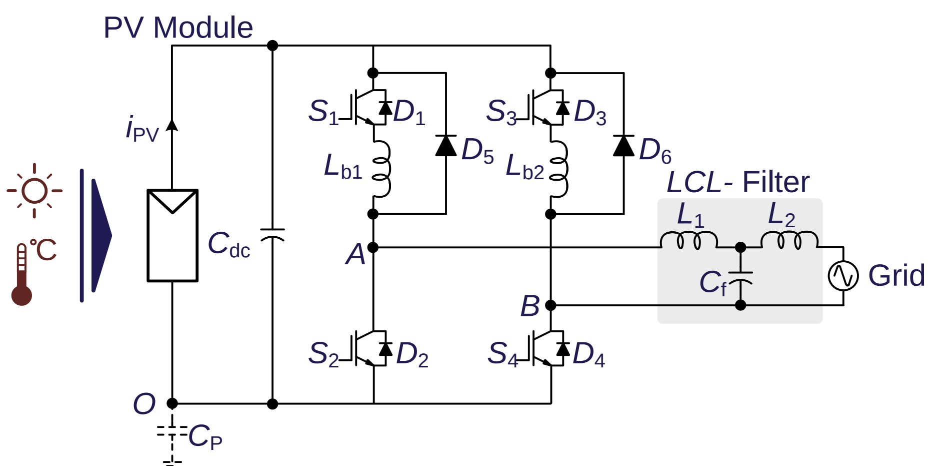
AC-Module PV Converters – Single-Stage

~ 300 W (several hundred watts)
High overall efficiency and High power desity.

Universal AC-module inverter



Buck-boost integrated full-bridge inverter

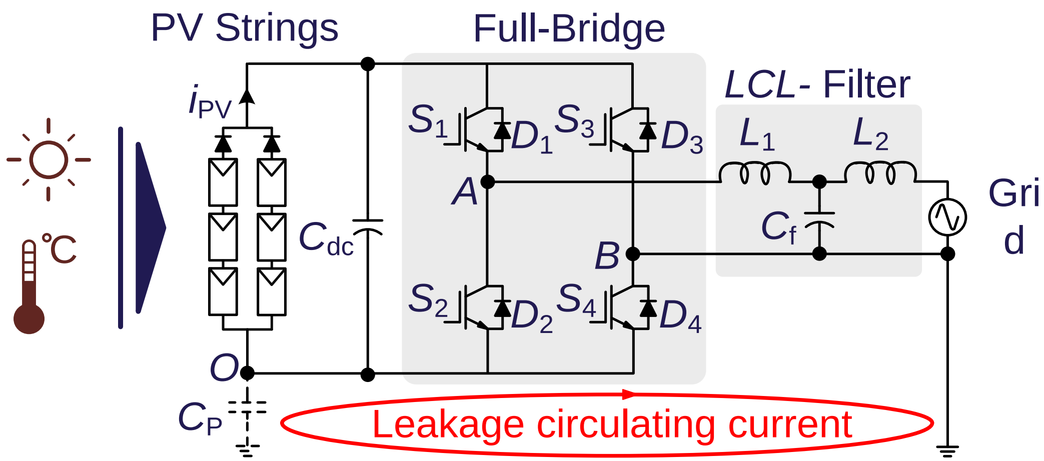


B.S. Prasad, S. Jain, and V. Agarwal, "Universal Single-Stage Grid-Connected Inverter," *IEEE Trans Energy Conversion*, 2008.
C. Wang "A novel single-stage full-bridge buck-boost inverter", *IEEE Trans. Power Electron.*, 2004.

String/Multi-String PV Inverters

1 kW ~ 30 kW (tens kilowatts)

High efficiency and also Emerging for modular configuration in medium and high power PV systems.

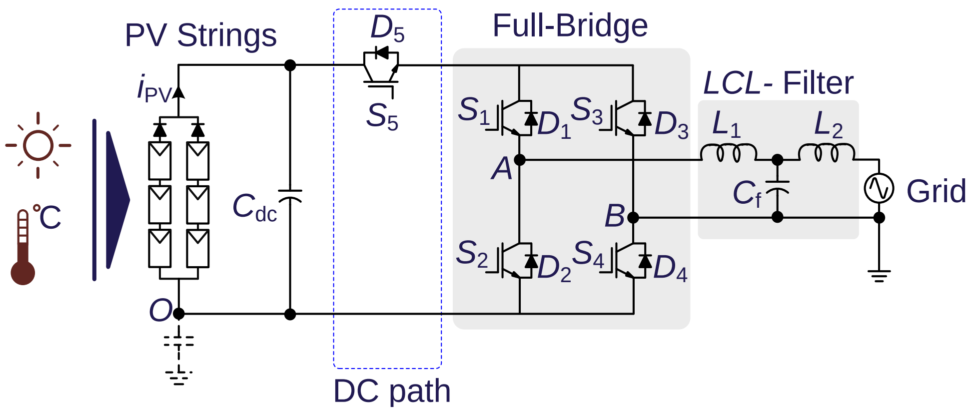


Bipolar Modulation is used:

- ❑ No common mode voltage → V_{PE} free for high frequency →low leakage current
- ❑ Max efficiency 96.5% due to reactive power exchange between the filter and C_{PV} during freewheeling and due to the fact that 2 switched are simultaneously switched every switching
- ❑ This topology is not special suited to transformerless PV inverter due to low efficiency!

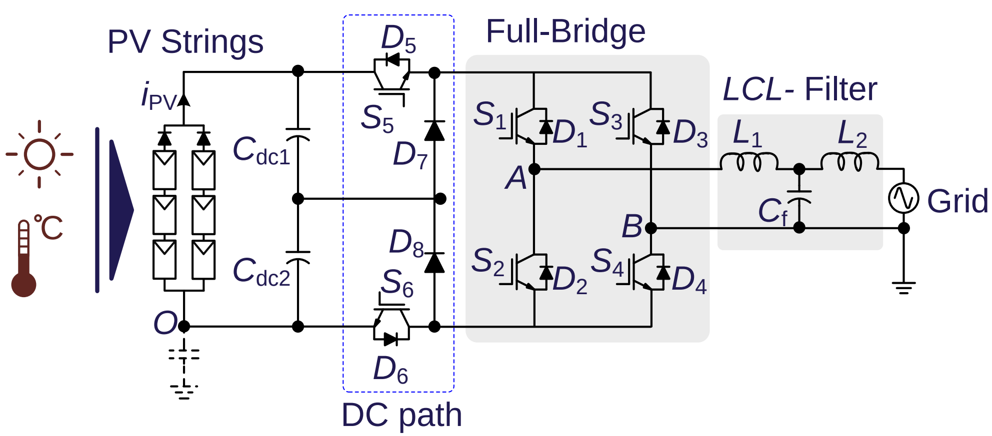
Transformerless String Inverters

H5 Transformerless Inverter (SMA)



- Efficiency of up to 98%
- Low leakage current and EMI
- Unipolar voltage accross the filter, leading to low core losses

H6 Transformerless Inverter (Ingeteam)

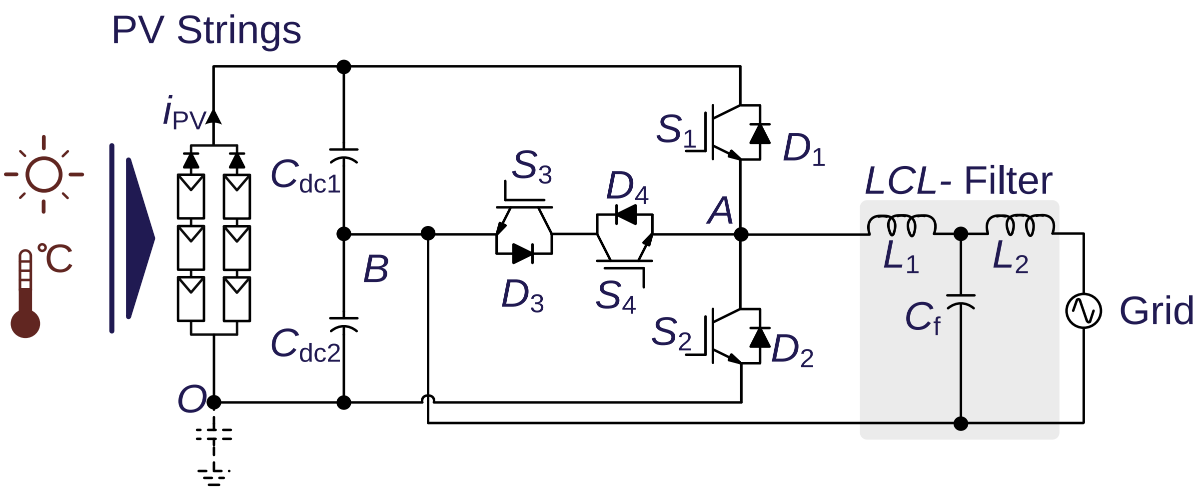


- High efficiency
- Low leakage current and EMI
- DC bypass switches rating: $V_{dc}/2$
- Unipolar voltage accross the filter

M. Victor, F. Greizer, S. Bremicker, and U. Hubler, U.S. Patent 20050286281 A1, Dec 29, 2005.
R. Gonzalez, J. Lopez, P. Sanchis, and L. Marroyo, "Transformerless inverter for single-phase photovoltaic systems," *IEEE Trans. Power Electron.*, 2007.

