Impact of interfacing PV inverters, EV charges, battery storage

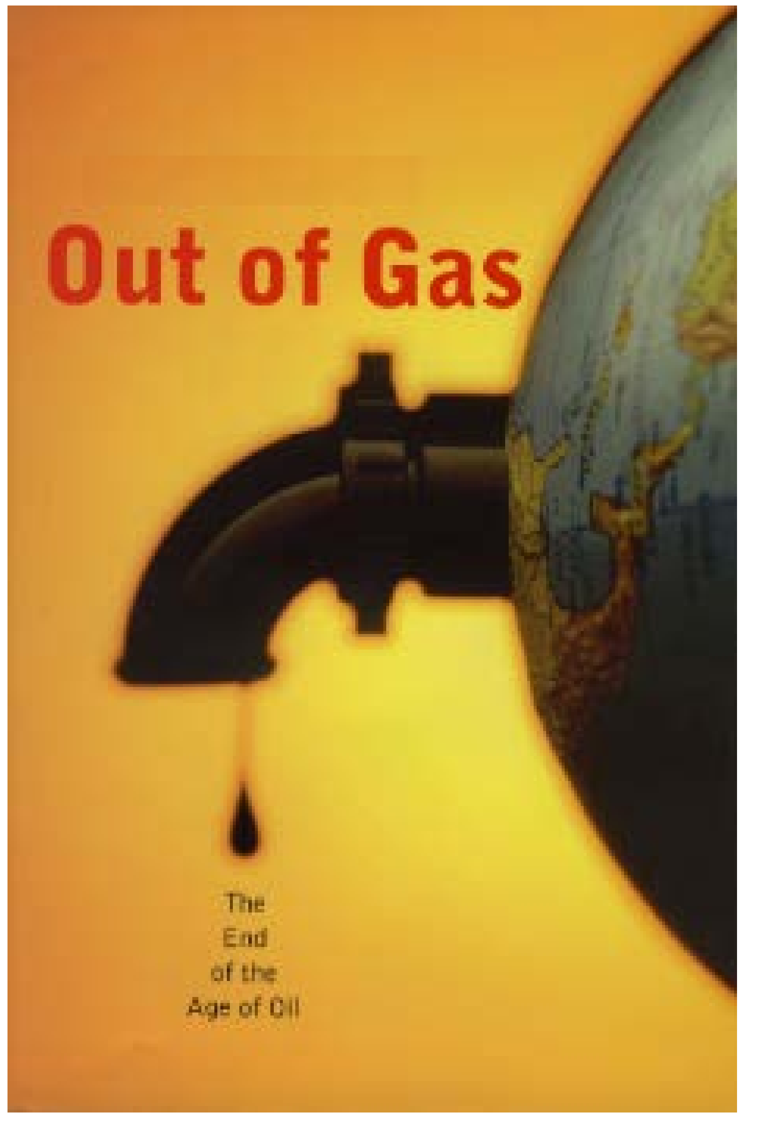
Dr. Haitham Abu-Rub
Chair of Electrical and Computer Engineering Program
Managing Director of the Smart Grid Center – Extension in Qatar (SGC-Q)
Electrical and Computer Engineering Department | Texas A&M University at Qatar

Agenda

Introduction	Power Electronic Topologies	Energy Storage systems	Integration of EV
7 Slides	11 Slides	7 Slides	6 Slides

Energy Major Challenges

- **Energy Security:** fuel supply resources for the future
- **Economic Growth:** accommodation of the developing nations' needs
- **Environmental Effects:** global warming and emission control
- **Electricity System Reliability:** assurance of integrity of electric power infrastructure



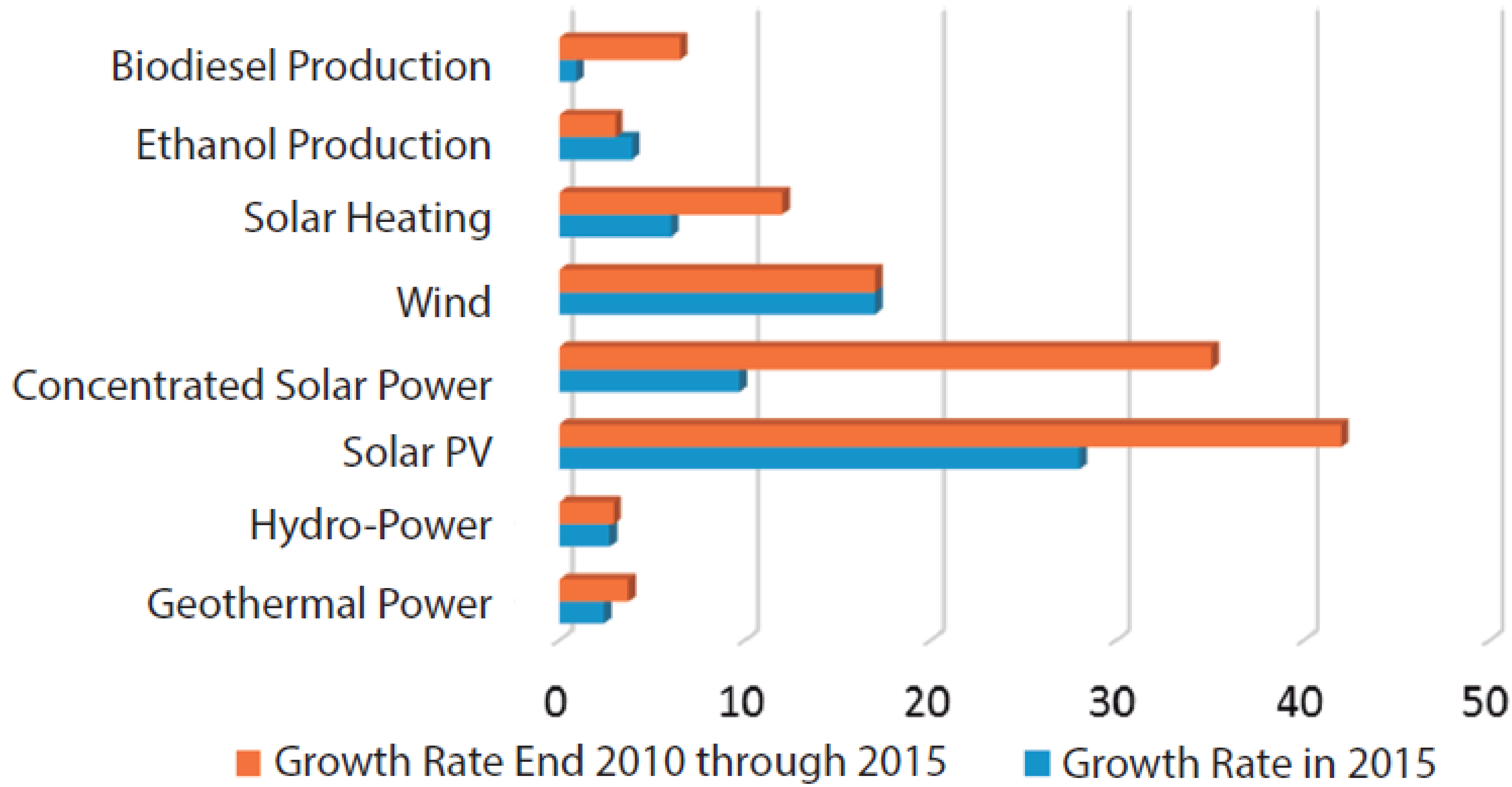
Why renewable energy resources?

- Fossil fuels life expectancy
- Global warming
- Green house gas emission

Introduction (Cont.)

The renewable energy growth rate in different areas is increasing sharply with promising target as shown in Figure

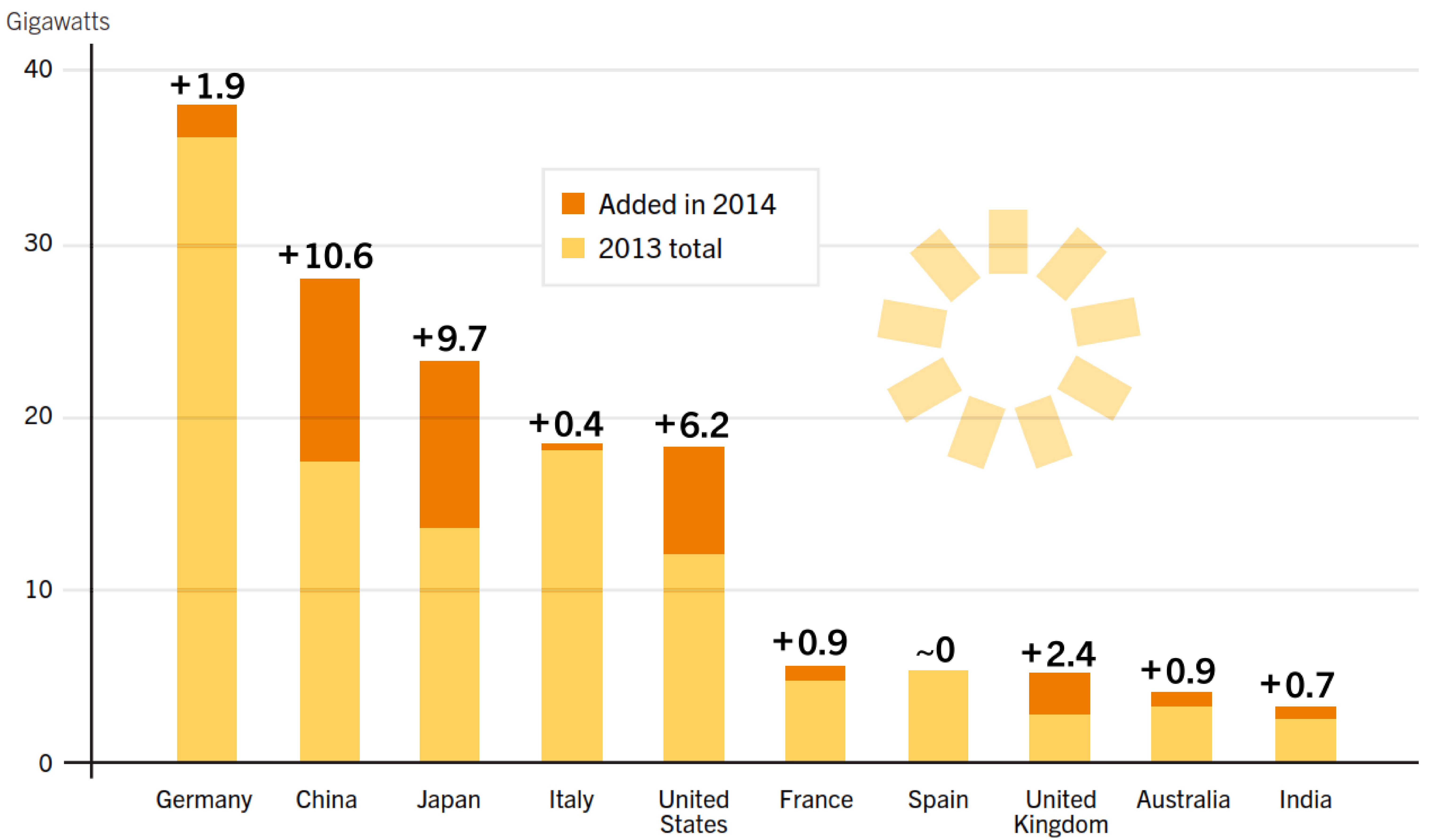
Renewable energies are expected to overtake coal around 2030 to become the largest power source and achieving 34% of total energy generation on 2040.



Source: "World energy outlook 2015," in *International Energy Agency (IEA)*, 2015.

Solar PV Energy

Solar PV global capacity, shares of top 10 countries



Source: Solar photovoltaic (PV)", http://decarboni.se/publications/renewables-2014-global-status-report/solar-photovoltaics-pv

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Introduction (Cont.)

Installation prices of residential, commercial, and utility scale PV systems

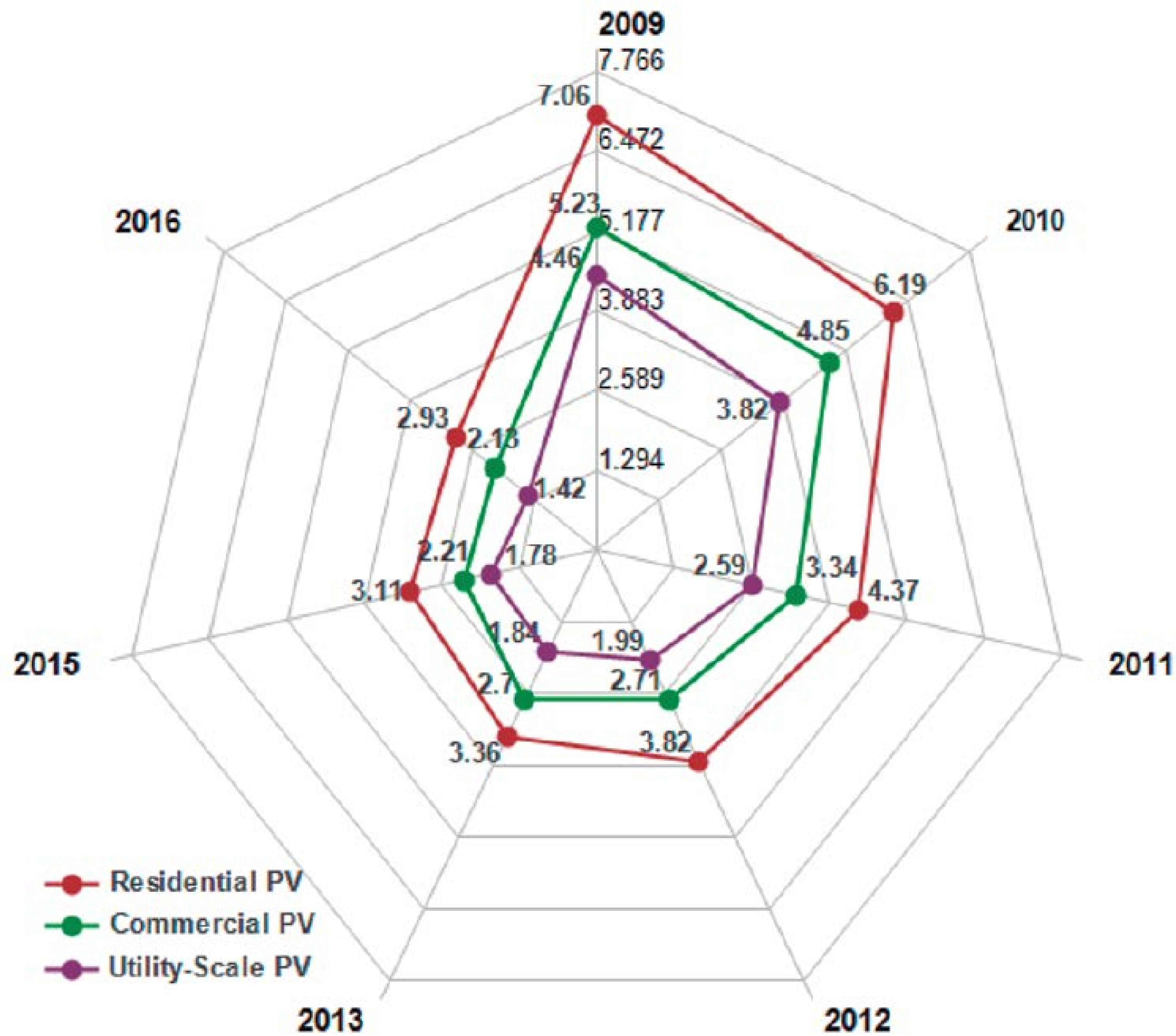


Figure shows trends of installation prices of residential and commercial PV systems. For the installation of large-scale PV power systems, prices are commonly below 1.79 USD/watt now. In some places, PV power has reached grid parity, the cost at which is competitive with coal or gas-fired generations.

