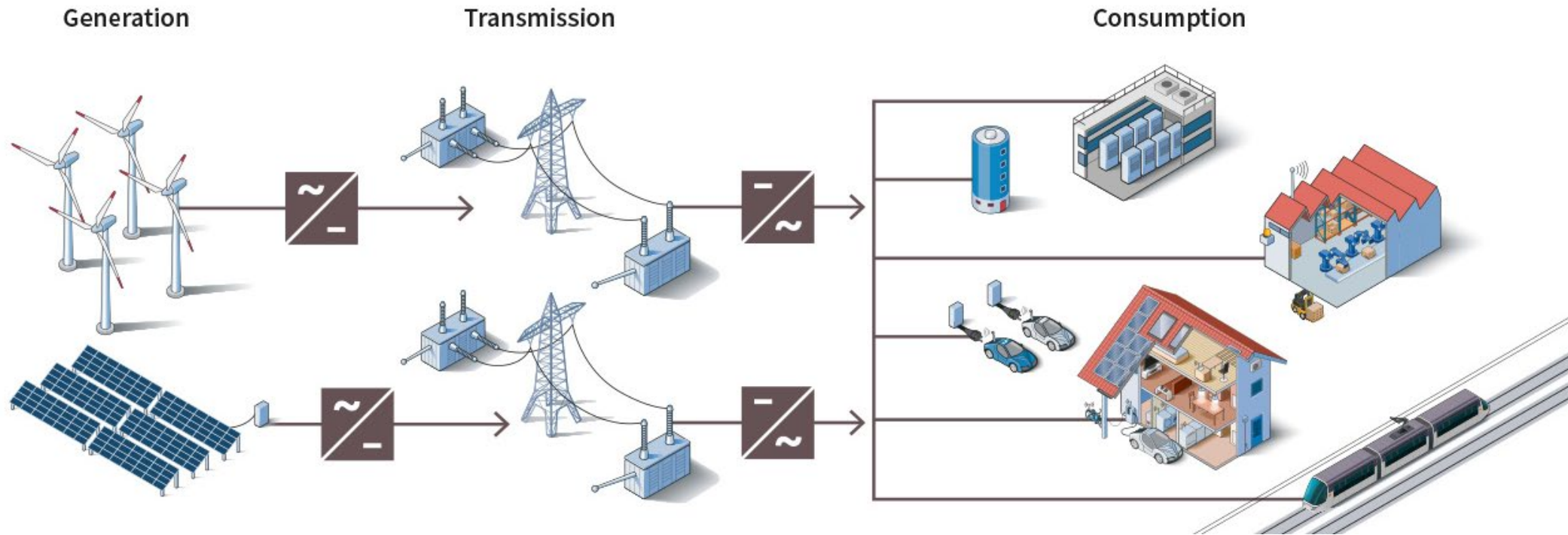# From Renewables to Energy Storage – Trends and solutions offered by Infineon

February, 2020

Renewable energy generation and its efficient implementation

Generation · Transmission · Consumption

Infineon offers power semiconductors for the whole electrical energy chain.
From Solar and Wind to Energy Storage Systems.