NPC Transformerless String Inverters

Neutral Point Clamped (NPC) converter for PV applications

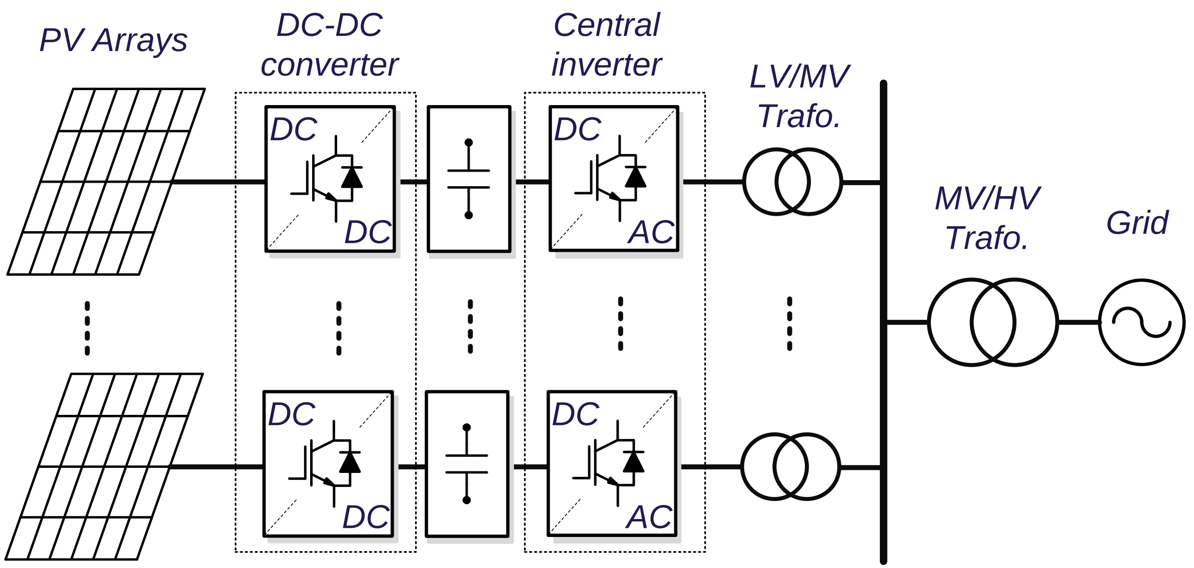


- Constant voltage-to-ground → Low leakage current, suitable for transformerless PV applications.
- High DC-link voltage (> twice of the grid peak voltage)

P. Knaup, International Patent Application, Publication Number: WO 2007/048420 A1, Issued May 3, 2007.

Central Inverters

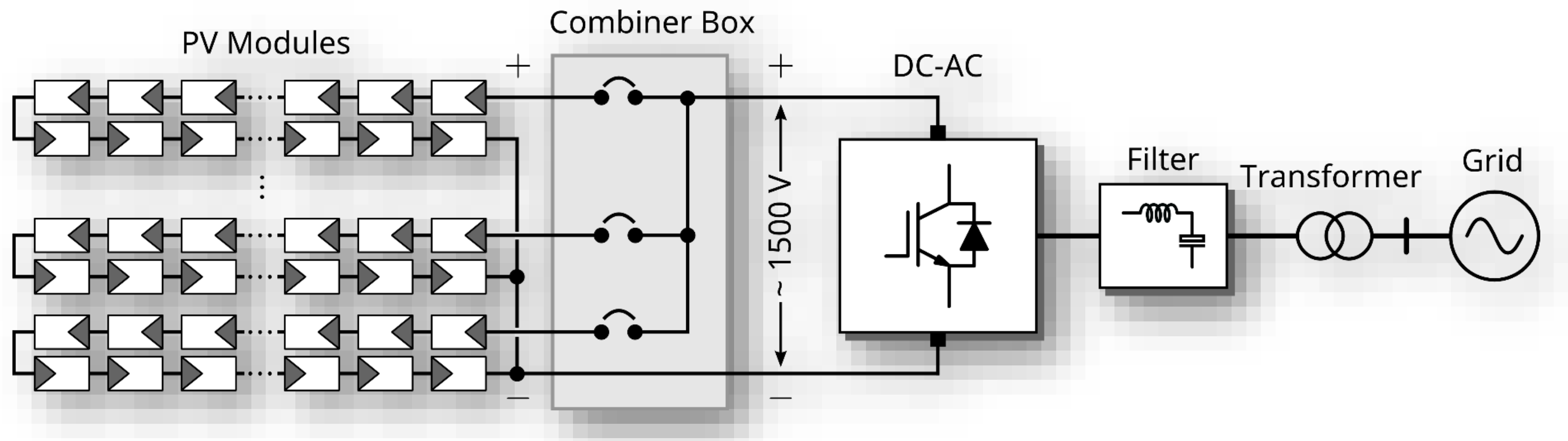
~ 30 kW (tens kilowatts to megawatts)
Very high power capacity.



- Large PV power plants (e.g. 750 kW by SMA), rated over tens and even hundreds of MW, adopt many central inverters with the power rating of up to 900 kW.
- DC-DC converters are also used before the central inverters.
- DC voltage becomes up to 1500 V
- Similar to wind turbine applications → NPC topology might be a promising solution.

1500-V DC PV System

Becoming the mainstream solution!



- Decreased requirement of the balance of system (e.g., combiner boxes, DC wiring, and converters) and Less installation efforts
- Contributes to reduced overall system cost and increased efficiency
- More energy production and lower cost of energy
- Electric safety and potential induced degradation
- Converter redesign – higher rating power devices

1500-V DC PV System

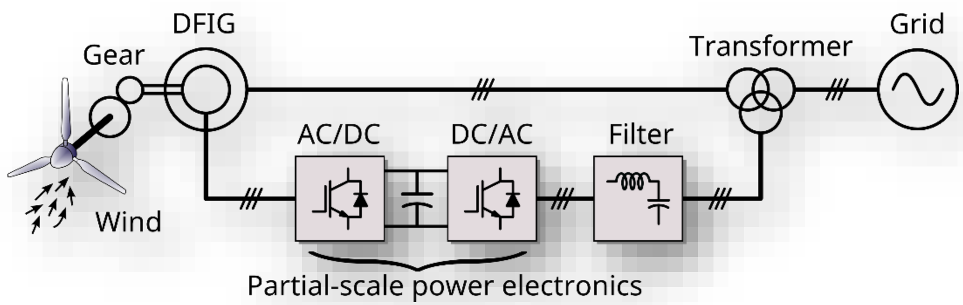
Becoming the mainstream solution!

ABB MW Solution

Sungrow five-level topology

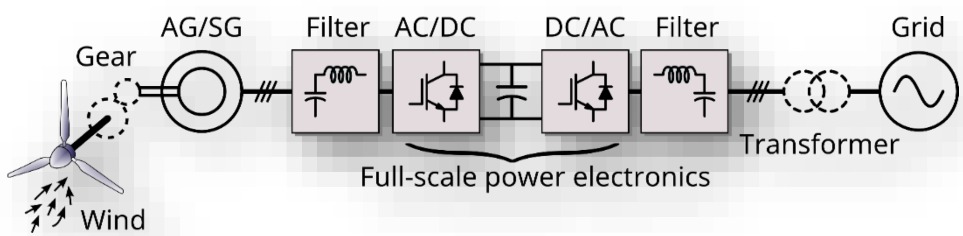
https://www.pv-tech.org/products/abb-launches-high-power-1500-vdc-central-inverter-for-harsh-conditions
https://www.pv-tech.org/products/sungrows-1500vdc-sg125hv-string-inverter-enables-5mw-pv-power-block-designs

Wind turbine concept and configurations



Partial scale converter with DFIG

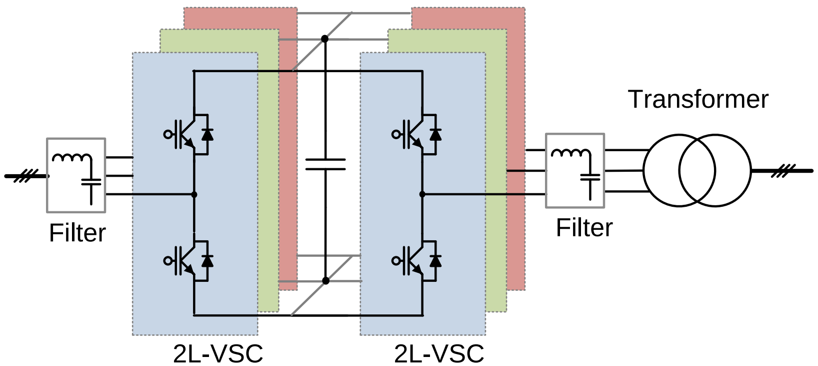
- Variable pitch – variable speed
- Doubly Fed Induction Generator
- Gear box and slip rings
- ±30% slip variation around synchronous speed
- Power converter (back to back/ direct AC/AC) in rotor circuit
- ✓ State-of-the-art solutions



Full scale converter with SG/IG

- Variable pitch – variable speed
- Generator
  Synchronous generator
  Permanent magnet generator
  Squirrel-cage induction generator
- With/without gearbox
- Power converter
  Diode rectifier + boost DC/DC + inverter
  Back-to-back converter
  Direct AC/AC (e.g. matrix, cycloconverters)
- ✓ State-of-the-art and future solutions

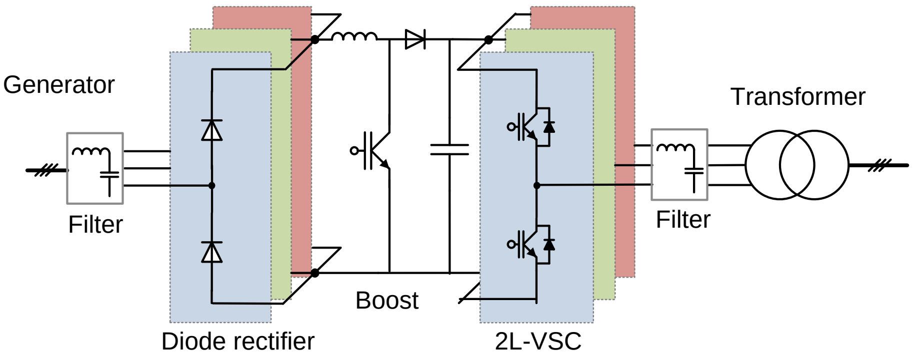
Converter topologies under low voltage (<690V)



Back-to-back two-level voltage source converter

- Proven technology
- Standard power devices (integrated)
- Decoupling between grid and generator (compensation for non-symmetry and other power quality issues)

- High dv/dt and bulky filter
- Need for major energy-storage in DC-link
- High power losses at high power (switching and conduction losses) → low efficiency

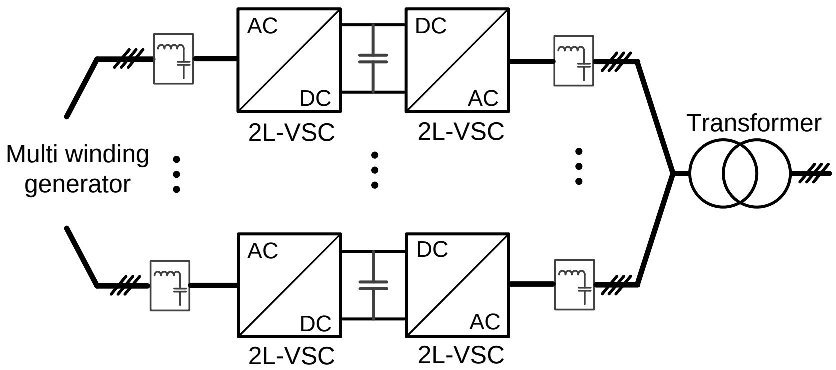


Diode rectifier + boost DC/DC + 2L-VSC

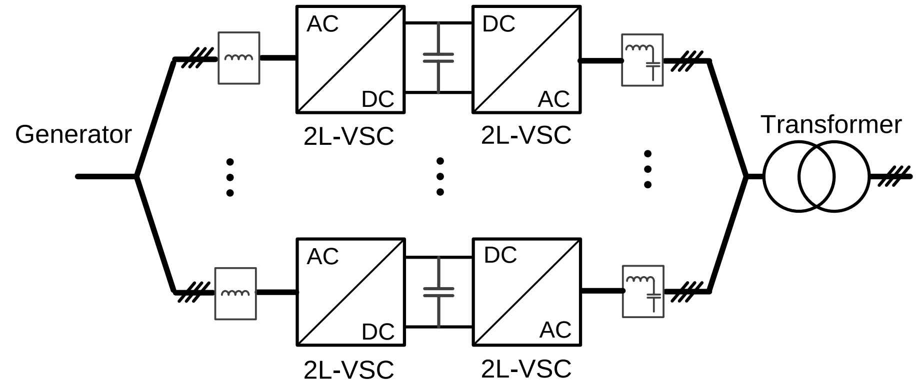
- Suitable for PMSG or SG.
- Lower cost

- Low THD on generator, low frequency torque pulsations in drive train.
- Challenge to design boost converter at MW.