Source: “Photovoltaic system pricing trends,” in *Solar Energy Industries Association (SEIA)*, 2011.

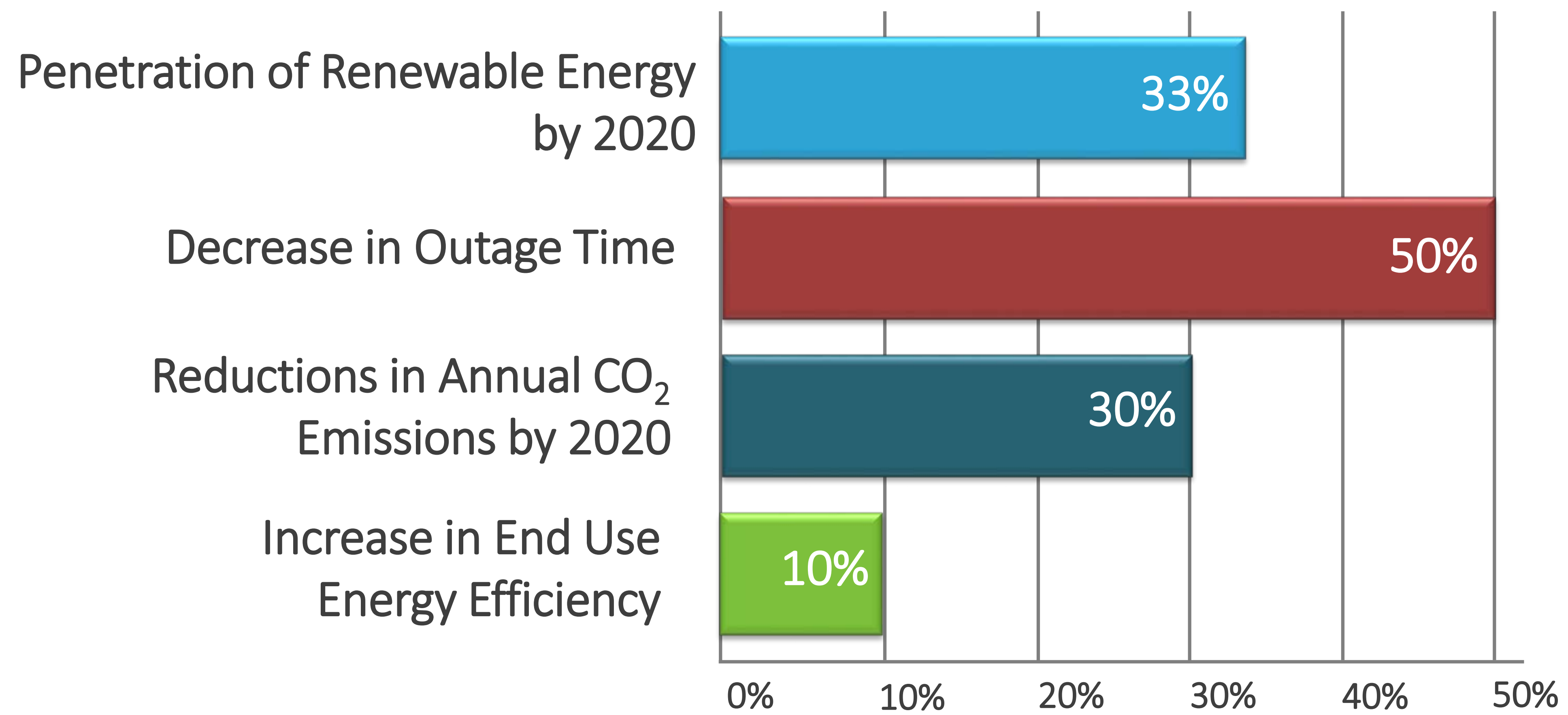
Introduction (Cont.)

Penetration of Renewable Energy:

Decrease in Outage Time

Reduced Annual CO_2 Emissions

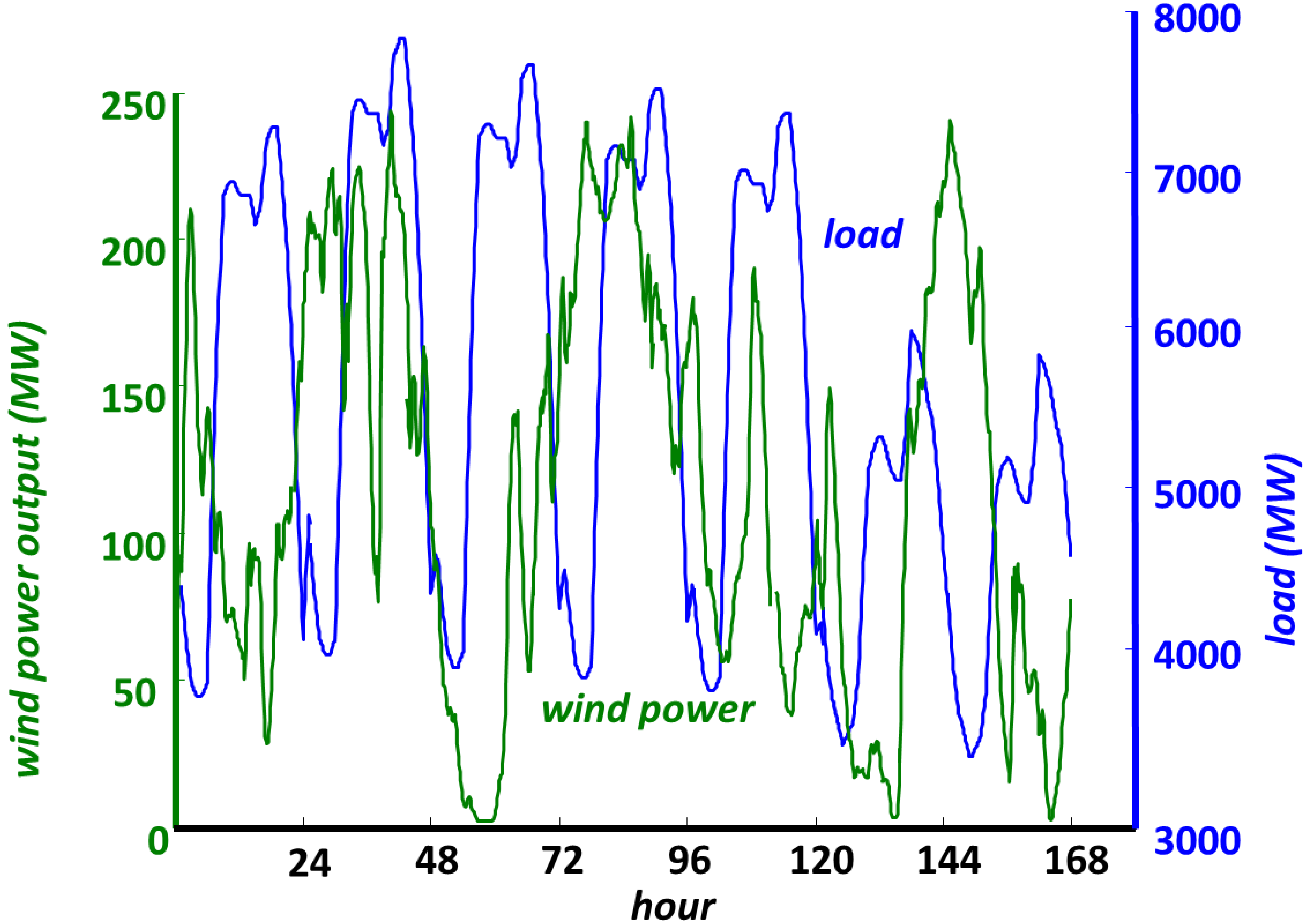
Increase in Energy Efficiency



Source: Prof. Mladen Kezunovic, ARC2014, QF, Doha Qatar

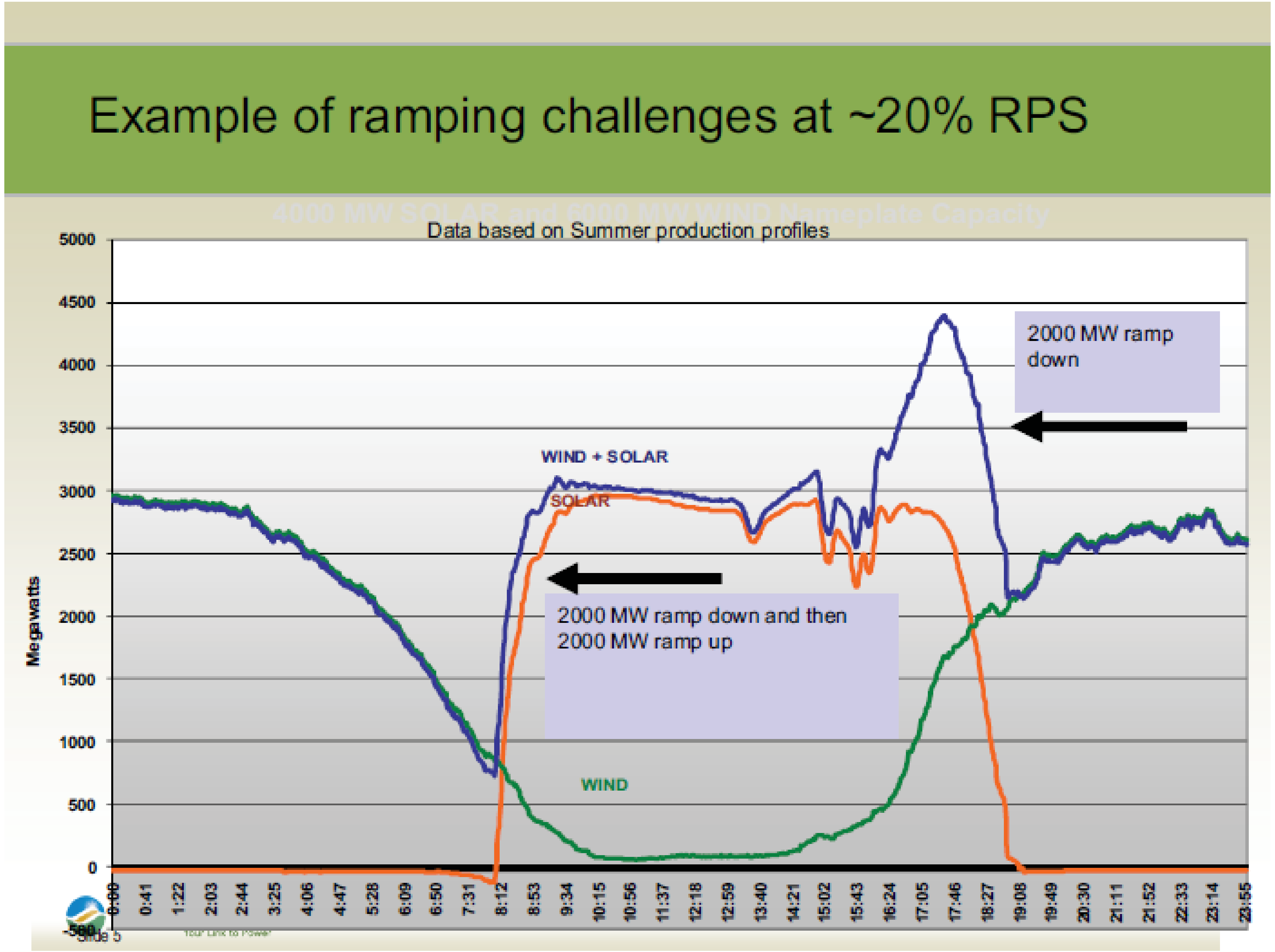
Introduction (Cont.)