Solar market segmentation and sub applications

Residential applications

- Installed in private spaces

- **up to 10 kW** of energy
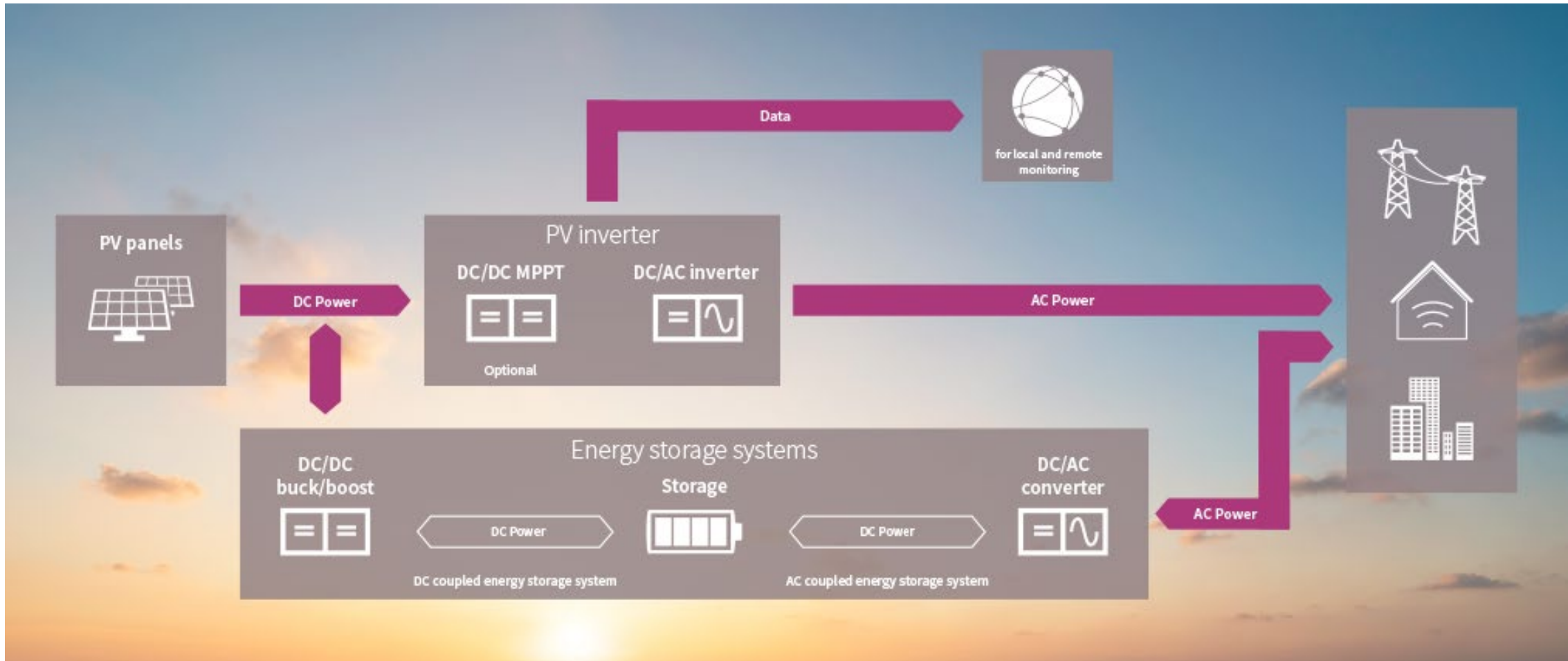
Commercial applications

- Installed in offices and factories
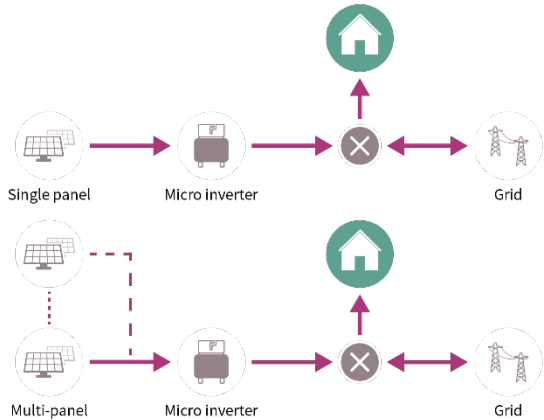
- **up to 5 MW** of energy

Utility scale applications

- Installed in the field

- **above 5 MW** of energy

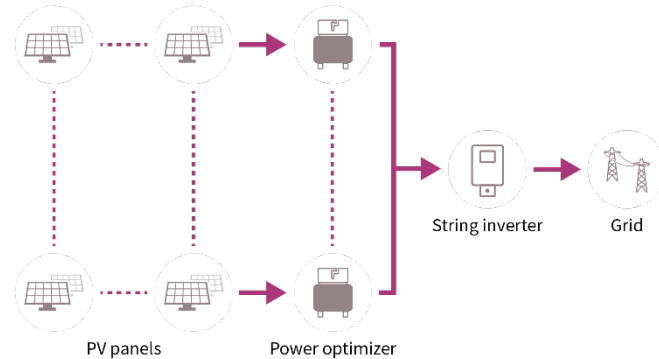# Structure of solar power generation

Types of solar inverter

Micro inverter

Single panel — Micro inverter — Grid

Multi-panel — Micro inverter — Grid

› Power conversion on each individual panel

› Sub application: Residential

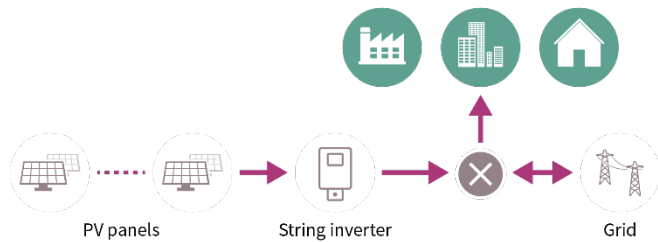## DC optimizer + multi string inverter

PV panels — Power optimizer — String inverter — Grid

› String inverter is connected with several (MPPT)[1] power optimizer at panel level or string level