Solution to extend the power capacity



Variant 1 with multi-winding generator.



Variant 2 with normal winding generator

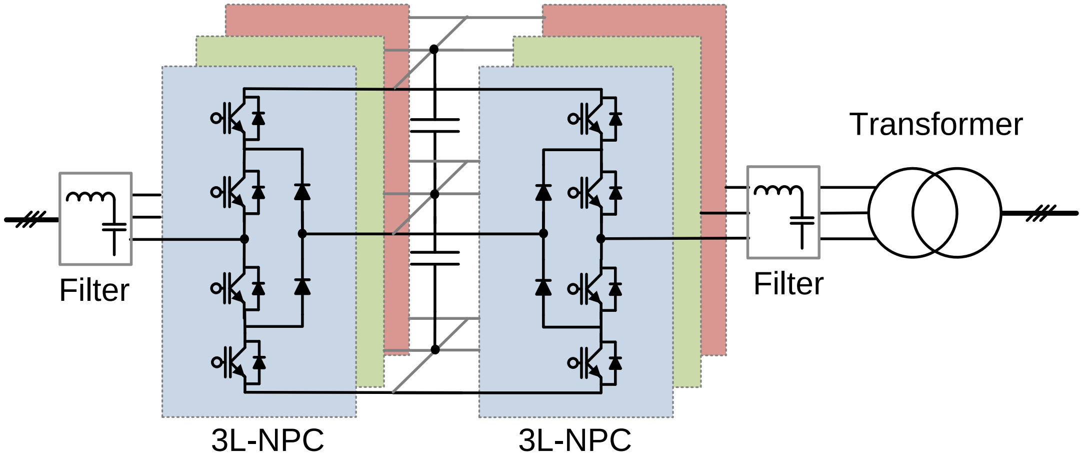
Parallel converter to extend the power capacity

- State-of-the-art solution in industry (>3MW)
- Standard and proven converter cells (2L VSC)
- Redundant and modular characteristics.

- Circulating current under common DC link with extra filter or special PWM

Multi-level converter topology – 3L-NPC

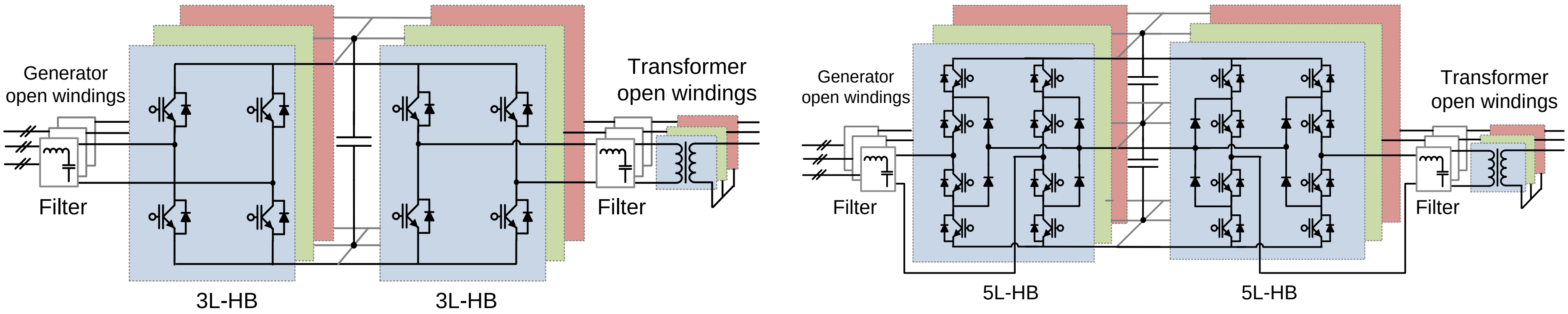
Three-level NPC



- Most commerciallized multi-level topology.
- More output voltage levels → Smaller filter
- Higher voltage, and larger output power with the same device rating
- Possible to be configured in parallel to extend power capacity.

- Unequal losses on the inner and outer power devices → derated converter power capacity
- Mid-point balance of DC link – under various operating conditions.

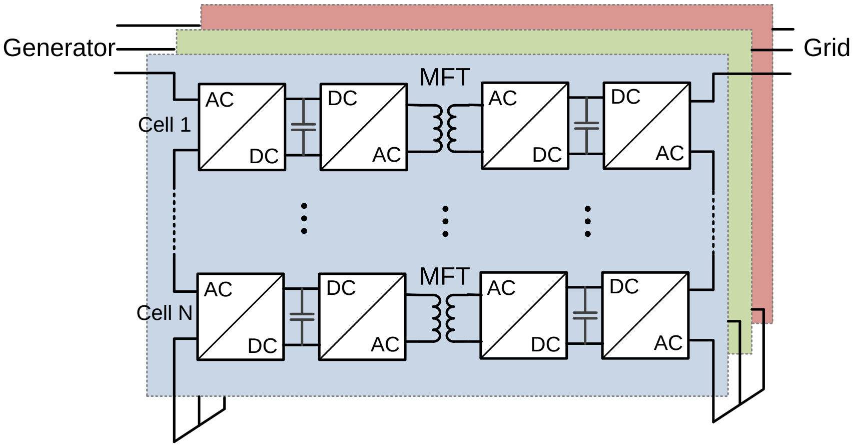
Multi-level converter topology - H-bridge back-to-back



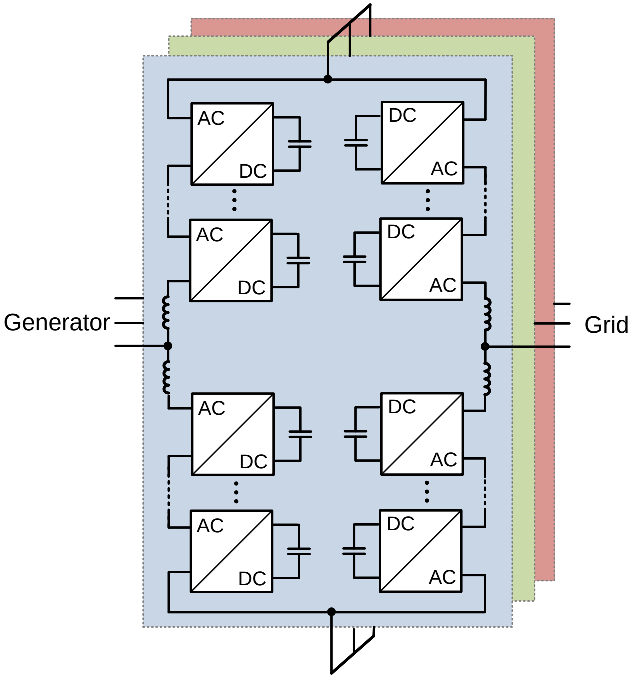
- More equal loss distribution → higher output power
- More output voltage levels compared to 2L VSC
- Redundancy if 1 or 2 phases failed.
- Higher controllability coming from zero sequence.

- Open windings for generator and transformer – higher cost
- Hard to be configured in parallel to extend power capacity.

Multi-cells converter topologies in future solution



CHB with medium frequency transformer



Modular multi level converter (MMC)

- Reduced transformer size for CHB-MFT
- Easily scalable power and voltage level.
- High redundancy and modularity.
- Filter-less design, direct connection to distribution grid.

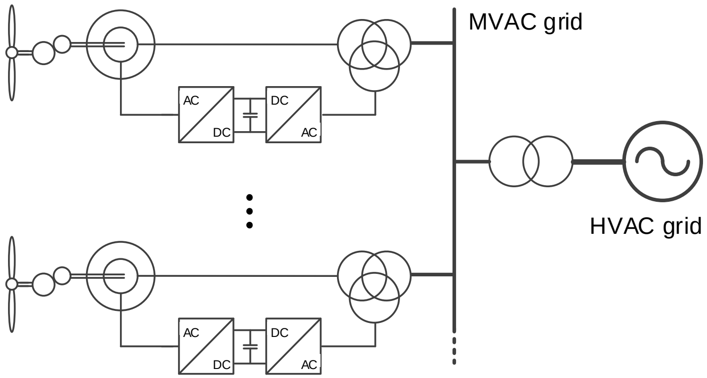
- Significantly increased components counts
- Still very high cost-of-energy.