Load vs. Generation



Source: Prof. Mladen Kezunovic, ARC2014, QF, Doha Qatar

Load and Generation



Source: Prof. Mladen Kezunovic, ARC2014, QF, Doha Qatar

Power Electronic Topologies

Introduction

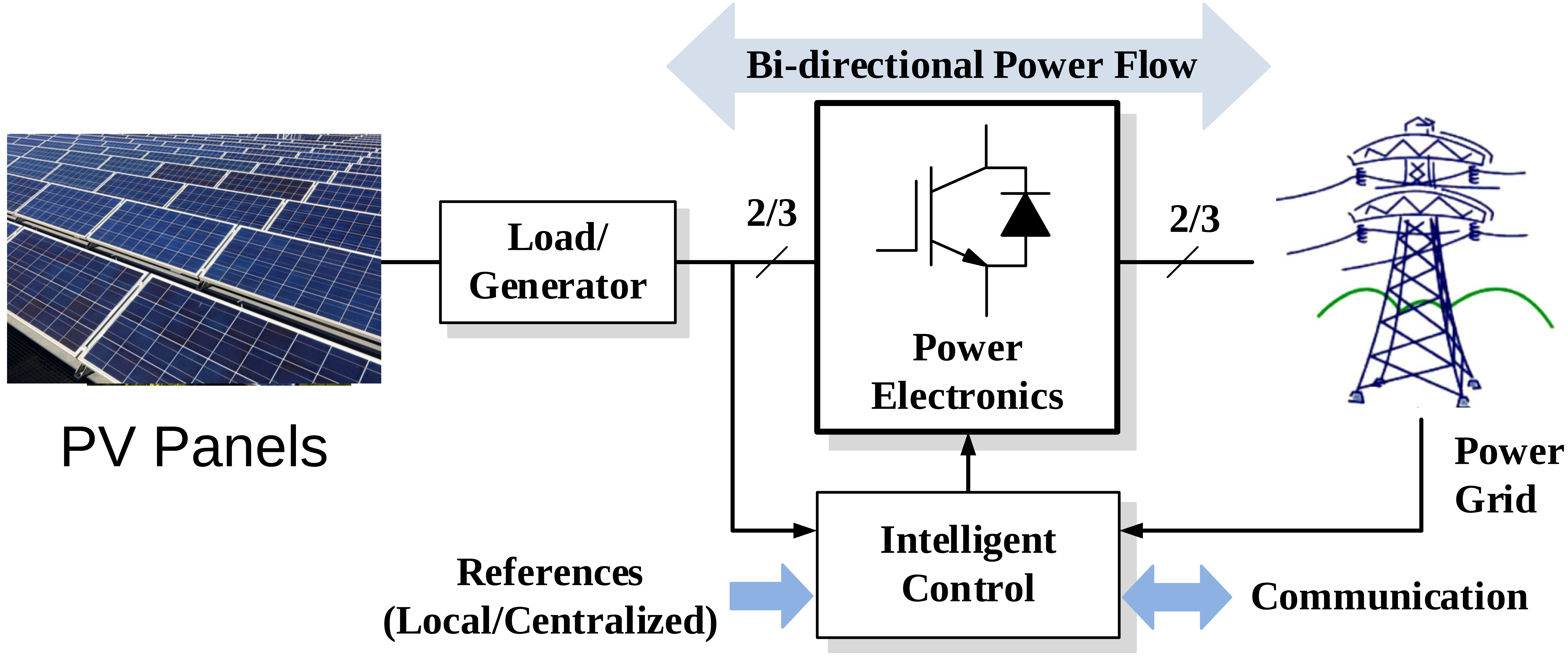
Energy Storage systems

7 Slides	11 Slides	7 Slides	6 Slides

Power Electronic Topologies

Integration of EV

Power Electronic Topologies



Important issues for power converters:

- Reliability/security of supply
- Efficiency, cost, volume, protection
- Control active and reactive power - grid
- Ride-through operation and monitoring - grid
- Power electronics enabling technology

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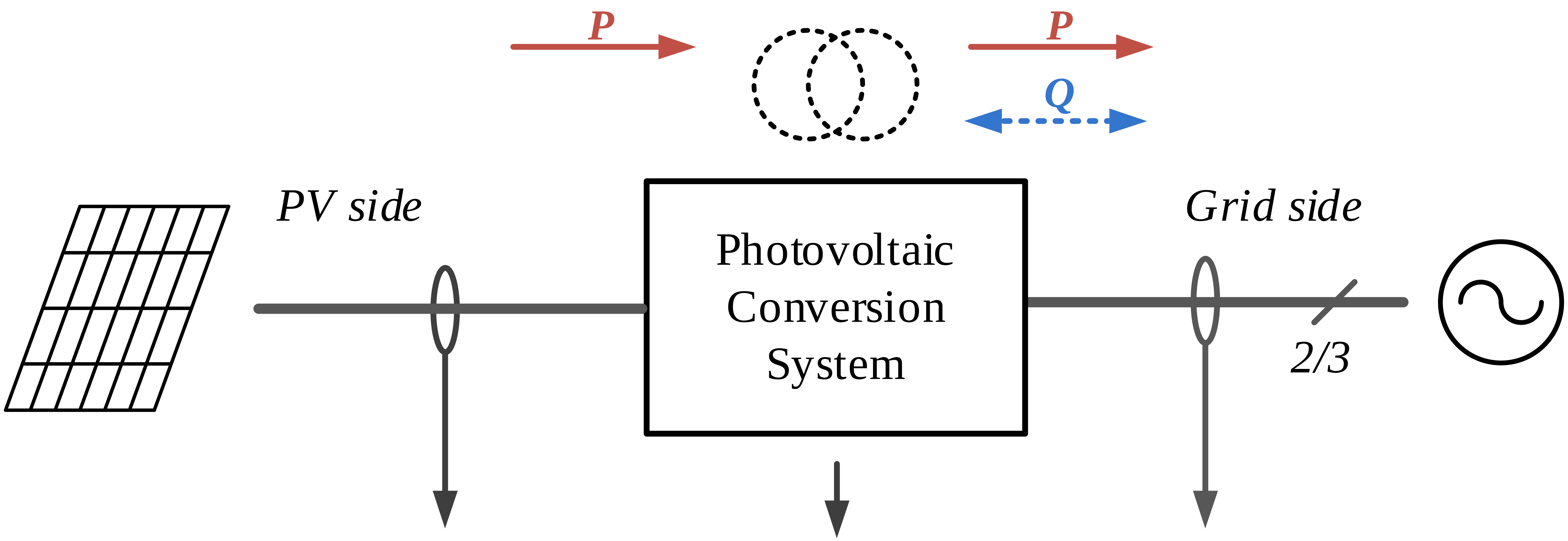
Power Electronic Topologies

General Requirements & Specific Requirements



1. Controllable *I* / (MPPT)
2. DC voltage / current

...

1. High efficiency
2. Temp. insensitive
3. Reliable
4. Safety
5. Communications

1. Low THD

In case of large scale:

2. *Freq.* – *P* control
3. *U* – *Q* control
4. Fault ride-through

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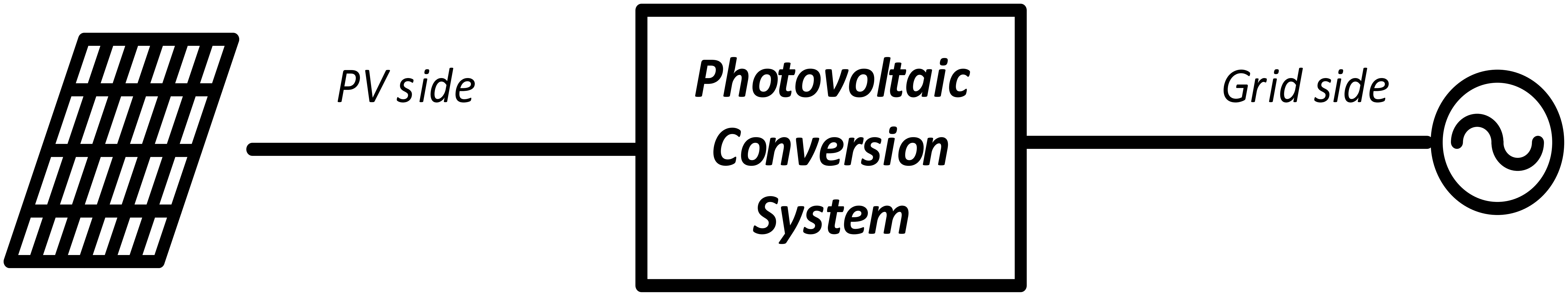
Usual Requirements for PV Converters



Performance Requirements

1. Installation Cost
2. Minimization of leakage current
3. High Efficiency
4. Power Density

Legal Requirements

1. Galvanic Isolation
2. Anti-Islanding Detection
3. Codes and standards

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Summary of international standards and recommendations for PV systems

Standard	Focus
$EN50524$	Data sheet and name plate for photovoltaic inverters in grid parallel operation
$EN50530$	Overall efficiency of photovoltaic inverters including the procedure to measure the accuracy of the MPPT
$UL1741$	Inverters, converters, controllers and interconnection system equipment for use in stand-alone or grid-connected power systems
$IEEE1547$	Interconnecting distributed resources with electric power systems including voltage and frequency regulation, power quality, ride-through capability and anti-islanding operation
$IEC61683$	Power conditioners - Procedure for measuring efficiency
$IEC62109-1$	Safety of Power Converters for Use in Photovoltaic Power Systems - Part 1: General Requirements
$IEC62109-2$	Safety of Power Converters for Use in Photovoltaic Power Systems - Part 2: Particular Requirements for Inverters

Classification of GCI

Grid Connected Inverters (GCI) are classified into two catagories based on the electrical isolation between the PV panels and the utility grid.