› Sub application: Residential, Small commercial

[1] MPPT – Maximum Power Point Tracking

String inverter

PV panels — String inverter — Grid

› Power conversion on solar panels are connected together into strings

› Sub application: Commercial and utility scale

Central inverter

PV panels — Central inverter — Grid
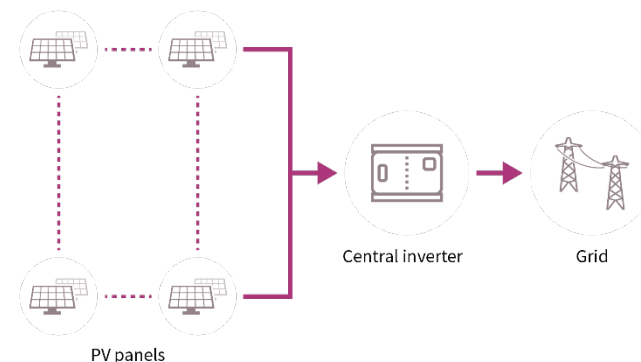
› Power conversion on multiple strings of solar panels are connected together

› Sub application: Utility scale

Technology trends

Micro inverters

› **Multi module:** Multiple panels attached per micro inverter

› **Usage of compact SMD packages** (Sourface-Mount-Device): SuperSO8, DirectFET™, TOLL

› **Reduced cooling system**, heatsinks and enclosure

› Micro inverter **producers partnering with panel manufacturers** for module level integration

String inverters

› **Commercial installation up to 1 MW**: Applied with a 1000 V PV voltage

› **Utility scale installation up to 20 MW**: Applied with a 1500 V PV voltage

› **NPC1 to ANPC** → Output power independent of pf

› **Multilevel topology in single phase inverter**: Cost, size and weight reduction through smaller magnetics & cooling
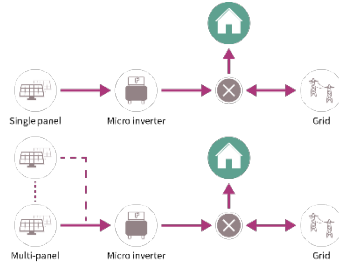

Central inverters
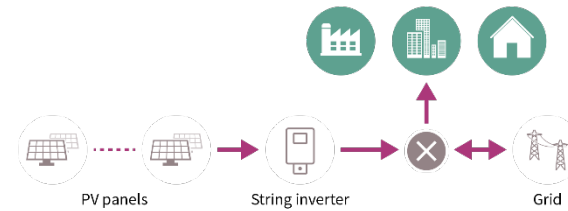
› **Utility scale from 20 MW**: Applied with a 1500 V PV voltage

› Inverter power grows from 3 MW to more than 5 MW

› **NPC1 to NPC2** → Typ. 3 … 4 kHz operation, NPC2 topology improves the power density, enable to use standard gate driver thanks to low stray inductance layout and reduce the cooling efforts
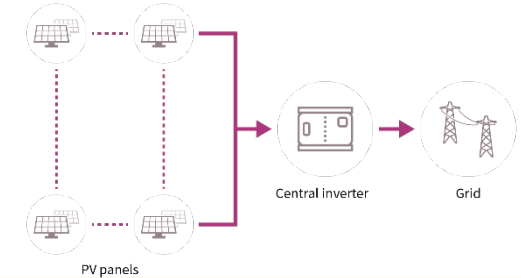
Application requirements at a glance