A 400 MW off-shore Wind Power System in Denmark

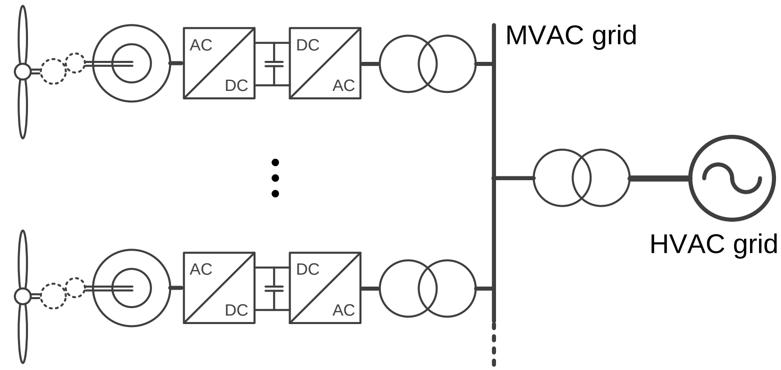
Anholt-DK (2016) – Ørsted

Wind Farm with AC and DC Power Transmission

HVAC power transmission

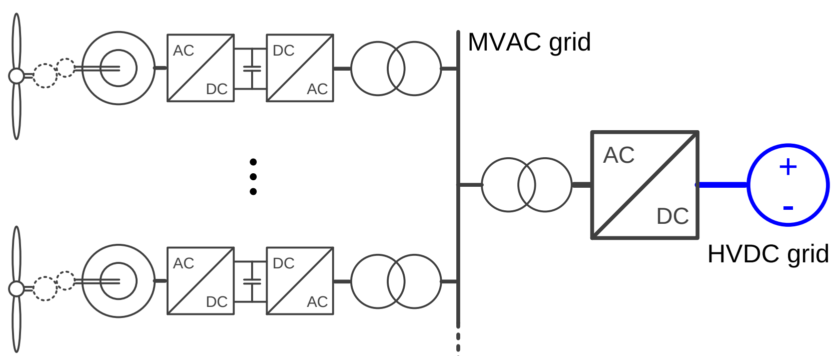


Partial-scale converter system

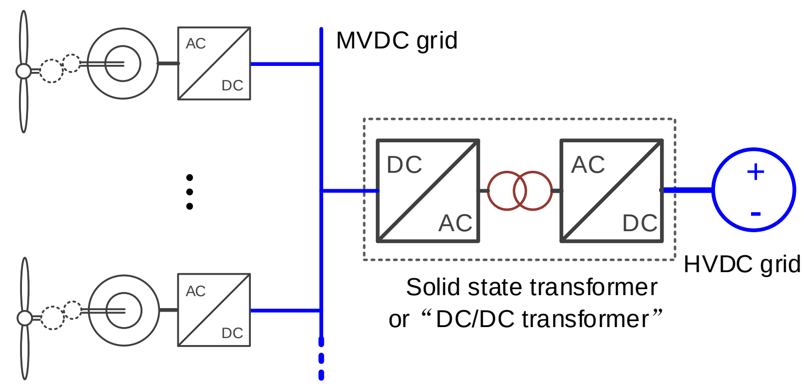


Full-scale converter system

HVDC power transmission

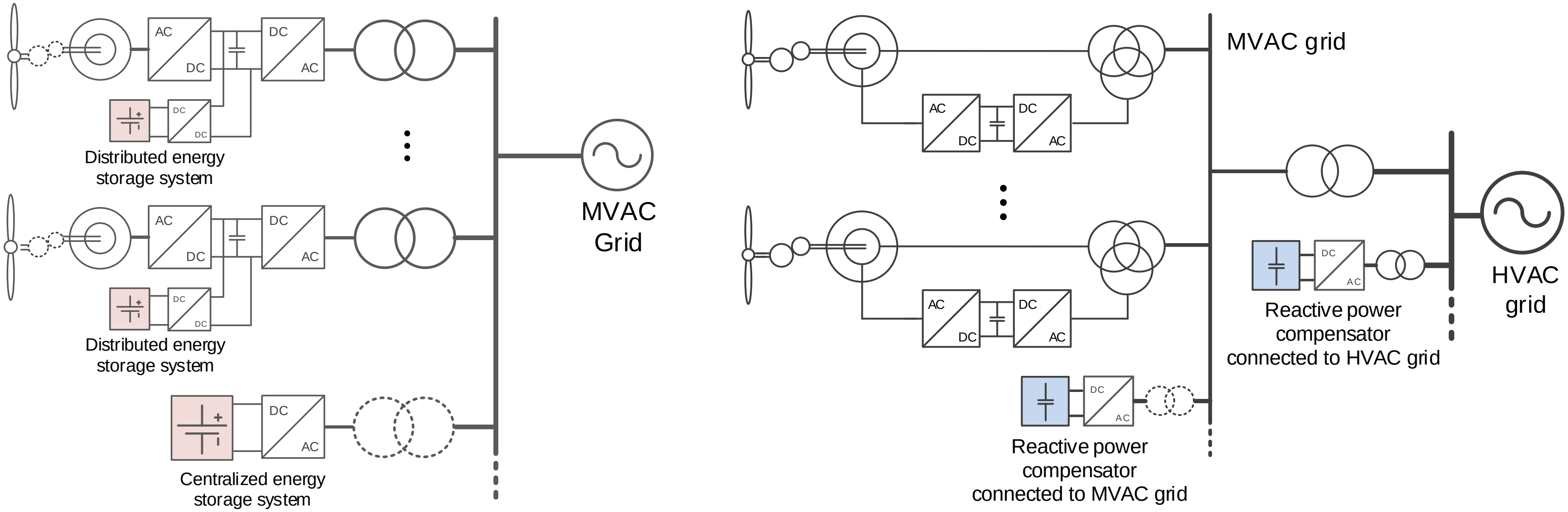


DC transmission grid



DC distribution & transmission grid

Active/Reactive Power Regulation in Wind Farm



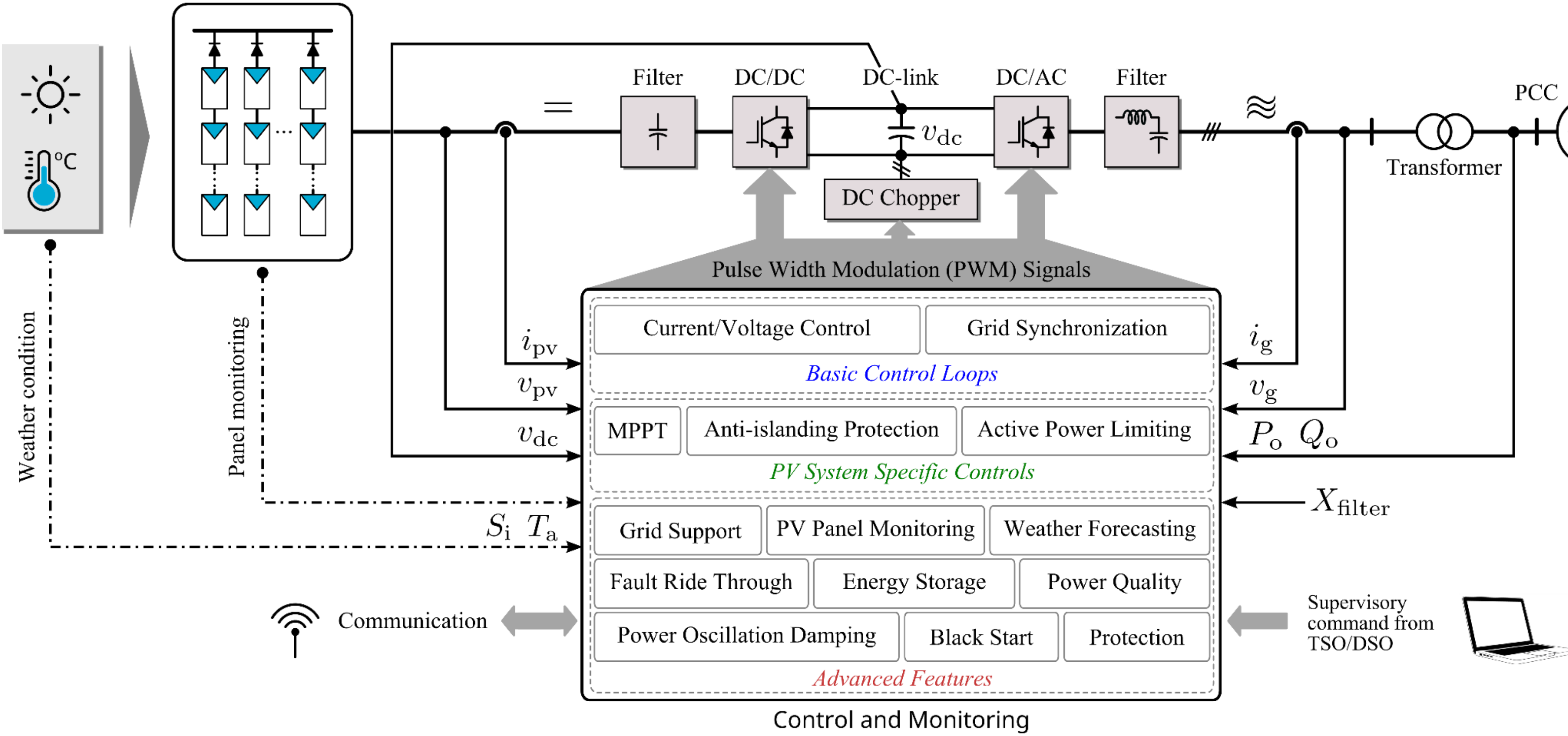
- ❖ Advanced grid support feature achieved by power converters and controls
- ❖ Local/Central storage system by batteries/supercapacitors
- ❖ Reactive power compensators
  - STATCOMs/SVCs
  - Medium-voltage distribution grid/High-voltage transmission grid

Potential power devices for wind power

	IGBT module	IGBT Press-pack	IGCT Press-pack	SiC-MOSFET module
Power Density	Low	High	High	Low
Reliability	Moderate	High	High	Unknown
Cost		High	High	High
Failure mode	Open circuit	Short circuit	Short circuit	Open circuit
Easy maintenance	+	-	-	+
Insulation of heat sink	+	-	-	+
Snubber requirement	-	-	+	-
Thermal resistance	Large	Small	Small	Moderate
Switching loss	Low	Moderate	Moderate	Low
Conduction loss	Moderate	Moderate	Moderate	Large
Gate driver	Moderate	Moderate	Large	Small
Major manufacturers	Infineon, Semikron, Mitsubishi, ABB	Westcode, ABB	ABB	Cree, Rohm, Mitsubishi
Voltage ratings	1.7 kV-6.5 kV	2.5 kV / 4.5 kV	4.5 kV / 6.5 kV	1.2 kV / 10 kV
Max. current ratings	1.5 kV - 750 A	2.3 kA / 2.4 kA	3.6 kA / 3.8 kA	180 A / 20 A

Controls for renewable energy systems

General Control Structure for PV Systems



Basic functions – all grid-tied inverters

- Grid current control
- DC voltage control
- Grid synchronization

PV specific functions – common for PV inverters

- Maximum power point tracking – MPPT
- Anti-Islanding (VDE0126, IEEE1574, etc.)
- Grid monitoring
- Plant monitoring
- Sun tracking (mechanical MPPT)