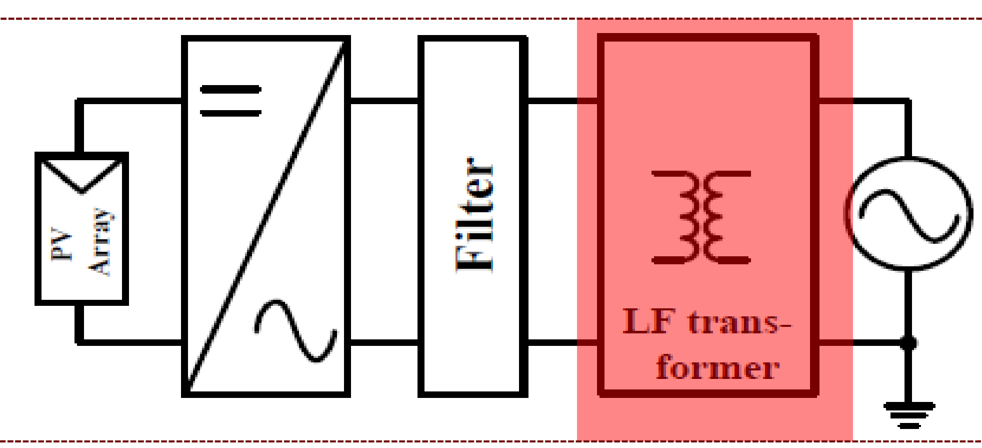
Grid Connected Inverter

Galvanic Isolation

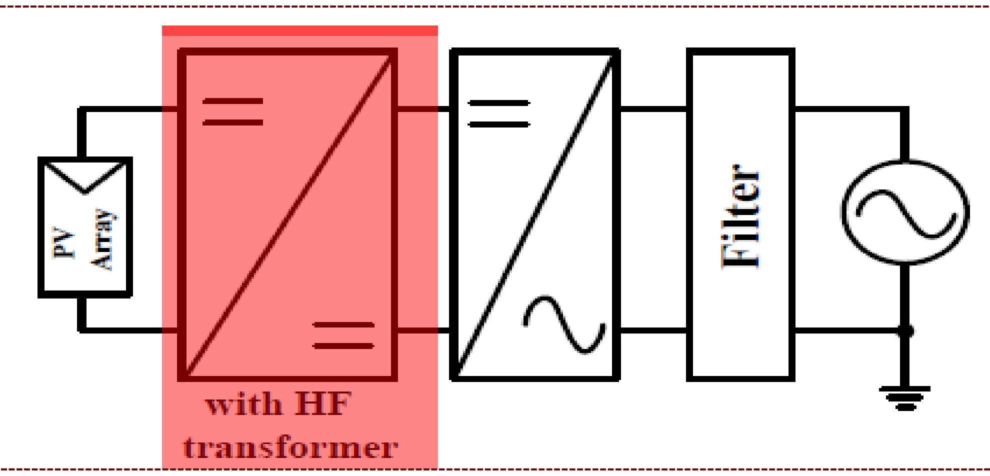
Without Galvanic Isolation

With Transformer

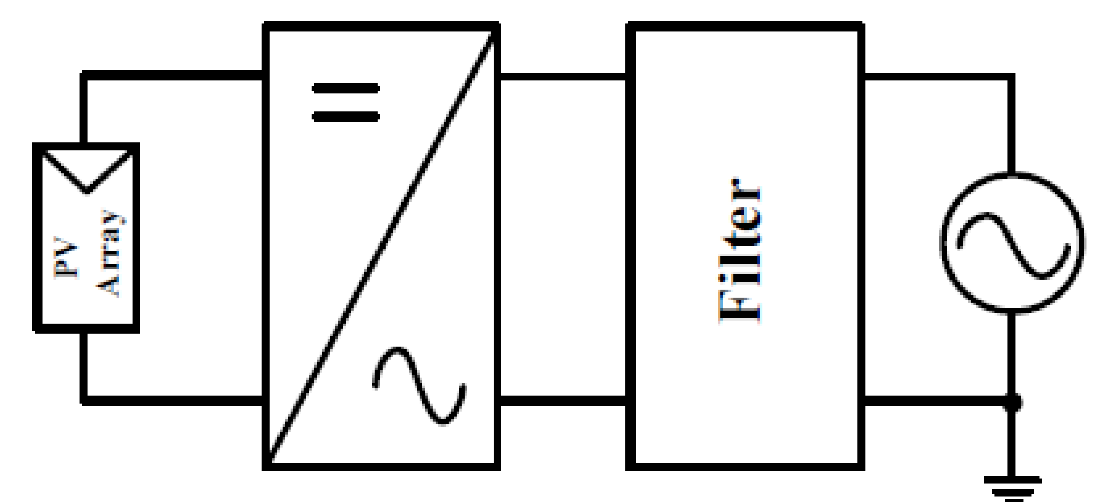
Low Frequency Transformer



High Frequency Transformer



Transformerless



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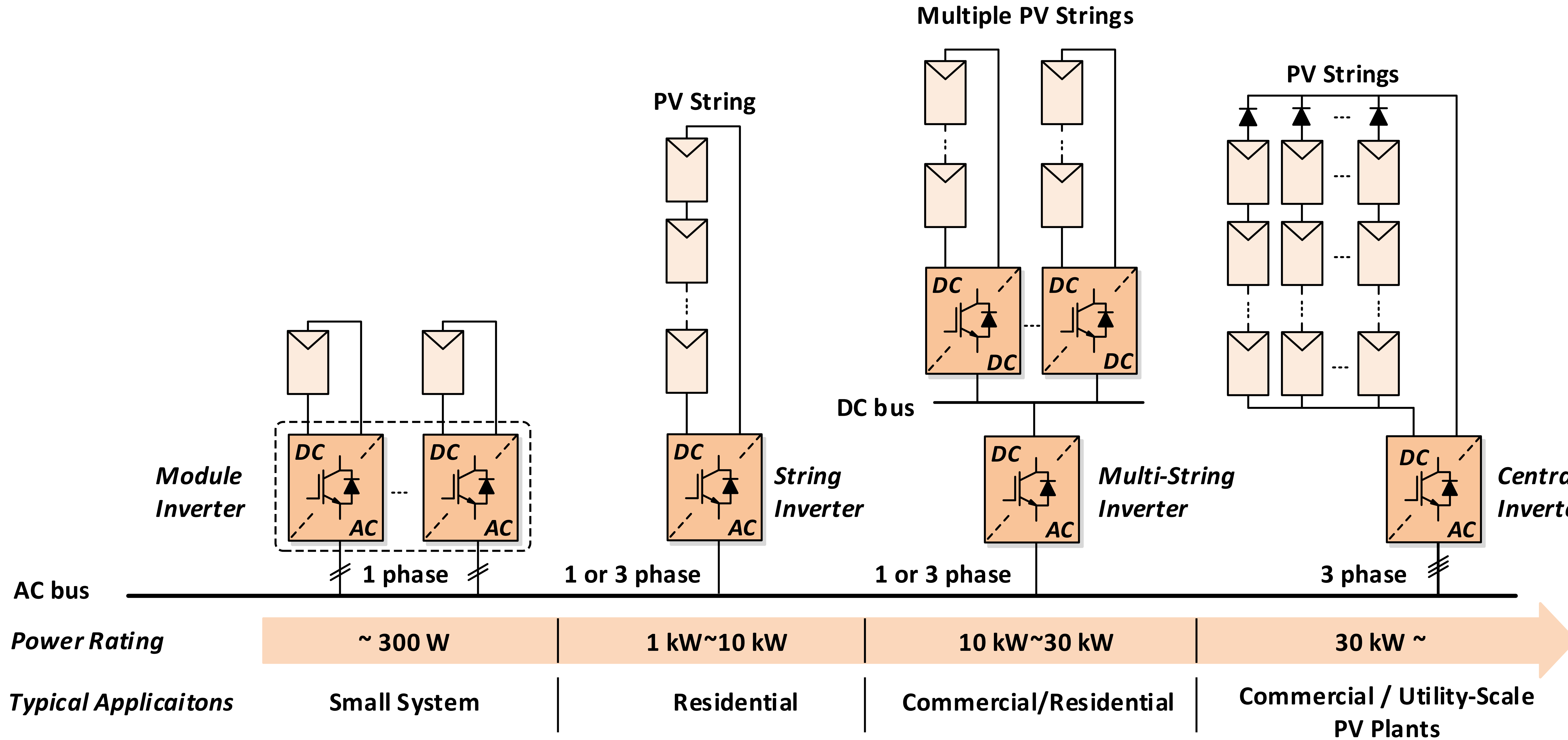
Power Electronic Topologies



- High efficiency mini-central (multi-string) PV inverters (8-15 kW) are also emerging for modular configuration in medium and high power PV systems
- Central inverters are available on market with very high power capacity
- Transformerless PV inverters can achieve high efficiency with increasing popularity

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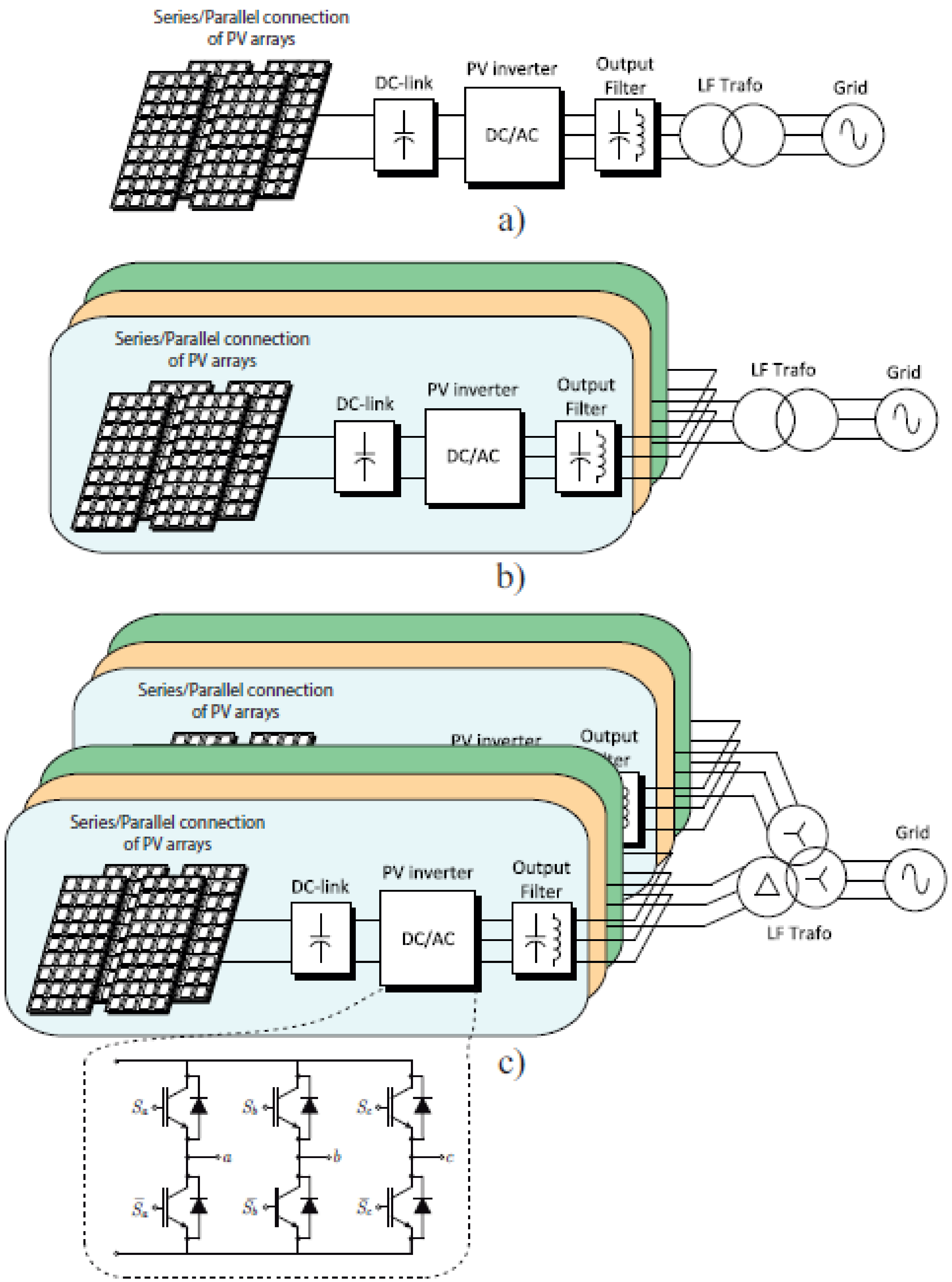
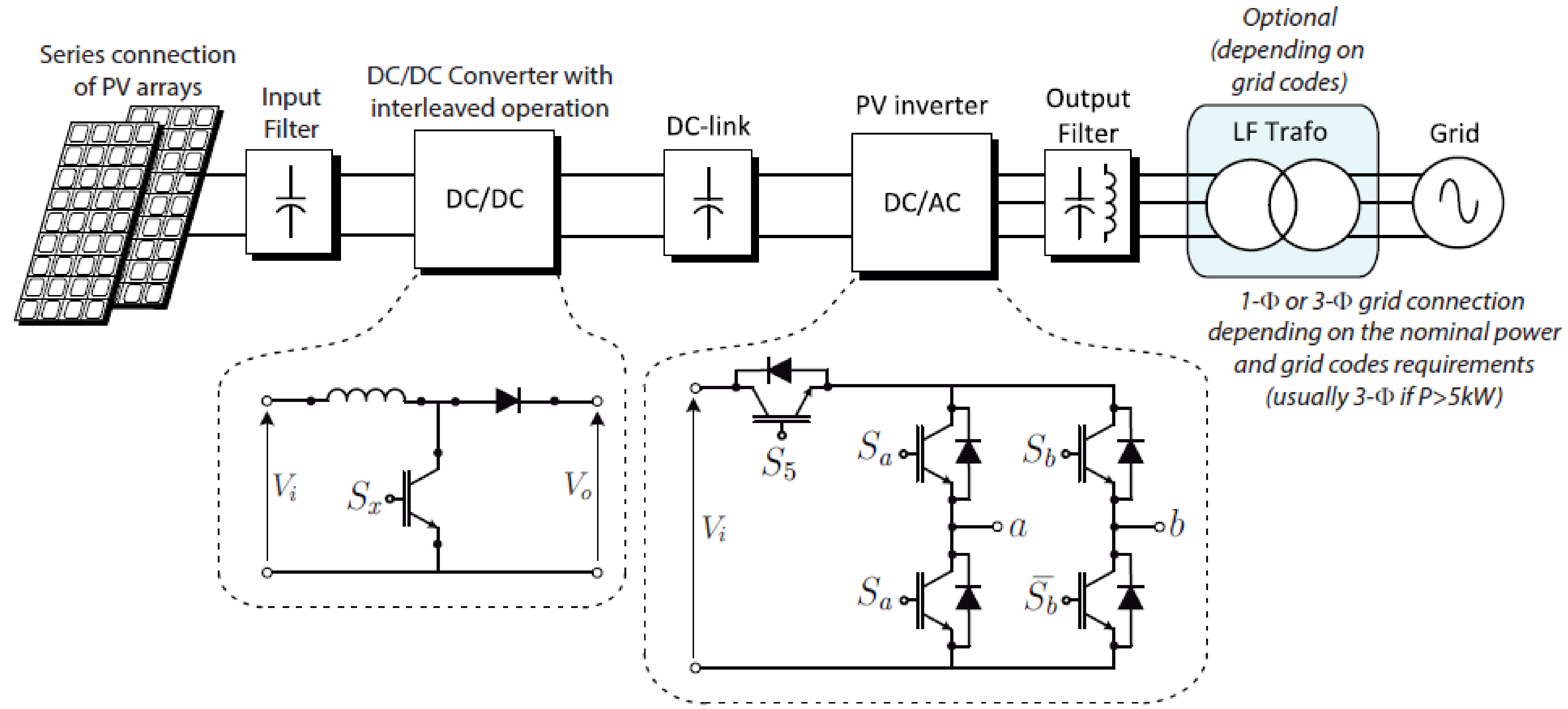
Power Electronic Topologies

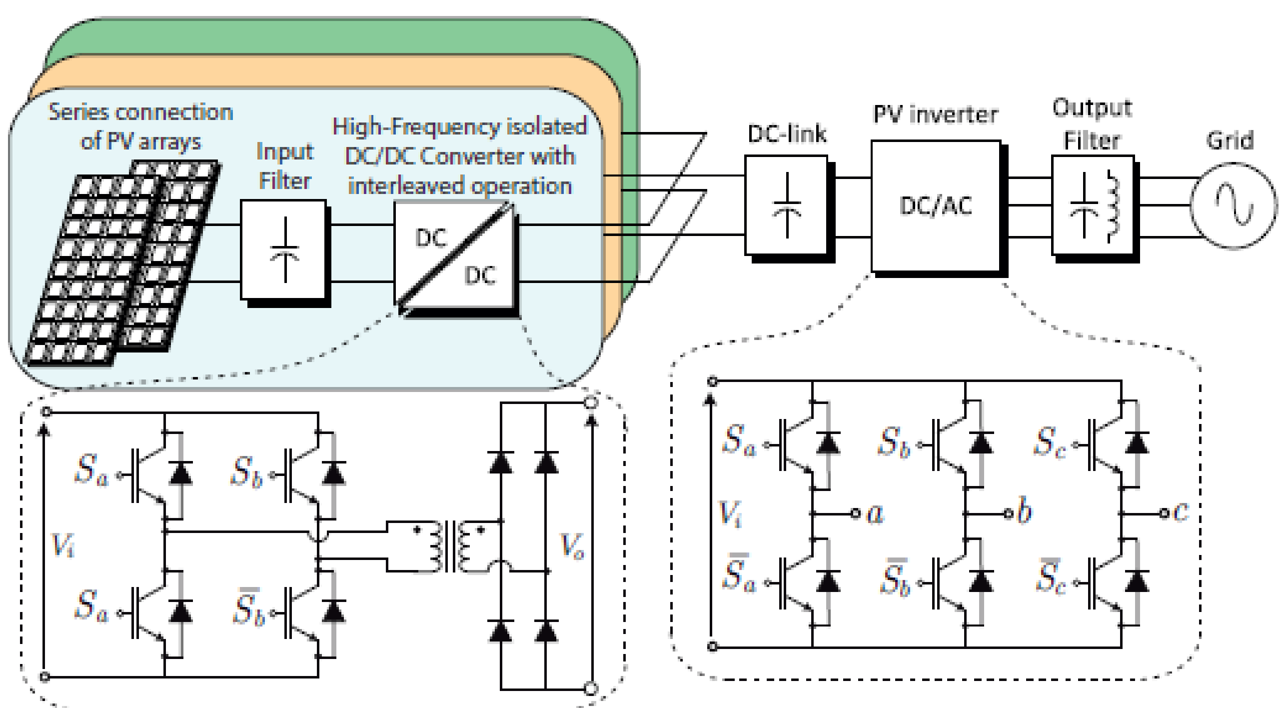


General schemes of high-power PV system based on central inverters a) single-channel central inverter b) multichannel central inverter c) dual central inverter