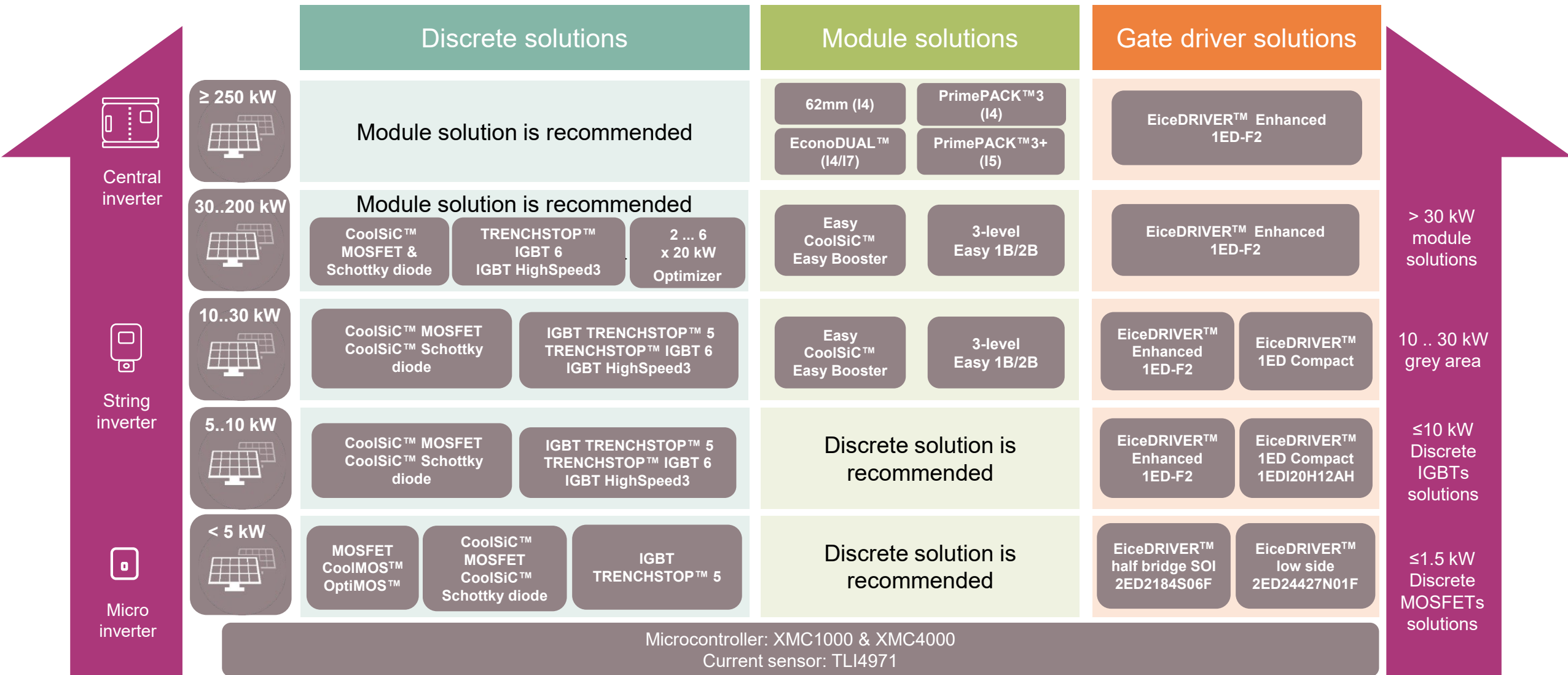|	μ-Inverters	String inverters	Central inverters
PV array voltage	40 … 80 V	600 V, 1000 V & 1500 V PV array	1000 V & 1500 V PV array
Power Range Switching Freq.	200 – 1500 W 40 … 80 kHz	1 … 200 kW 20 … 35 kHz	600 … 1250 kW 2 … 4 kHz
Output voltage	110V / 230V (1Φ)	110 / 230V (1Φ) 360 … 800V (3Φ)	320 … 690V (3Φ)
Topology	DC/DC + DC/AC Stage DC-DC: LLC or Flyback DC-AC: 2-Level or Cyclo-converter	DC/DC + DC/AC Stage DC-DC: Single or Dual Boost 1Φ: 2-Level, H5, H6 & HERIC 3Φ: 3l: NPC1, NPC2 & ANPC	DC/AC Stage 2-Level (3Φ Full Bridge) 3l: NPC1, NPC2 & ANPC
Type of Installation	Residential	Residential, Commercial & Utility Scale	Big Commercial & Utility Scale
Pros and cons	• Higher flexibility & scalability / harvesting • Moderate 94% of efficiency • Higher system cost	• Widely used / Up to 98% efficiency • Higher flexibility & scalability / Harvesting • Moderate system cost	• Highest efficiency upto 99% • Lower system cost • Low flexibility & scalability / Harvesting