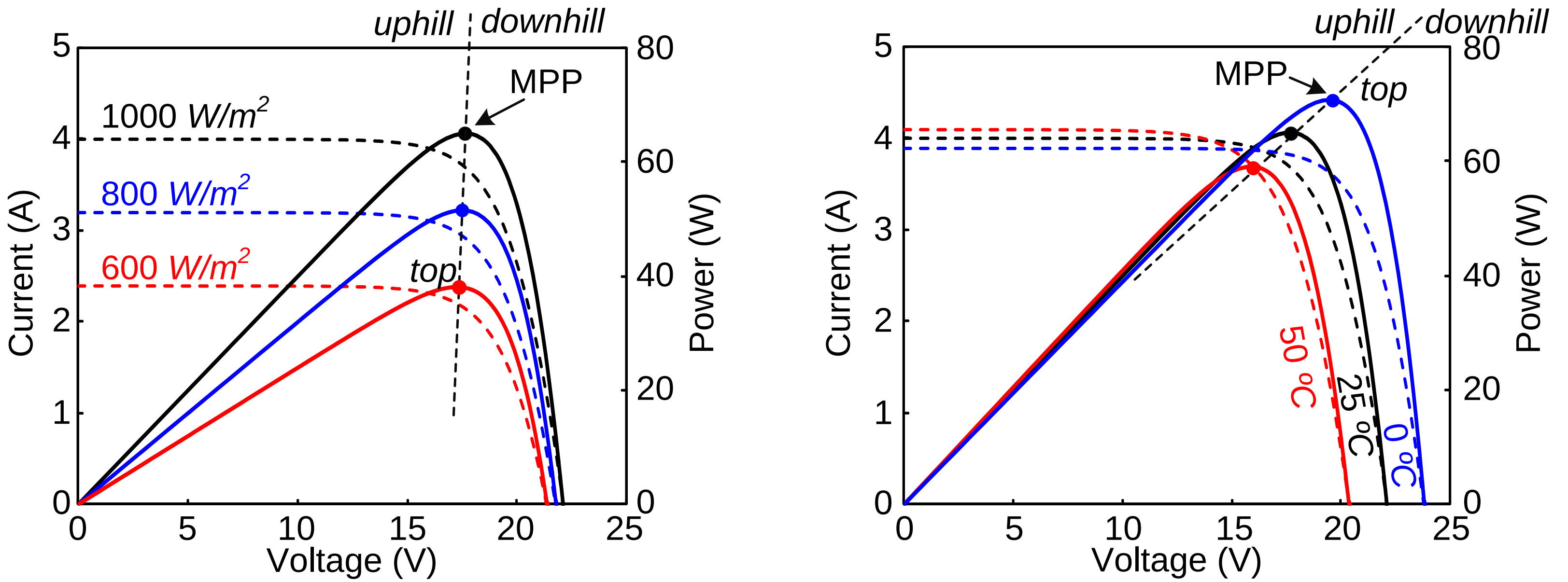
Ancillary support – in effectiveness

- Voltage control
- Fault ride-through
- Power quality
- …

Maximum Power Point Tracking (MPPT)

Role of MPPT - namely to maximize the energy harvesting

- PV array characteristic is non-linear → Maximum Power Point (MPP)
- MPP is weather-dependent → Maximum Power Point Tracking (MPPT)



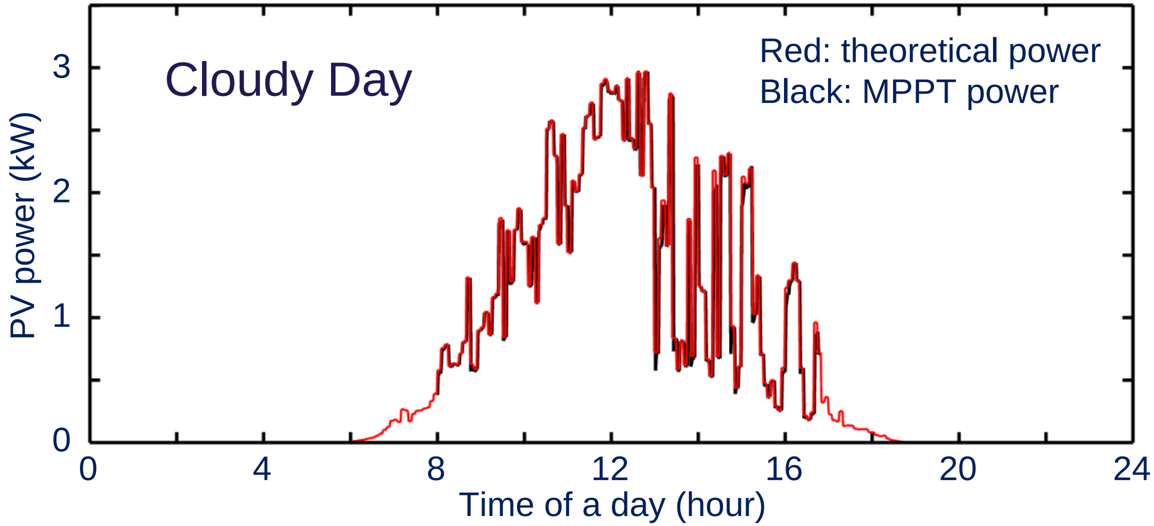
MPPT Algorithms

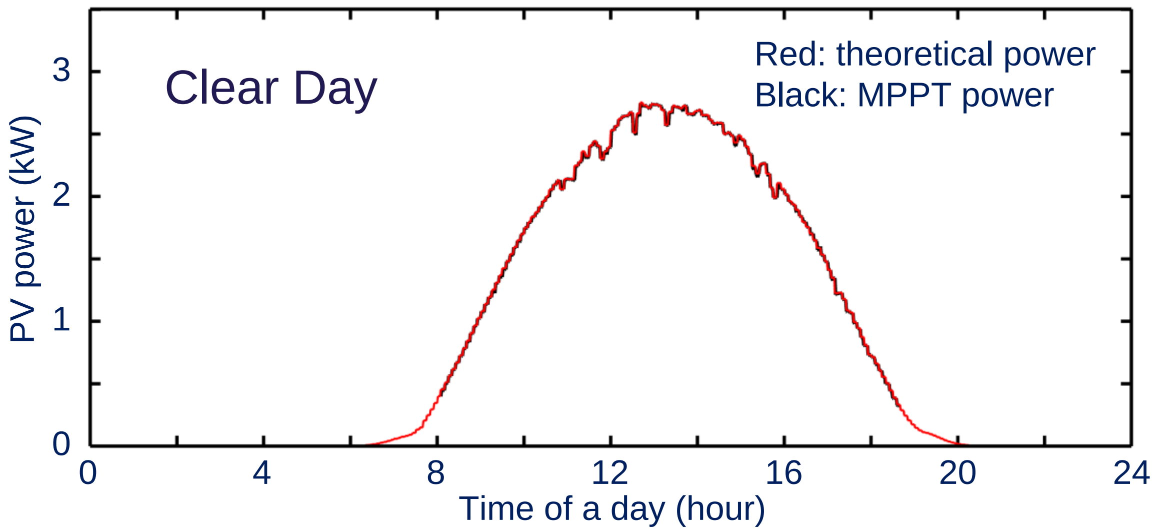
MPPT Methods	Advantages	Disadvanteges
Perturb & Observe (P&O) / Incremental Conductance	• Simple • Low computation • Generic	• Tradeoff beteween speed and accuracy • Goes to the wrong way under fast changing conditions
Constant Voltage (CV)	• Much simple • No ripple due to perturbation	• Energy is wasted during Voc measurement • Inaccuracy
Short-Current Pulse (SCP, i.e., constant current)	• Simple • No ripple due to perturbation	• Extra swith needed for short-circuiting • Inaccuracy
Ripple Correlation Control	• Ripple amplitude provides the MPP information • Noneed for perturbation	• Tradeoff between efficiency loss due to MPPT or to the ripple

P&O – the most commonly used MPPT algorithm!

Example of MPPT Control

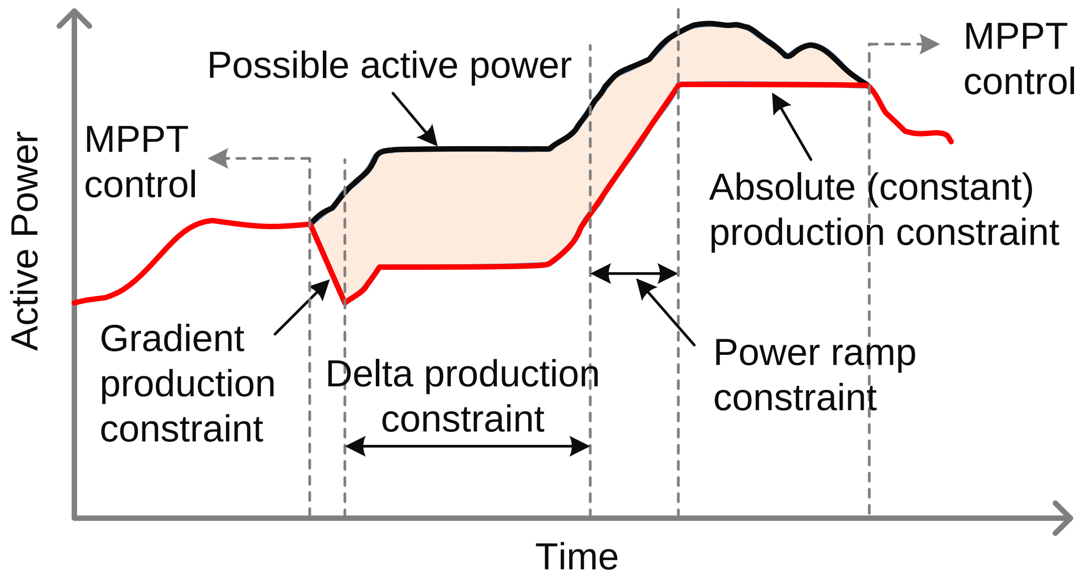
Experiments of P&O on a 3-kW double-stage system:





Constant Power Generation (CPG) Concept

CPG – one of the Active Power Control (APC) functions



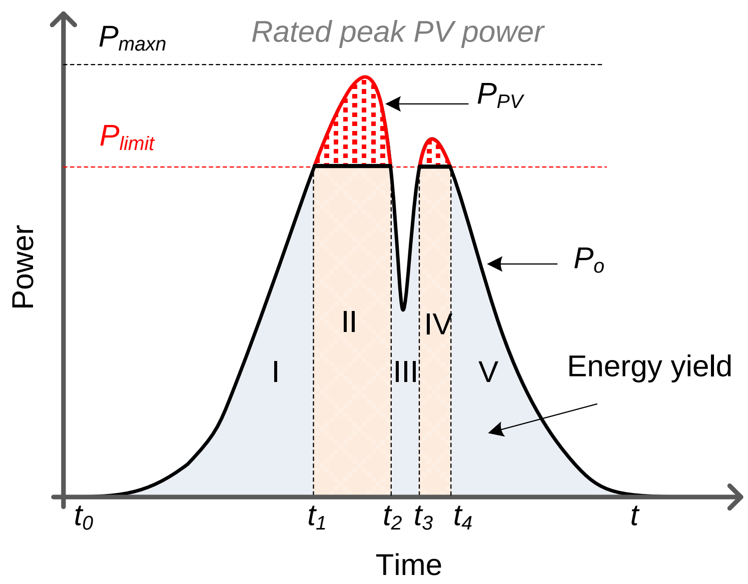
Extend the CPG function for WTS in Denmark to wide-scale PV applications?