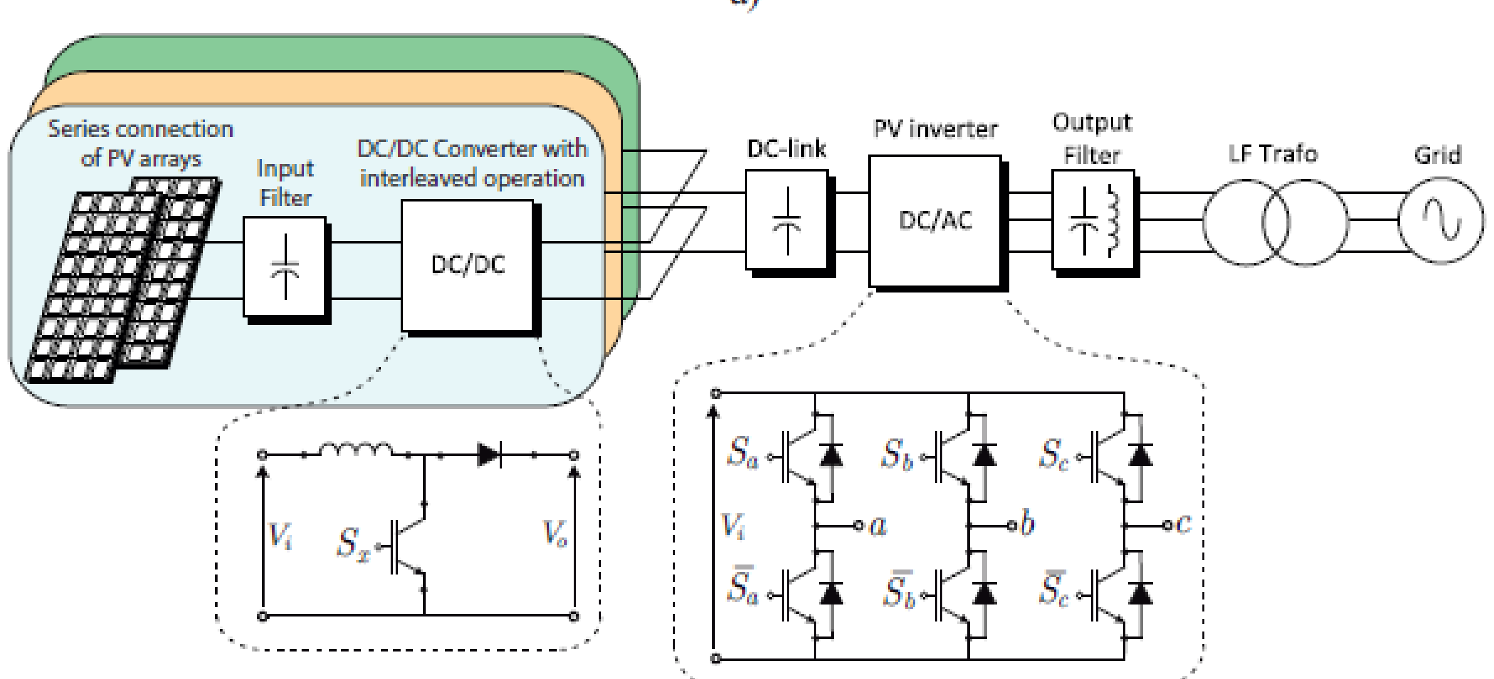
Power Electronic Topologies

General scheme of a two-stage medium-power PV system based on a string structure formed by a boost dc/dc converter and an H5 inverter





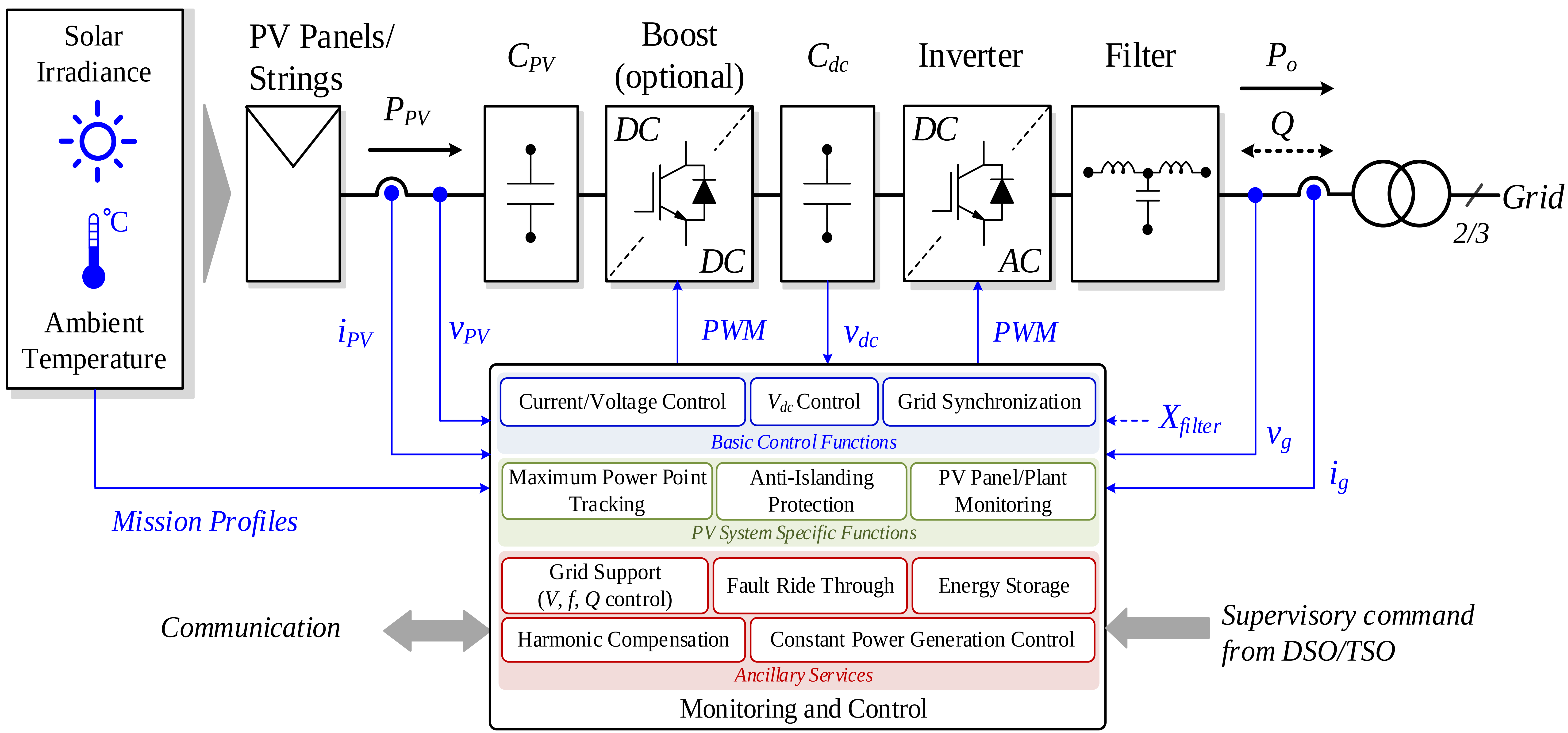
a)



b)

General schemes of a medium-power PV system based on a multi-string structure a) with high-frequency isolated dc/dc stage b) with non-isolated dc/dc stage with low frequency grid-connected transformer

Control Structure for a PV System



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
- …

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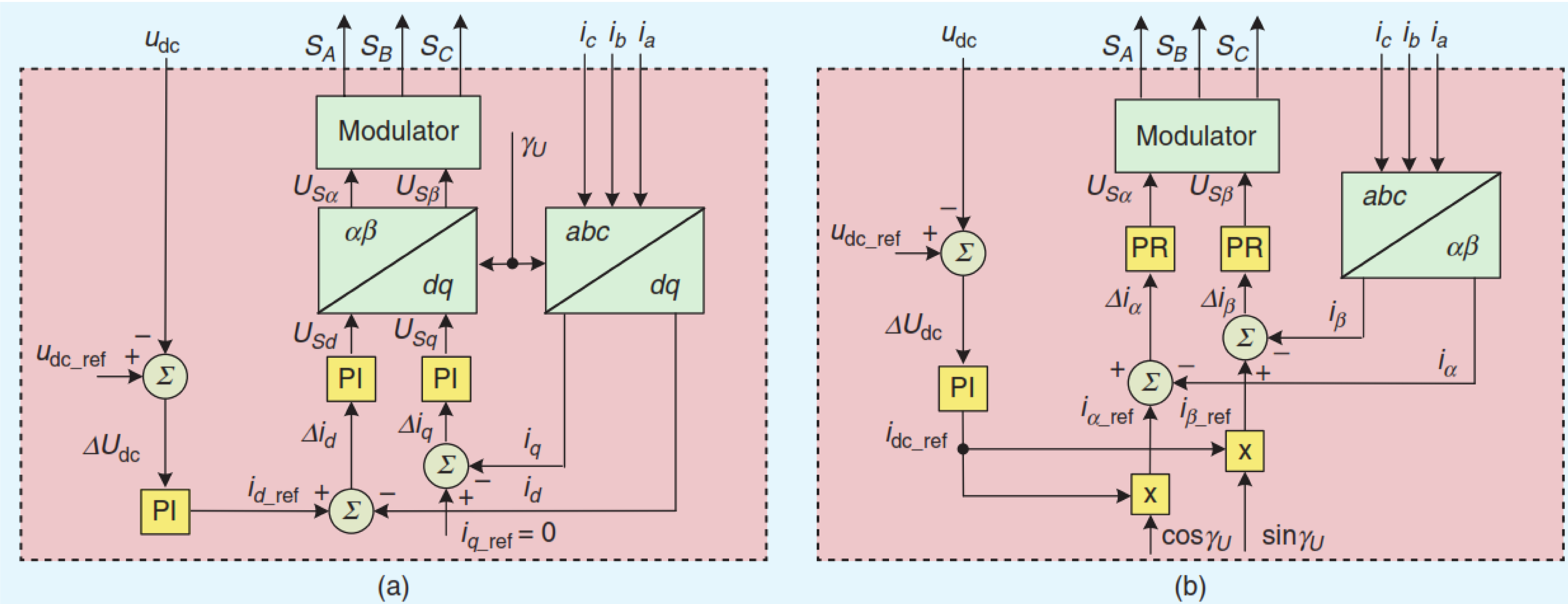
Control Structure for a PV System

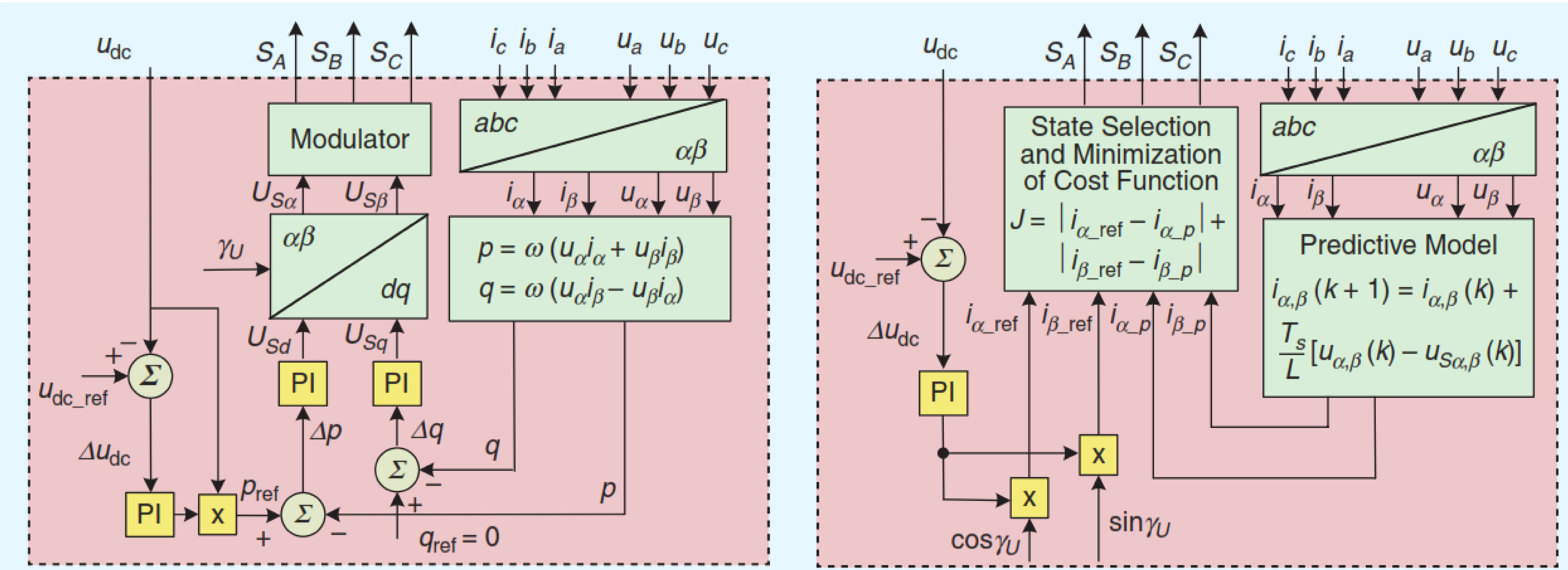


(a) Voltage-oriented control (VOC) in the synchronous rotating coordinate system

(b) VOC in the stationary coordinate system

E. Romero-Cadaval, B. Francois, M. Malinowski and Q. C. Zhong, "Grid-Connected Photovoltaic Plants: An Alternative Energy Source, Replacing Conventional Sources," IEEE Industrial Electronics Magazine, vol. 9, no. 1, pp. 18-32, March 2015.

Control Structure for a PV System



(c) (d)

(c) direct power control–space vector modulated (DPC-SVM)
(d) model-predictive control (MPC).