Infineon's power solution positioning for solar application

	Power	Discrete solutions	Module solutions	Gate driver solutions	
Central inverter	≥ 250 kW	Module solution is recommended	62mm (I4) · PrimePACK™3 (I4) · EconoDUAL™ (I4/I7) · PrimePACK™3+ (I5)	EiceDRIVER™ Enhanced 1ED-F2	> 30 kW module solutions
	30..200 kW	Module solution is recommended / CoolSiC™ MOSFET & Schottky diode · TRENCHSTOP™ IGBT 6 IGBT HighSpeed3 · 2 ... 6 x 20 kW Optimizer	Easy CoolSiC™ Easy Booster · 3-level Easy 1B/2B	EiceDRIVER™ Enhanced 1ED-F2	
String inverter	10..30 kW	CoolSiC™ MOSFET CoolSiC™ Schottky diode · IGBT TRENCHSTOP™ 5 TRENCHSTOP™ IGBT 6 IGBT HighSpeed3	Easy CoolSiC™ Easy Booster · 3-level Easy 1B/2B	EiceDRIVER™ Enhanced 1ED-F2 · EiceDRIVER™ 1ED Compact	10 .. 30 kW grey area
	5..10 kW	CoolSiC™ MOSFET CoolSiC™ Schottky diode · IGBT TRENCHSTOP™ 5 TRENCHSTOP™ IGBT 6 IGBT HighSpeed3	Discrete solution is recommended	EiceDRIVER™ Enhanced 1ED-F2 · EiceDRIVER™ 1ED Compact 1EDI20H12AH	≤10 kW Discrete IGBTs solutions
Micro inverter	< 5 kW	MOSFET CoolMOS™ OptiMOS™ · CoolSiC™ MOSFET CoolSiC™ Schottky diode · IGBT TRENCHSTOP™ 5	Discrete solution is recommended	EiceDRIVER™ half bridge SOI 2ED2184S06F · EiceDRIVER™ low side 2ED24427N01F	≤1.5 kW Discrete MOSFETs solutions

Microcontroller: XMC1000 & XMC4000
Current sensor: TLI4971

Micro inverter – Topology and device selection

# of PV panels per micro inverter	Single		Multiple
Type	Full bridge	Cyclo inverter	Full bridge
Topology			
PV array voltage	≤ 60 V		
Blocking voltage	60 V – 650 V (Primary side: 60 V…150 V & Secondary side: 650 V)		
Focus product / technology	OptiMOS™ CoolMOS™ CoolGaN™ CoolSiC™ Schottky Diode EiceDRIVER™		

OptiMOS™   CoolMOS™   CoolSiC™   CoolGaN™

300 W   1500 kW

Power Optimizer / MPPT – Booster – Topology and device selection

Location	PV panel level	PV String level	
Type	Full bridge	Single boost	Dual boost
Topology			
PV array voltage	≤ 60 V	600 V / 1000 V	1500 V
Blocking voltage	60 V – 150 V	650 V / 1200 V	1200 V
Discrete solution	OptiMOS™ CoolGaN™	CoolMOS™ or CoolSiC™ MOSFET IGBT TRENCHSTOP™ 5 S5/H5 IGBT HighSpeed3 H3 / TRENCHSTOP™ IGBT6 S6	CoolSiC™ MOSFET or HighSpeed3 IGBT H3 / TRENCHSTOP™ IGBT6 S6
Module solution	Not recommended	EasyPACK™ 1B/2B	-
Gate driver solution	EiceDRIVER™ SOI (2ED218x) EiceDRIVER™ low side (2ED24427)	EiceDRIVER™ 1ED Compact EiceDRIVER™ low side (1ED4417x)	EiceDRIVER™ 1ED Compact EiceDRIVER™ low side EiceDRIVER™ Enhanced 2ED-F2
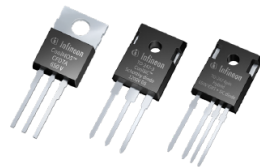
SMD | TO-220 / TO247-3 / TO247-4 | Easy 1B/2B