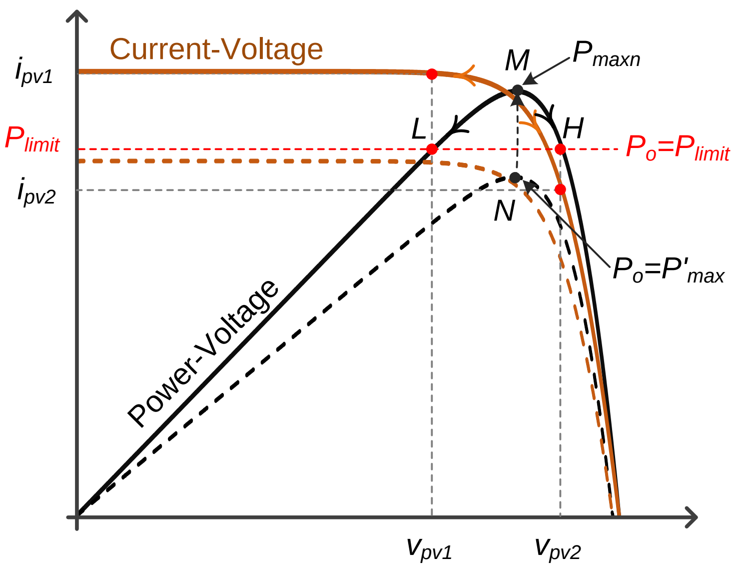
Y. Yang, F. Blaabjerg, and H. Wang, "Constant power generation of photovoltaic systems considering the distributed grid capacity," in *Proc. of APEC*, pp. 379-385, 16-20 Mar. 2014.

Constant Power Generation (CPG) Concept

Implementation of CPG in single-phase PV systems

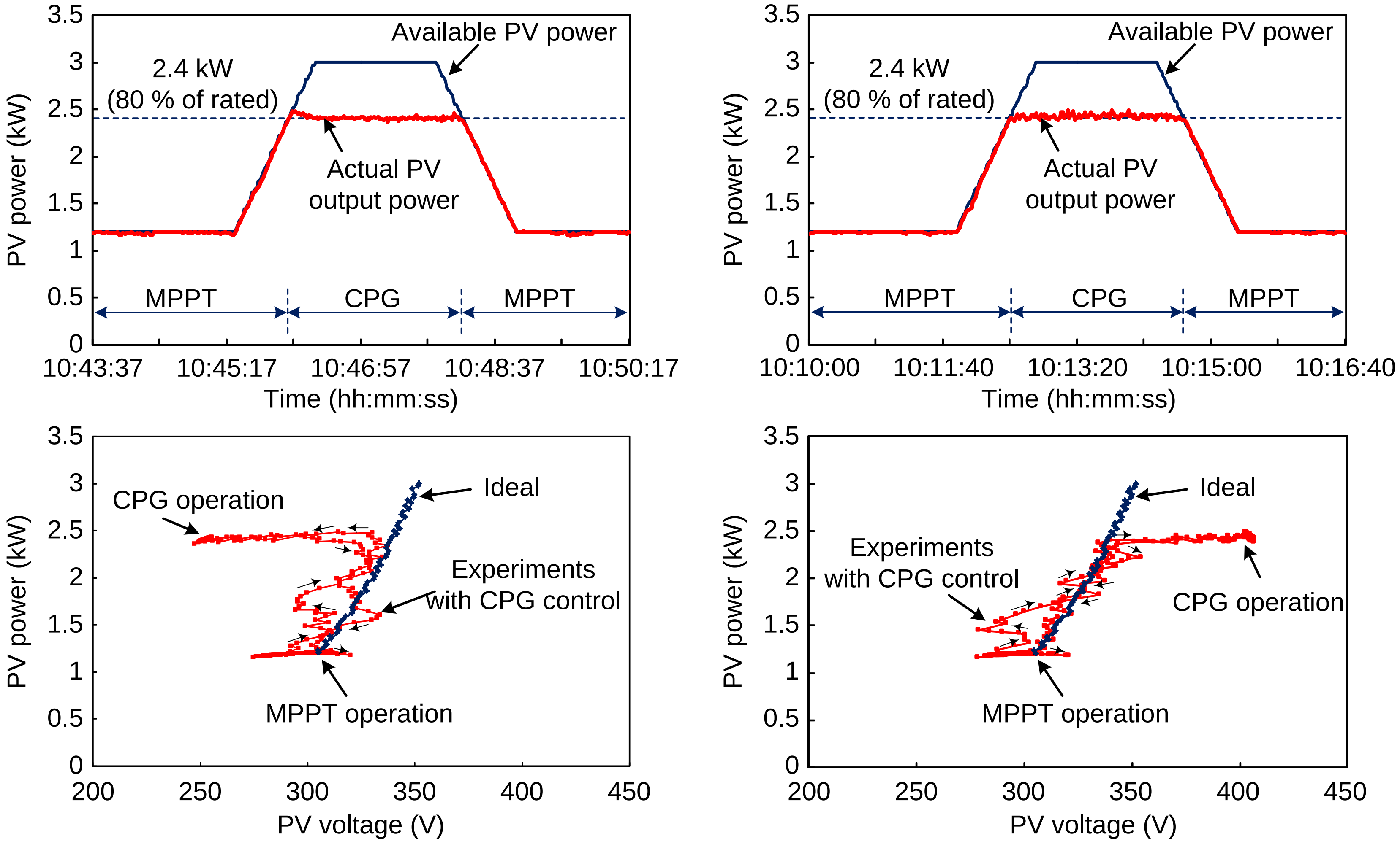
- Energy “reservoir” – storage elements
- Power management/balancing control
- Modifying the MPPT





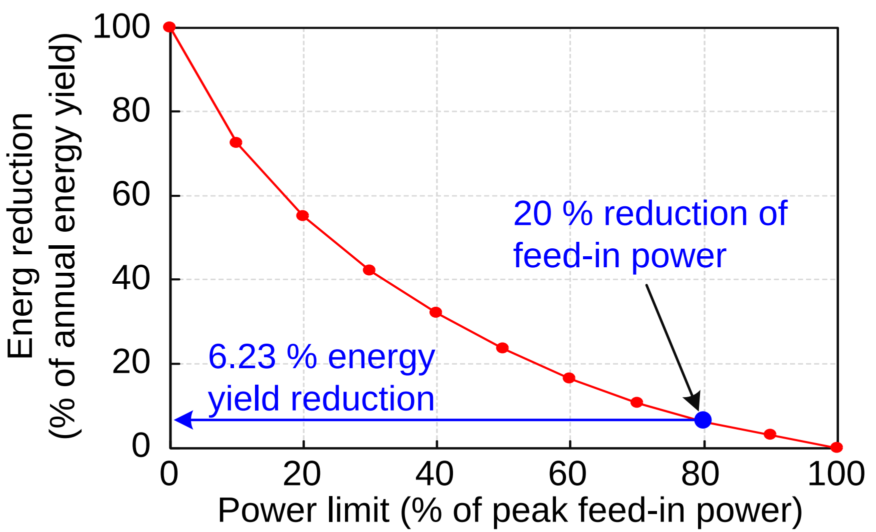
Constant Power Generation (CPG) Concept

Operation examples of CPG control (experiments)



More Stringent Requirements

Beyond the fundamentals, more stringent are coming:

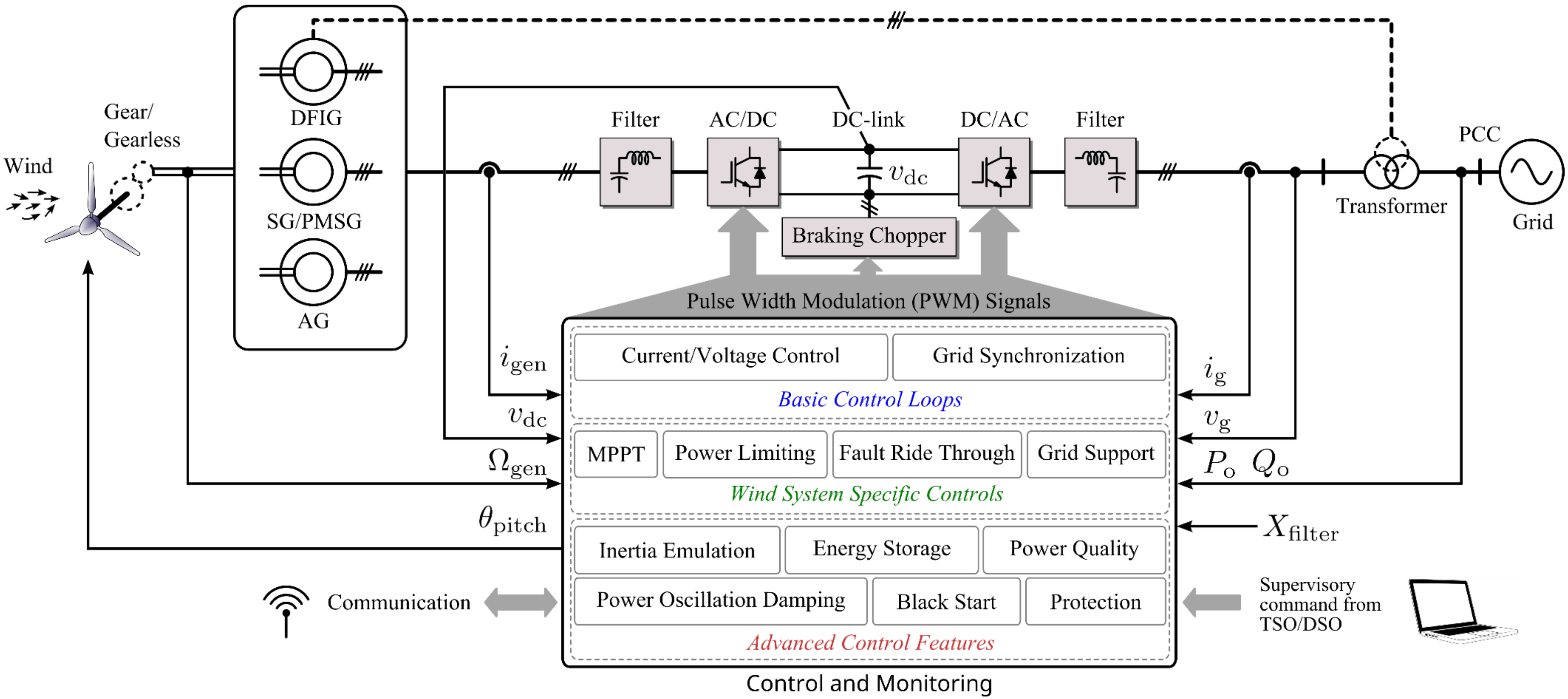


PV system with limited maximum feed-in power control.