Energy Storage systems

Introduction

Energy Storage systems

Introduction	Power Electronic Topologies	Energy Storage systems	Integration of EV
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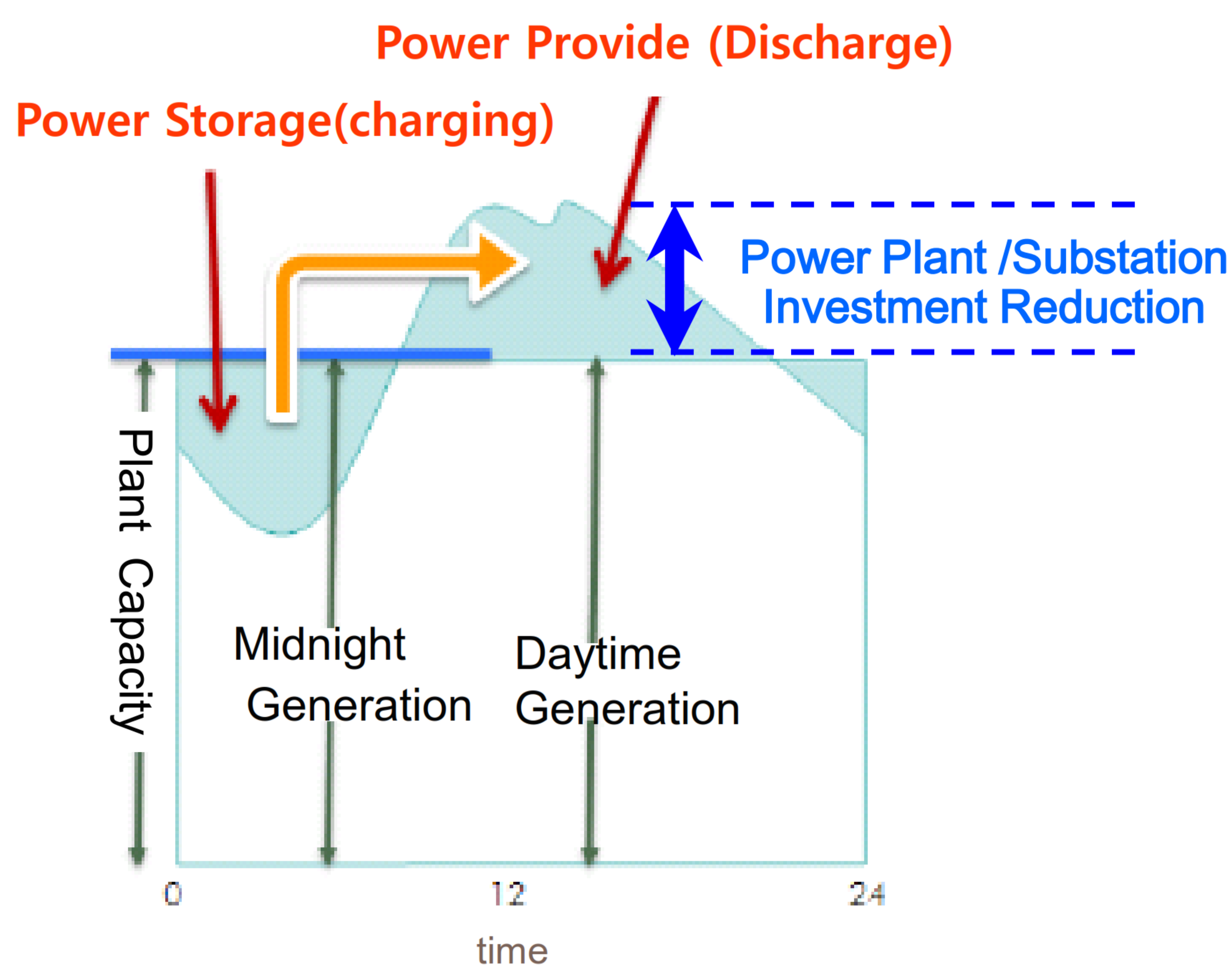
Power Electronic Topologies

Integration of EV

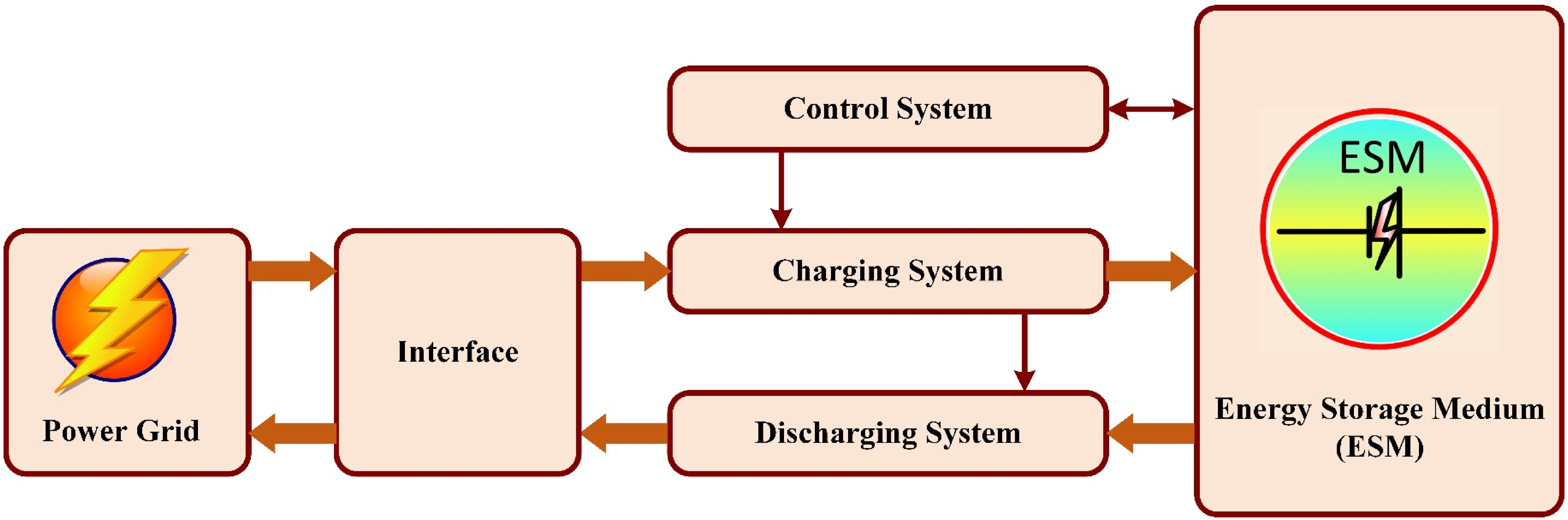
Why Do We Want Energy Storage Systems ?

- Customer load varies significantly over time.
- Some generation technologies cannot adjust output to match demand (limited ramp rates, minimum loads, etc.).
- Some generation technologies (wind and solar) are intermittent and can change output very quickly opposite to demand and can disappear for extended periods of time across the province.
- Storage is an integrating technology – enables supply to better match demand.



Why Do We Want Energy Storage Systems ?

- Energy storage devices "charge and discharge" normally require power conversion devices, to **transform electrical energy** (AC or DC) into a **different form of electrical, thermal, mechanical or chemical energy.**



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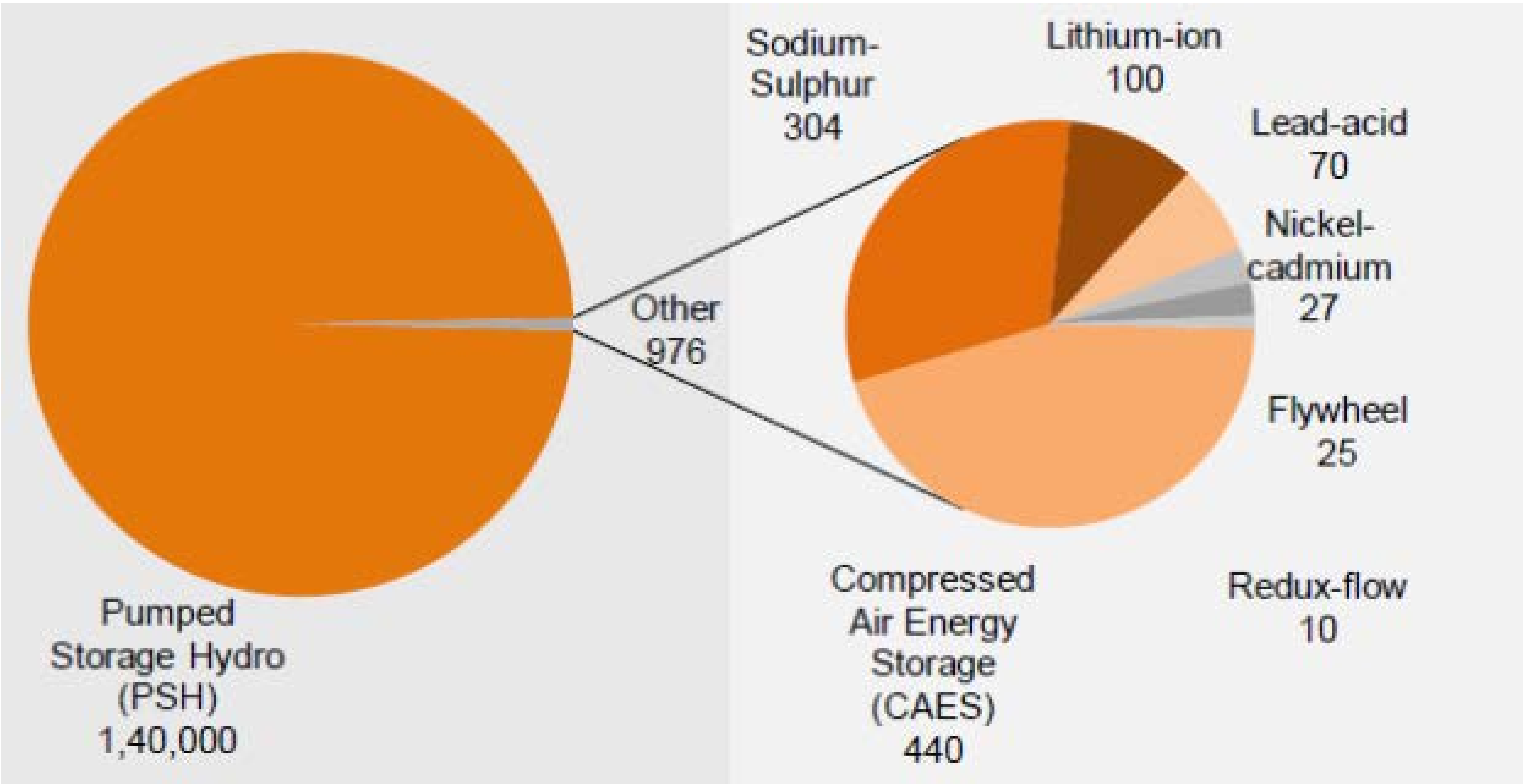
Benefits of Energy Storage Systems

- Storage can support voltage regulation and grid frequency regulation.
- Storage reduces the amount of dispatching (load following) imposed on generators (improves plant capacity factors)
- Storage reduces the natural gas plant capacity needed to meet peak demand and reserves.
- Storage can reduce the required capacity of transmission and_distribution lines if it is located optimally.

The Challenges for Energy Storage Systems

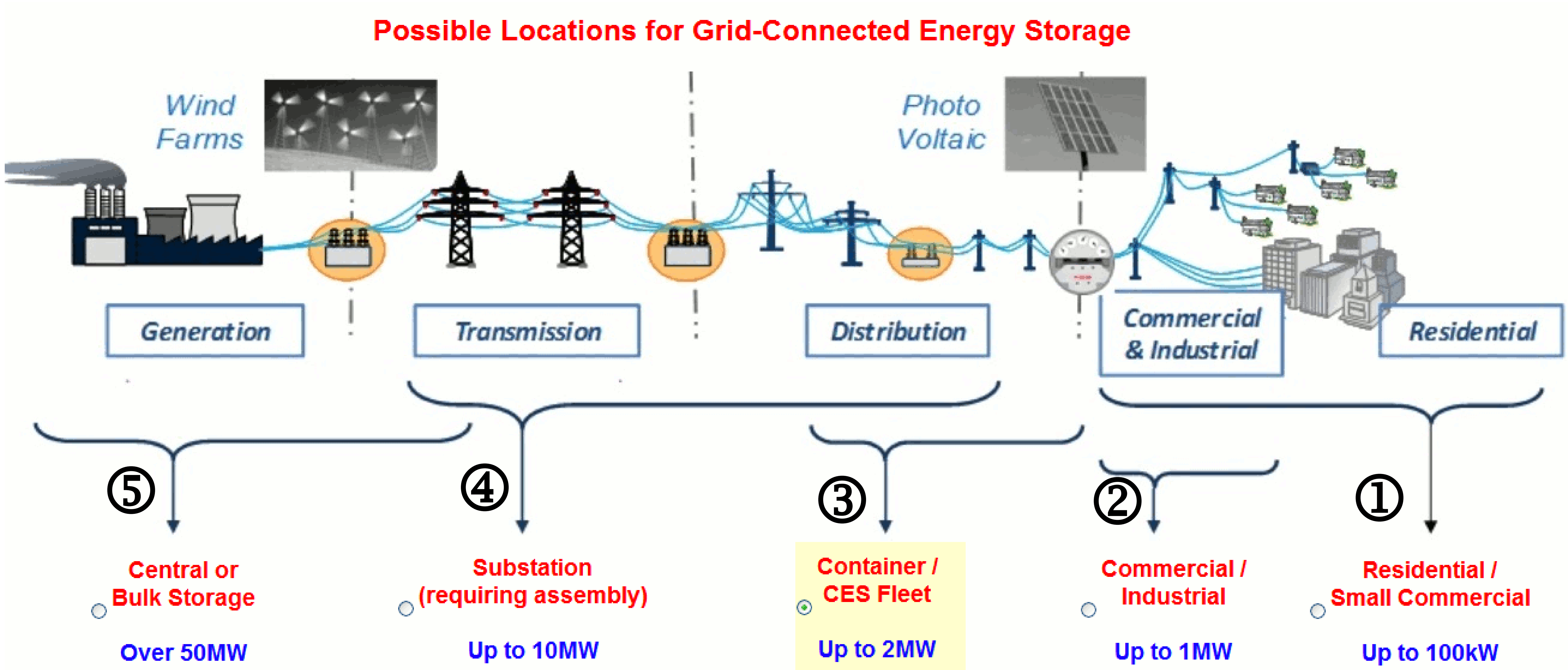
- Large electrical demand variation increases the required peak power rating of storage.
- Seasonal storage (shifting production from spring to summer and autumn to winter) is the most valuable but it is also the most expensive and environmentally disruptive.
- All storage options lose some of the stored energy over time (5 to 50% depending on technology and storage duration).
- Hydroelectric storage Is the cheapest large scale storage but you need ideal geography – not available everywhere.