200 W | 10 kW | up to 25 kW

1-phase String Inverter – Topology and device selection

Type	2-level	HERIC	H6	Multilevel
Topology				
Blocking voltage	600 V / 650 V	600 V / 650 V	600 V / 650 V	150 V
Focus product / technology	S1 … S3: CoolSiC™ MOSFET / CoolMOS™ / IGBT TRENCHSTOP™ 5 S5 / H5	S1 … S4: CoolMOS™ / IGBT TRENCHSTOP™ 5 L5 / S5 S5/S6: CoolMOS™ / IGBT TRENCHSTOP™ 5 L5	S1/S2: CoolMOS™ / IGBT TRENCHSTOP™ 5 L5/S5 S3 … S6: CoolMOS™ / IGBT TRENCHSTOP™ 5 S5 / H5	S1 … S8: OptiMOS™ / CoolGaN™
Gate Driver	EiceDRIVER™ SOI (2ED218x) / EiceDRIVER™ low side (2ED24427)	EiceDRIVER™ SOI (2ED218x) / EiceDRIVER™ 1ED Compact	EiceDRIVER™ SOI (2ED218x) / EiceDRIVER™ 1ED Compact	EiceDRIVER™ 1ED Compact / EiceDRIVER™ high side (IRS20752)

DirectFET / D2PAK / SS08 / TOLL

TO-247

TO-247-PLUS

| 1 kW | 3 kW | 6 kW | < 10 kW |

3-phase String Inverter – Topology and device selection

Type	2-level	3-level NPC1	3-level NPC2	3-level ANPC
Topology				
PV array voltage	1000 V	1000 V	1000 V	1500 V
Blocking voltage	1200 V	650 V	1200 V + 650 V	950 / 1200 V
Discrete solutions	CoolSiC™ MOSFET or IGBT High-Speed3 H3 / TRENCHSTOP™ IGBT 6 S6	S1/S4: IGBT TRENCHSTOP™ 5 S5 / H5 S2/S3: IGBT TRENCHSTOP™ 5 L5 / S5 D5/D6: CoolSiC™ Schottky Diode	S1/S4: CoolSiC™ MOSFET / IGBT HighSpeed3 H3 / TRENCHSTOP™ IGBT 6 S6 S2/S3: IGBT TRENCHSTOP™ 5 L5 / S5	-
Module solutions	DUAL, Easy 1B/2B (CoolSiC™ MOSFET)	3-level, Easy 1B/2B	3-level, Easy 1B/2B	3-level, Easy 2B (CoolSiC™ or S7/L7)
Gate Driver	EiceDRIVER™ Enhanced (1ED-F2) / EiceDRIVER™ 1ED Compact			

Discretes   Easy 1B   Easy 2B
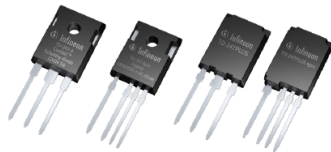
10 kW   30 kW   100 kW

Central Inverter – Topology and module selection

Type	2-level	3-level NPC1	3-level NPC2	3-level ANPC
Topology				
PV array voltage	1000 V	1500 V	1000 V	1500 V
Module configuration	DUAL	DUAL (x3)	DUAL + Common emitter or Common collector	DUAL (x3)
Module Package	62 mm EconoDUAL™ 3 PrimePACK™ 3 PrimePACK™ 3+	EconoDUAL™ 3 PrimePACK™ 3 PrimePACK™ 3+	62 mm	EconoDUAL™ 3 PrimePACK™ 3 PrimePACK™ 3+
Gate Driver	EiceDRIVER™ Enhanced (1ED-F2) / EiceDRIVER™ 1ED Compact			

62 mm	EconoDUAL™ 3	PrimePACK™ 3	PrimePACK™ 3+
≤ 250 kW	≤ 500 kW	800 kW	≥ 1000 kW

Infineon product offerings for solar application

EiceDRIVER™
IGBT & MOSFET Gate drivers

Discrete: MOSFETs & IGBTs
&
IGBT modules

Photovoltaic panels

DC / DC (Booster)

DC / AC (Inverter)

Grid

Sensing

Gate Driver

Sensing

Microcontroller

Auxiliary power supply

Communication to user

Human-Machine Interface (HMI)