(already in effectiveness in some countries)

- New demands for grid integrations, communications, power flow control, and protection are needed to accept more renewables.
- Power electronic converters are important in this technology transformation.

General Control structure for Wind Turbine System



Level I – Power converter

- ✓ Grid synchronization
- ✓ Converter current control
- ✓ DC voltage control

Level II – Wind turbine

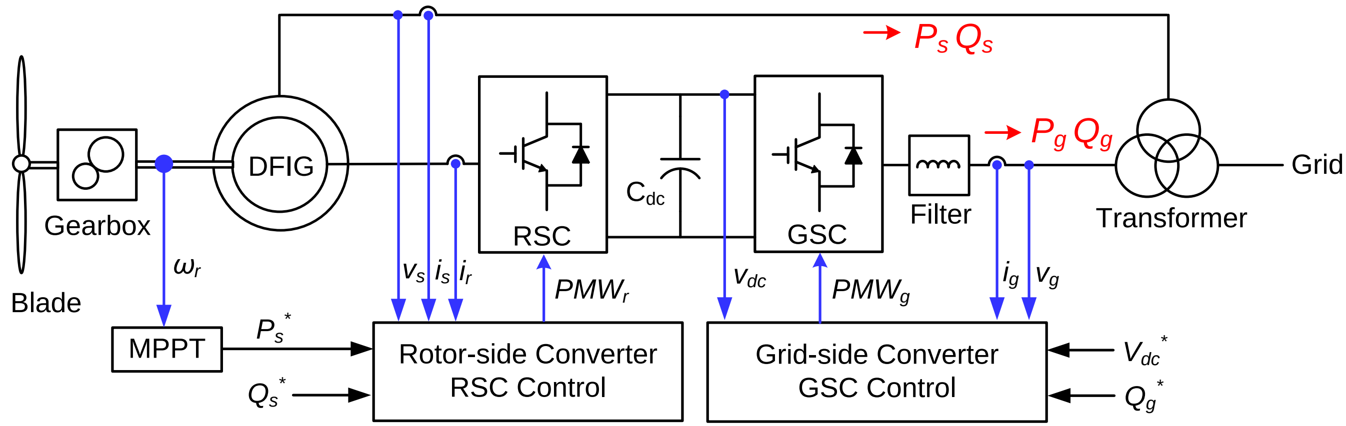
- ✓ MPPT
- ✓ Turbine pitch control
- ✓ DC Chopper

Level III – Grid integration

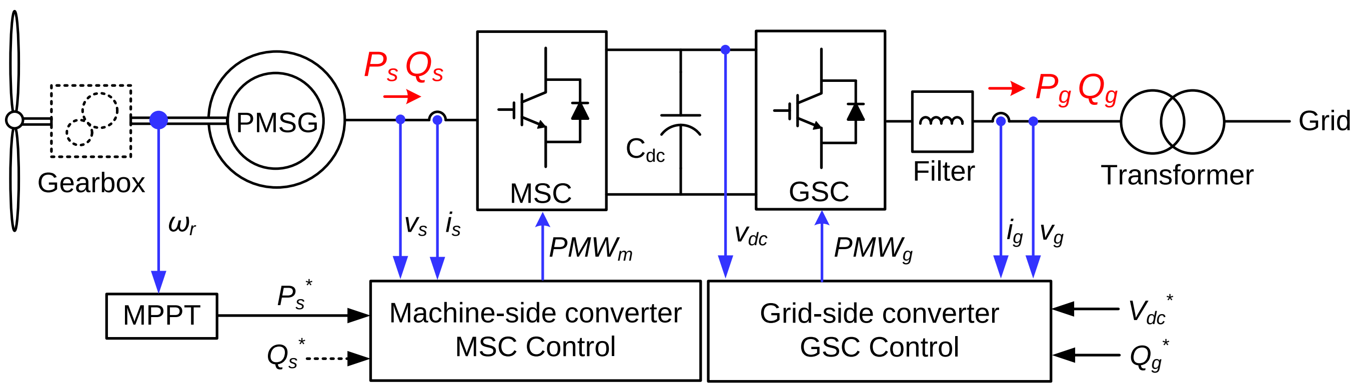
- ✓ Voltage regulation
- ✓ Frequency regulation
- ✓ Power quality

MPPT Control for two wind turbine systems

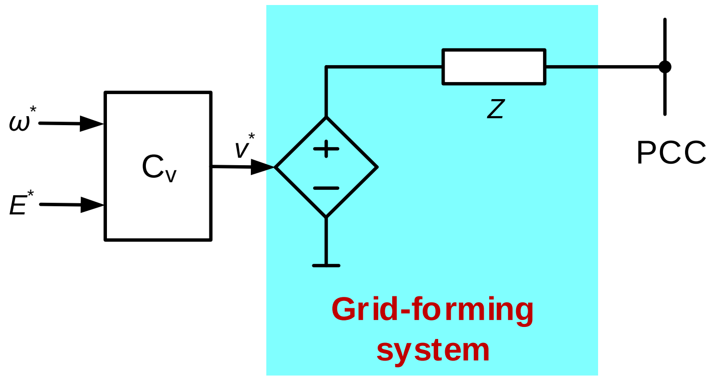
- DFIG system

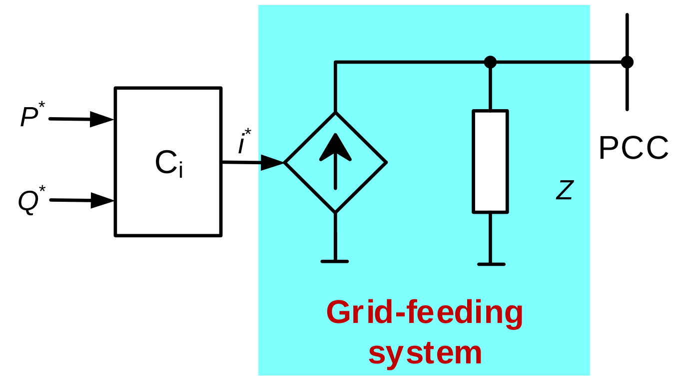


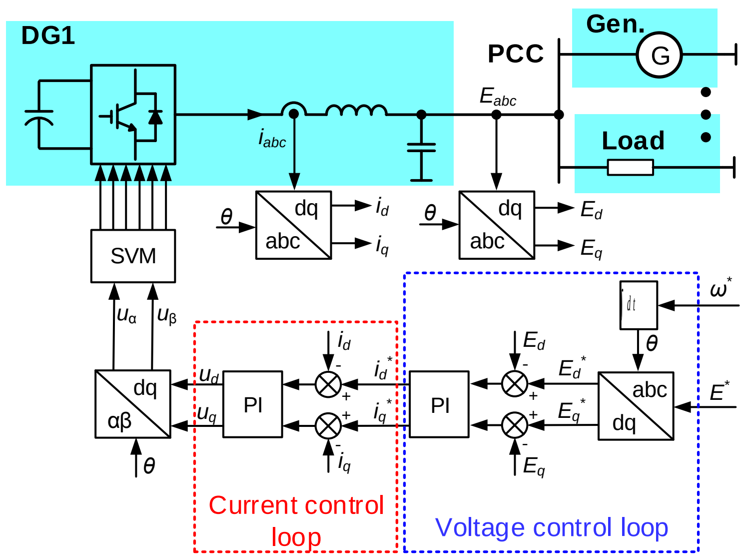
- PMSG system

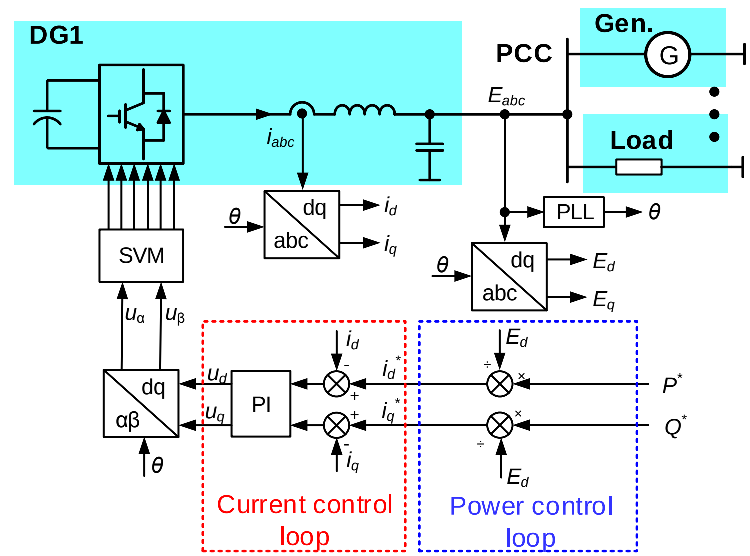


Grid-forming & Grid-feeding Systems (examples)