The Current Landscape for Energy Storage



Source : IEA, Technology Roadmap 2014

Possible Locations for Grid-Connected Energy Storage



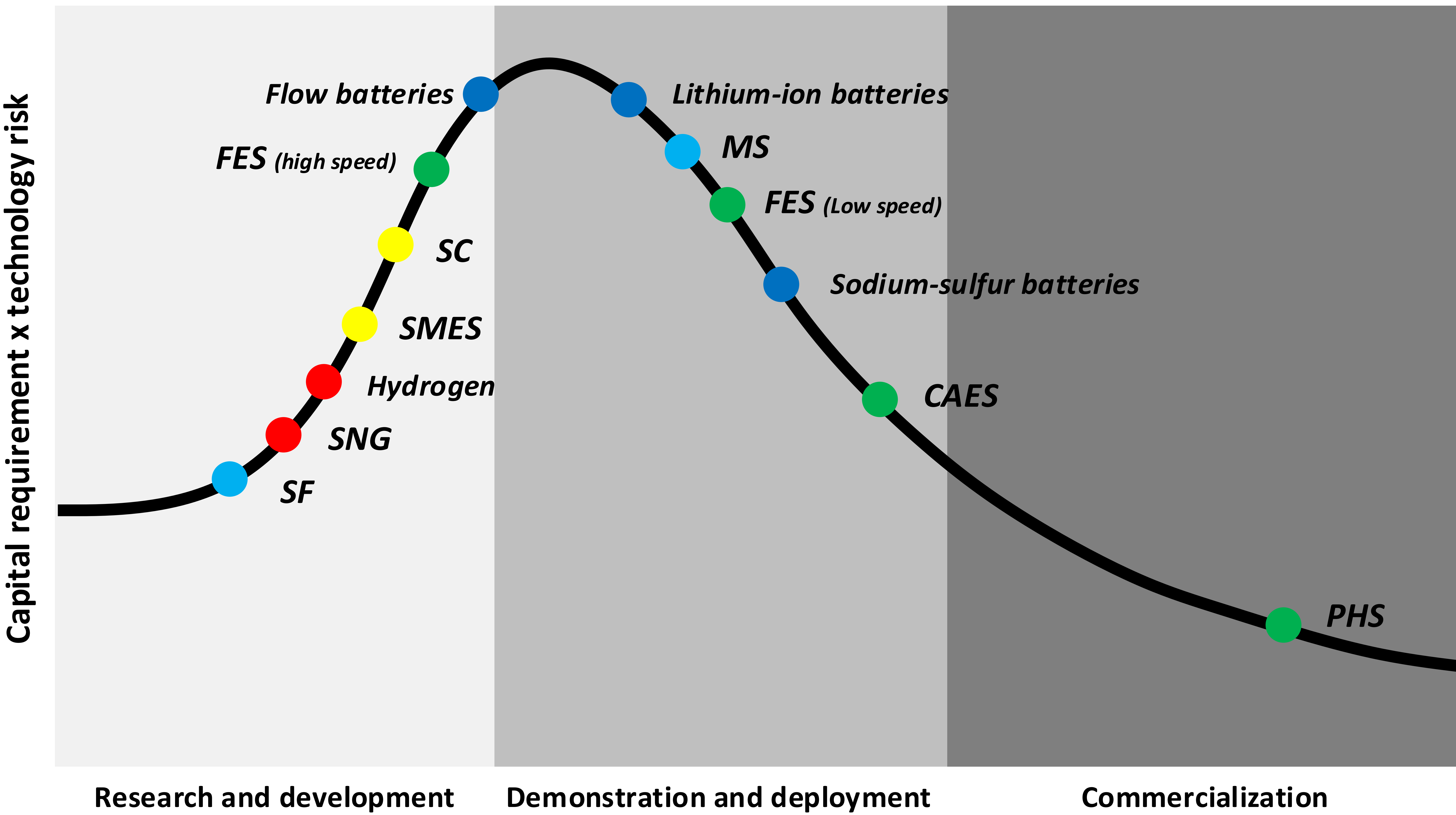
Key points to consider:
- Installation cost
- Available grid applications
- Available energy storage options

Battery requirements:
- Deep cycle: 80% DOD, 15+ years
- Shallow cycle: pulses, 15+ years
- Round trip efficiency: >80%
- Cost: $200/kWh
- Safety: international standards

O Ellabban, H Abu-rub, "Energy Storage As An Enabling Technology For The Smart Grid", Qatar Foundation Annual Research Conference, 2014.

Energy Storage Systems Grid Integration

The Current Landscape for Energy Storage



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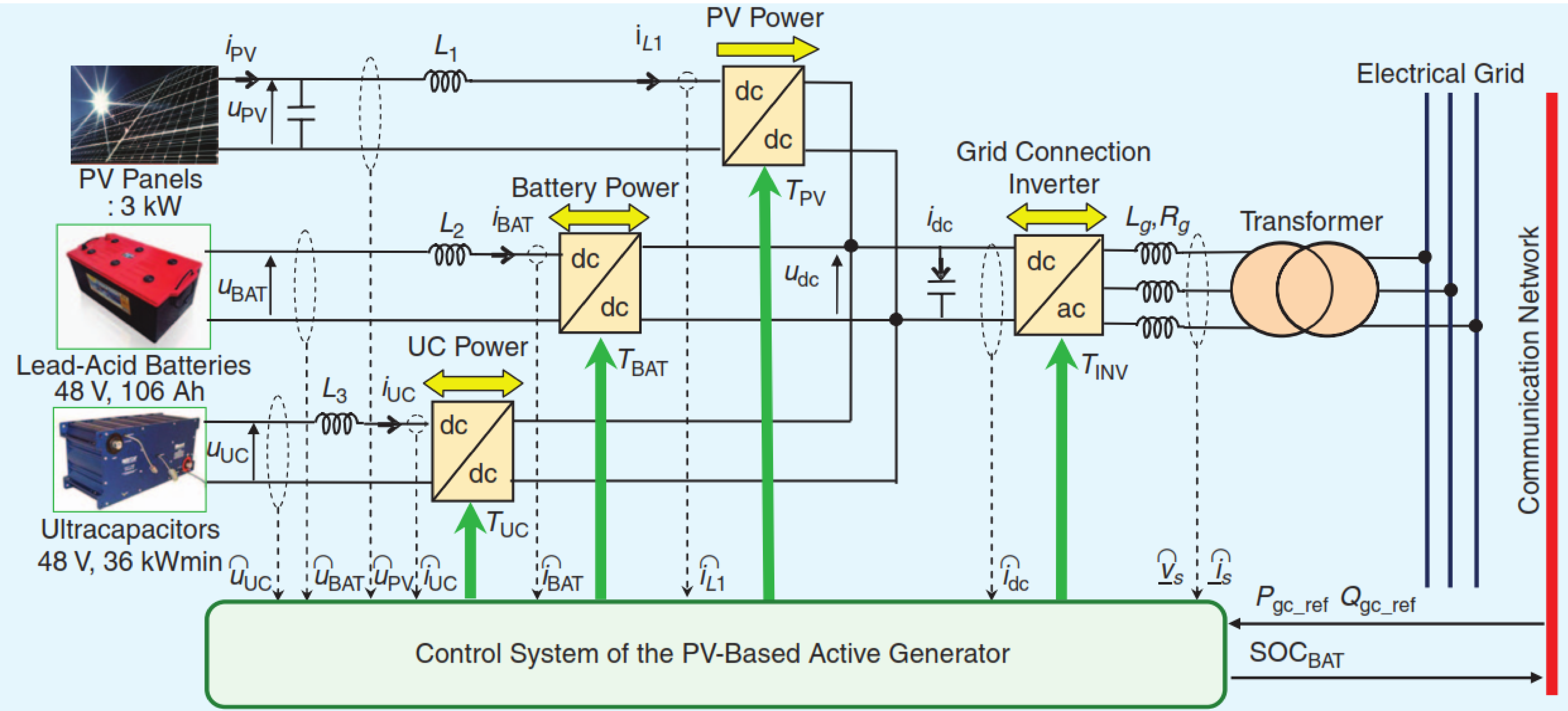
Energy Storage Systems Grid Integration

PV Hybrid System



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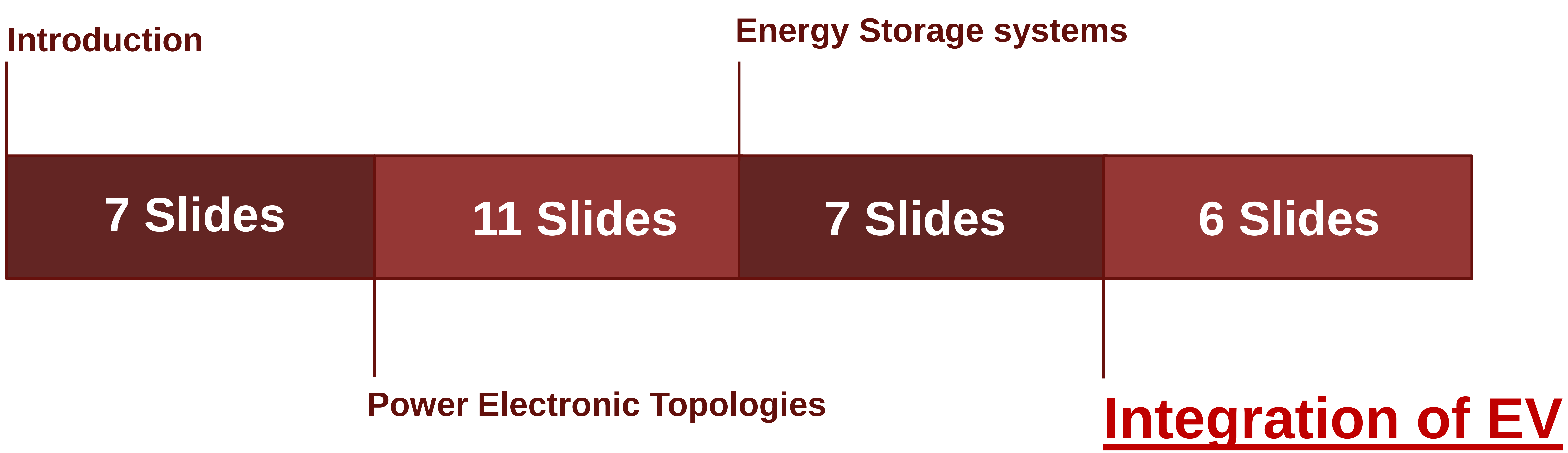
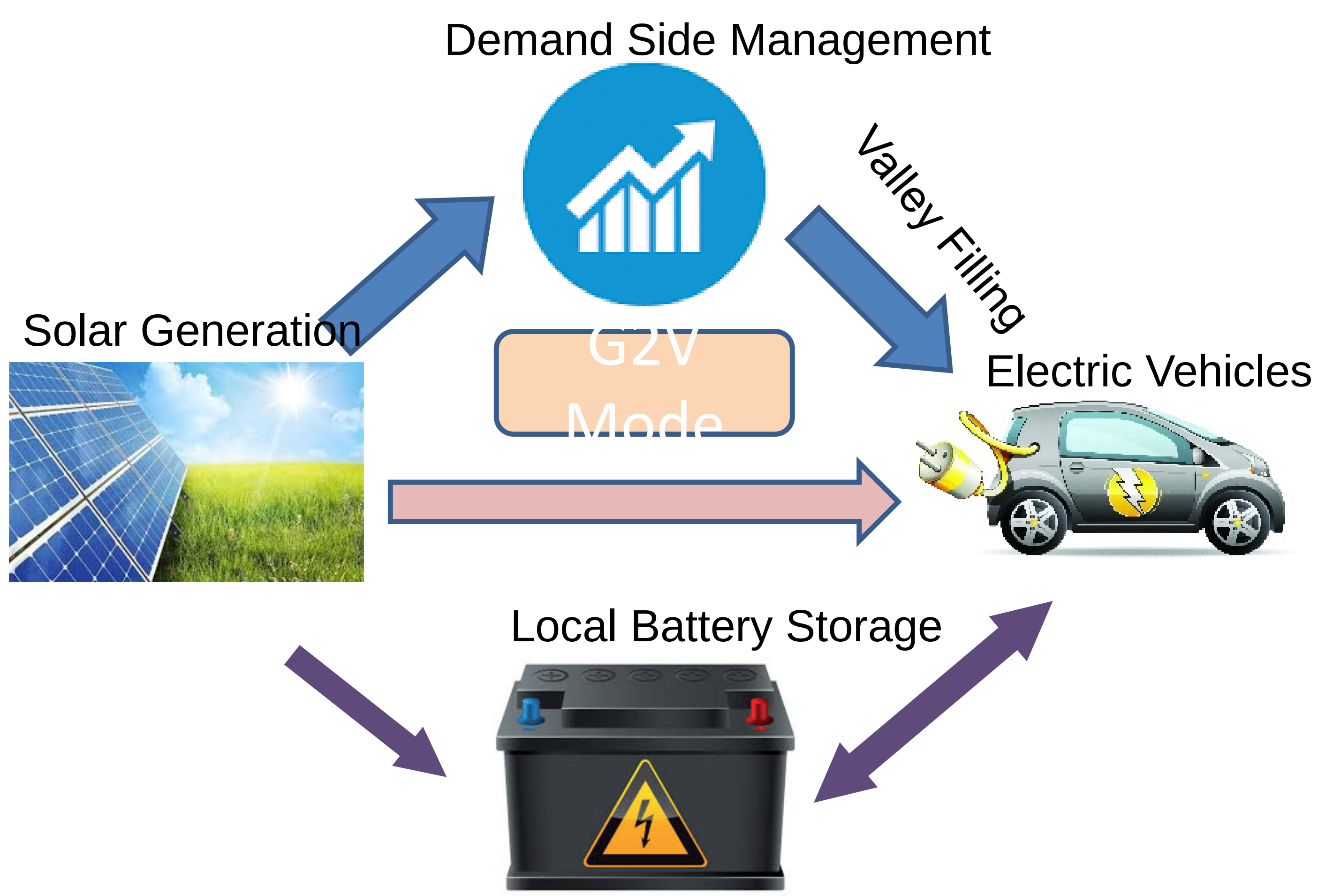
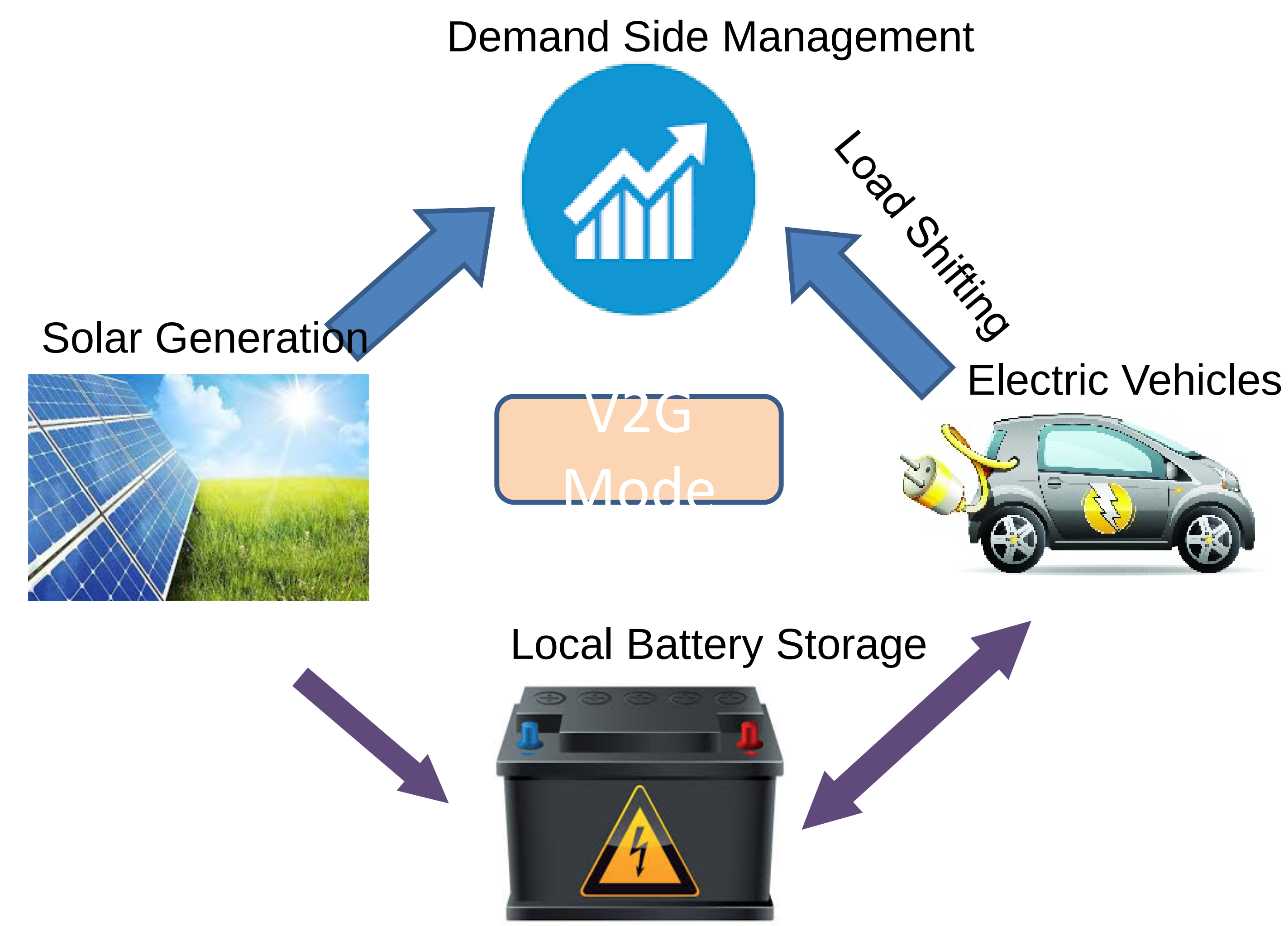
Integration of EV