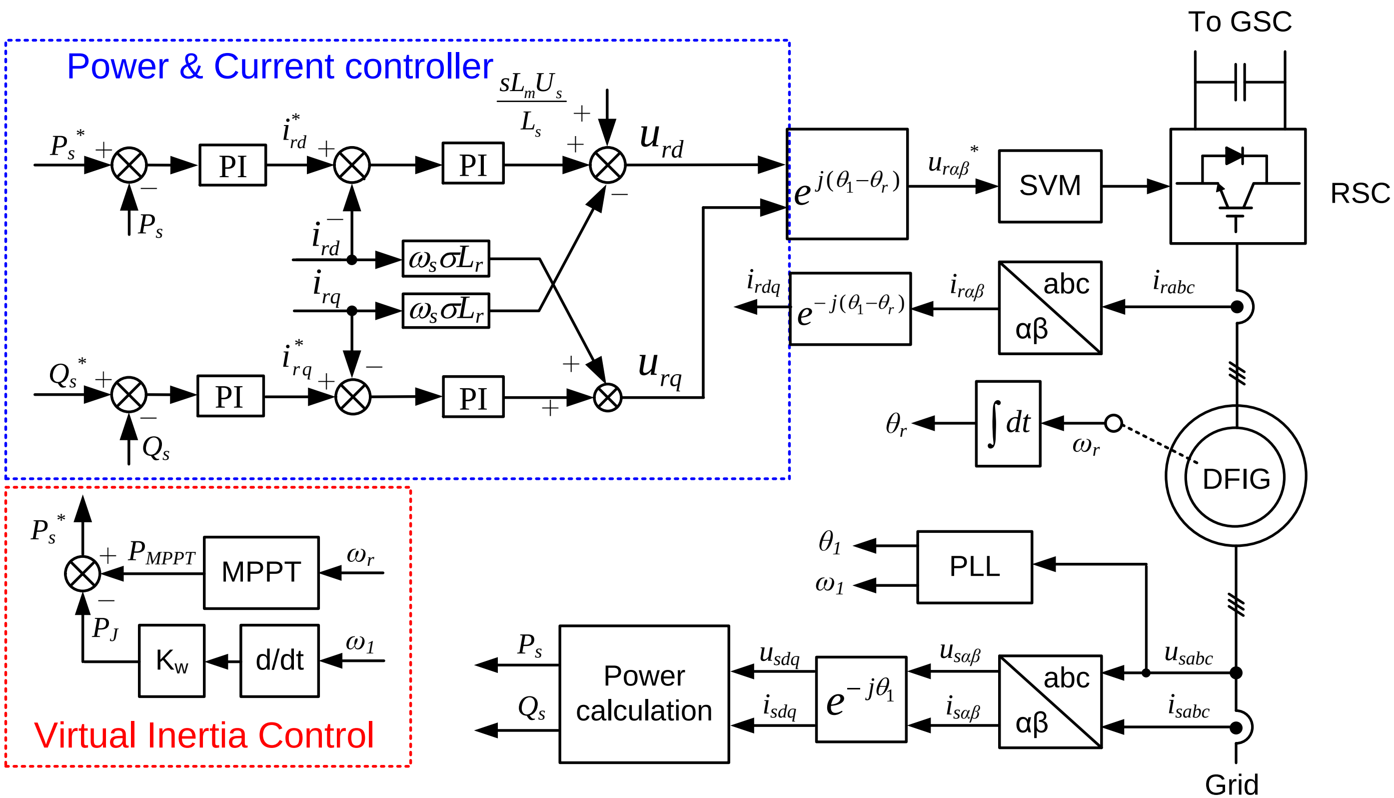




- Voltage-source based inverter
- Control reference: voltage amp. & freq.

- Current-source based inverter
- Control reference: active & reactive power

Virtual Inertia Emulation – DFIG example

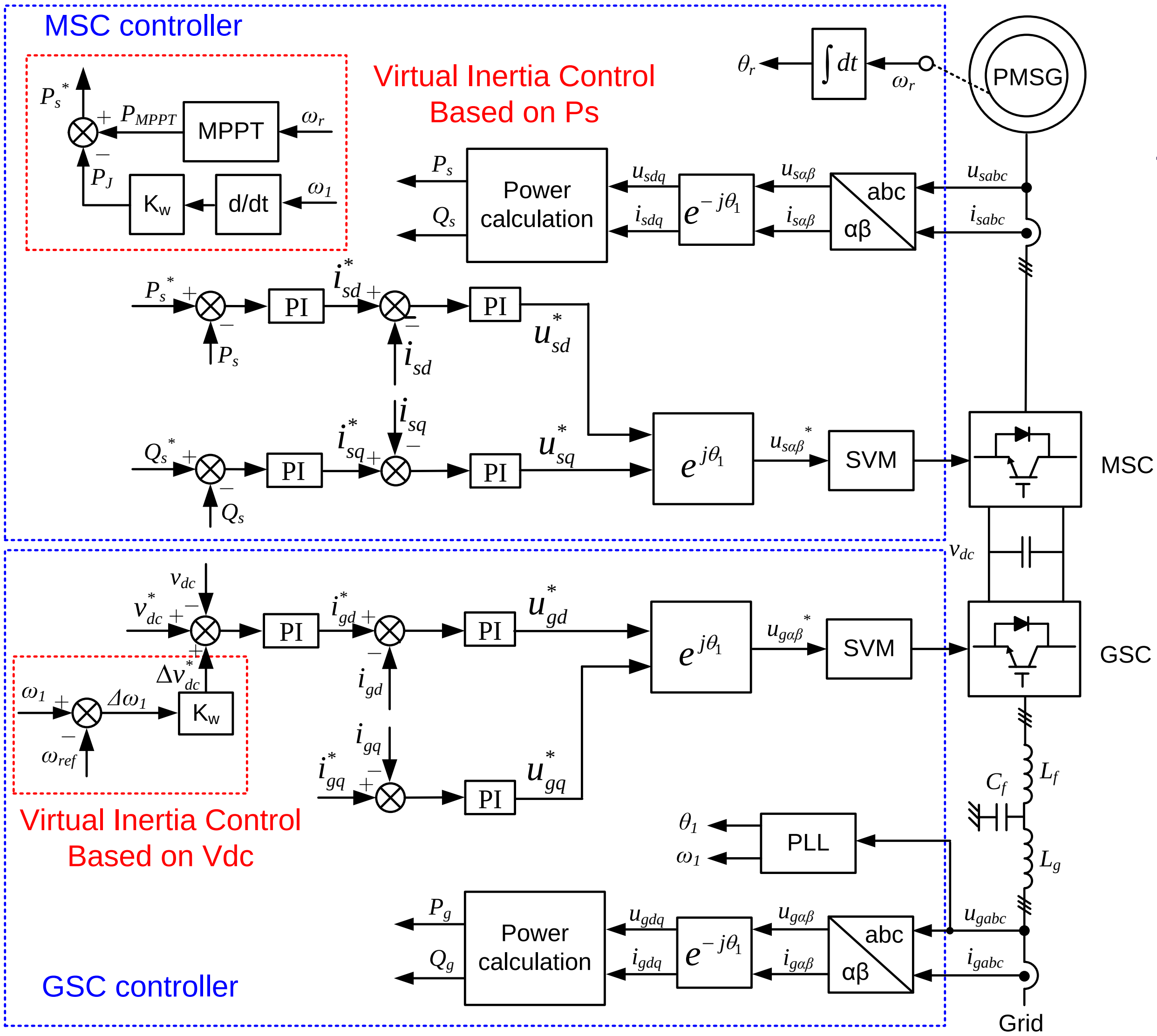


The reference value of stator output active power:

$$P_s^* = P_{MPPT} - P_J = f_{MPPT}(\omega_r) - K_\omega \frac{d\omega_1}{dt}$$

where, P_{MPPT} and P_J are the output power reference by MPPT and virtual inertia control respectively. ω_1 and ω_r are the grid angular speed and rotor angular speed respectively. K_ω is the coefficient of virtual inertia control.

Virtual Inertia Emulation in PMSG based Wind System



Two virtual inertia solutions:

1) Virtual inertia control based on Ps in MSC controller;

2) Virtual inertia control based on Vdc in GSC controller;

Summary

Summary of presentation

- Cost of Energy more down incl low failure-rate
- Reliability important topic for future
- Control of power electronic system emerging
- Stability in solid state based power grid as well as conventional power system
- More stringent grid codes will still be developed
- Still new technology in renewables (WBG etc..)
- New power converters with new power devices

- And much more..

Acknowledgment

Dr. Yongheng Yang, Dr. Xiongfei Wang and Dr. Dao Zhou, Dr. Ke Ma

from Department of Energy Technology
Aalborg University

Look at

www.et.aau.dk
www.corpe.et.aau.dk
www.harmony.et.aau.dk

Thank you for your attention!

Aalborg University
Department of Energy Technology
Aalborg, Denmark

AALBORG UNIVERSITY
DENMARK

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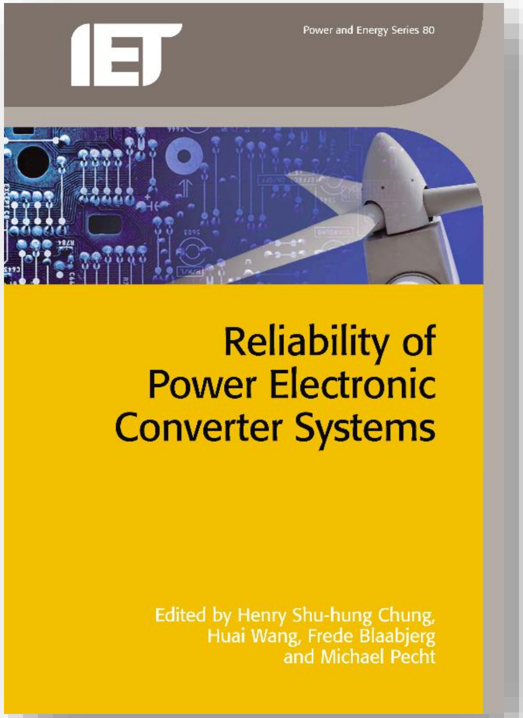

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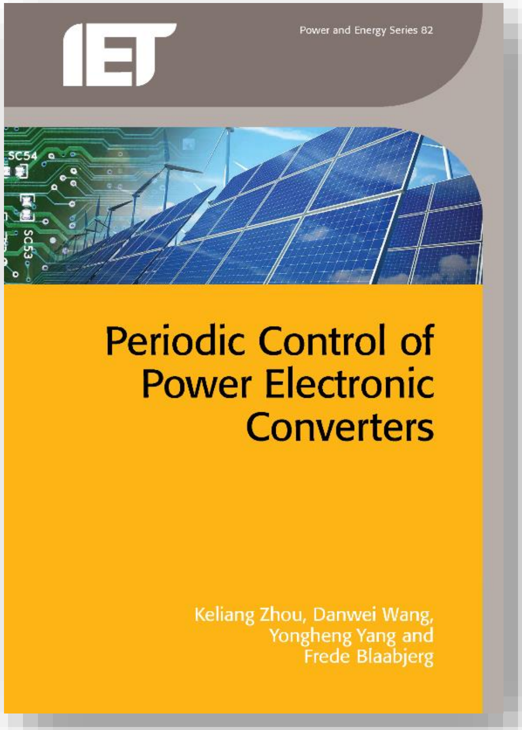

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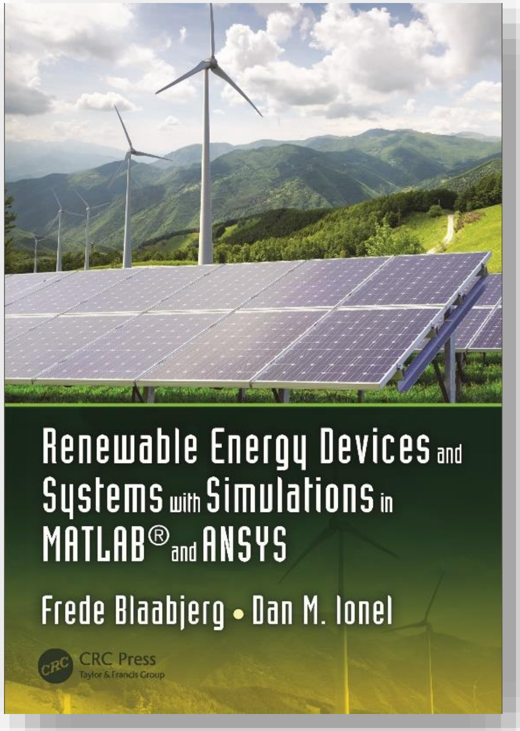

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