Demand Response and Smart Grid

Demand Side Management Scenarios



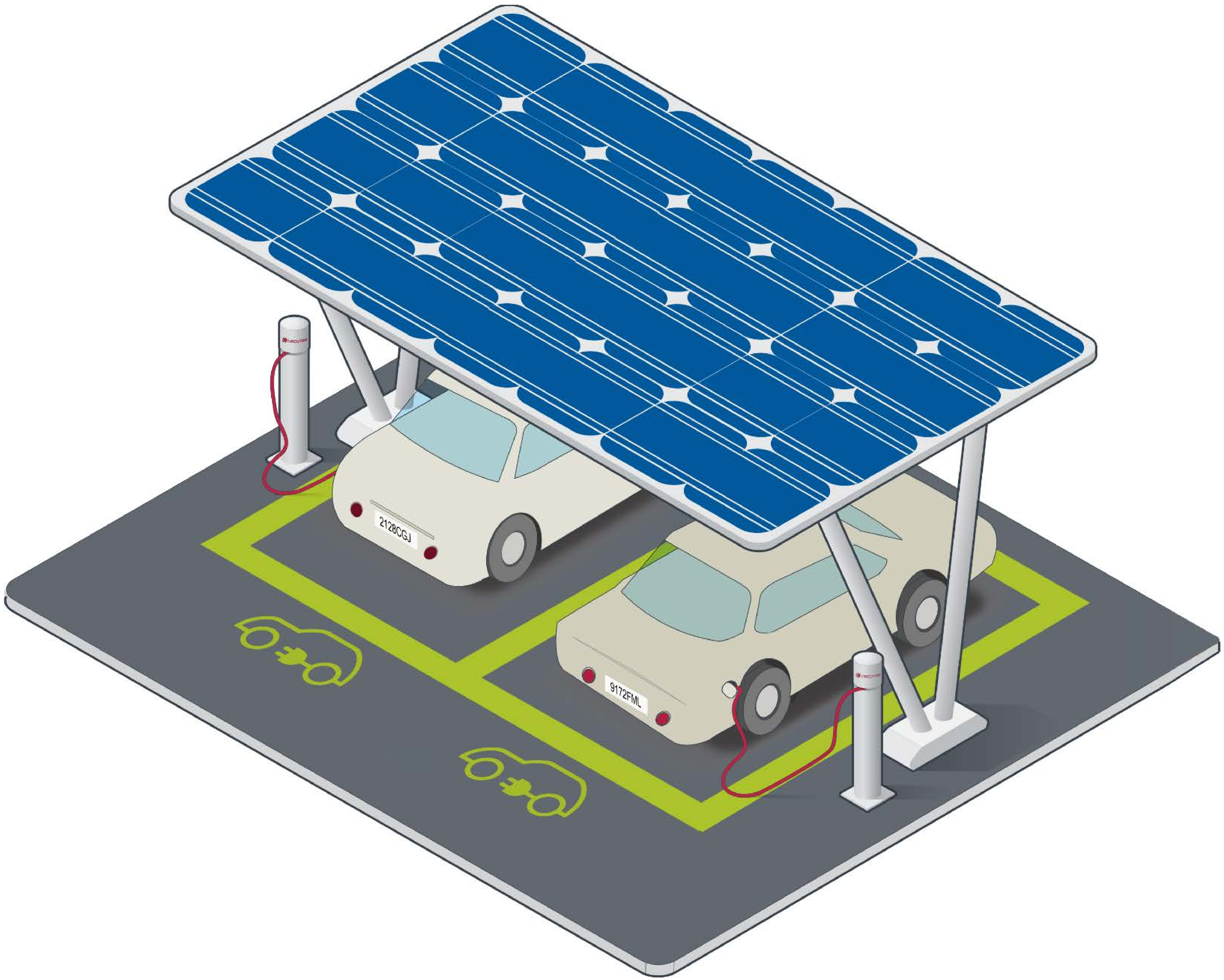


Future Electricity Grid

Consumer → Prosumer → Prostormer → Customer

Source: Mladen Kezunovic, ARC2014, QF, Doha Qatar

Integration of EV



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Categorization of HEV, PHEV and BEV

Type	Characteristics	Example Make/Model
Hybrid electric vehicle (HEV)	ICE with small battery pack "Dual-fuel vehicle" Battery recharged by ICE and regenerative braking. No electric socket for external charging.	Ford Fusion Hybrid Toyota Prius Honda Civic Hybrid
Plug-in hybrid electric vehicle (PHEV)	ICE with medium size battery pack "Dual-fuel vehicle" Battery recharged by ICE, regenerative braking. Electric plug-in socket available.	Chevrolet Volt Toyota Prius PHV
Full Battery electric vehicle (BEV)	Electric battery pack. "Single fuel vehicle" Battery recharged by regen. braking and plug-in socket	Nissan LEAF Tesla Roadster

Source: "Hybrid and Plug-in Electric Vehicles," *California's Alternative and Renewable Fuel and Vehicle Technology Program,* 9 Feb. 2014.

Integration of EV

Impacts of EV Charging on the grid

- Overloading of circuits by excessive instantaneous demand.
- DC fast chargers easily overload residential neighborhood circuits.
- Icrease distribution transformer losses, voltage deviations, harmonics distortion, thermal loading on distribution system.
- Impact on the lifespan of transformer.

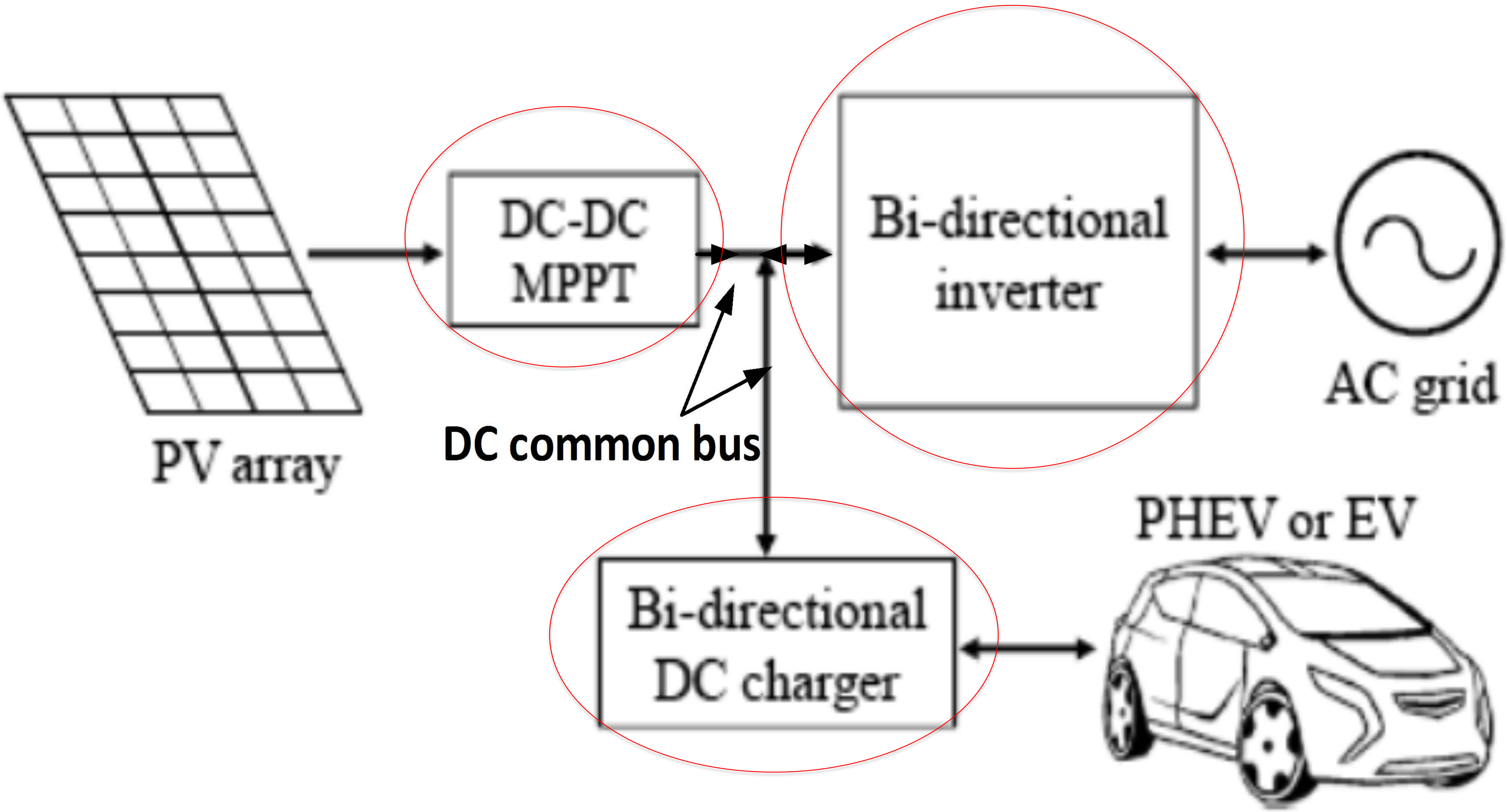
EV Charging Management

- Large power drawn during peak hours. Need to be managed.
- Time-of-use (TOU) rates may be used to encourage customers to charge their vehicles during off-peak periods.
- Grid cost and reliability issues.

Solar PV Charging

- Motivation:
  - Price declines of PV modules and balance of system (BOS) costs.
  - Incentives for PV system owners: Feed-in Tariff, Capital subsidises, Tax breaks
- PV-EV charging is ideal for smart grid system.
- Natural integration.
- Multi-purpose.
- Two types:
  - PV-grid charging
  - PV Standalone charging

Solar PV Charging



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Conclusion

THANK YOU FOR YOUR ATTENTION ANY QUESTIONS?

Haitham Abu-Rub
haitham.abu-rub@qatar.tamu.edu