XENSIV™
TLI4971

XMC™

1.7 kV CoolSiC™ &
CoolSET™
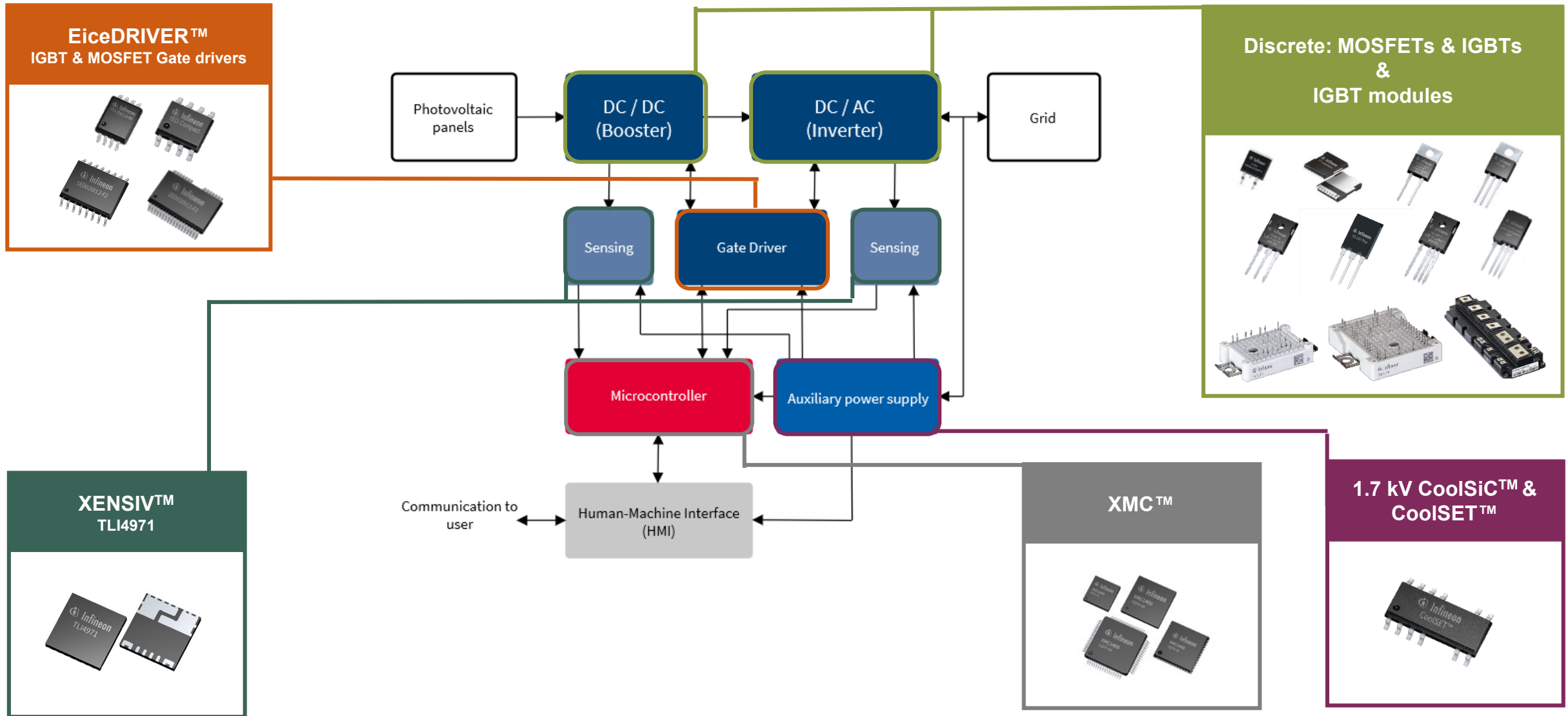
Overview of Wind application clusters

On-shore

Located in such as windfarm or single wind turbine

👍 Lower construction cost and much closer to the electricity grid

👎 Has an impact on environment e.g. noise pollution

Off-shore

Located mostly close to the shore (<100 km) to lower the power transmission cost

👍 Larger power rated turbines and lower pay-back time

👎 Higher construction cost

Our offering is a perfect mix to get most out of the wind at optimal costs

Requirements	Features	Benefits
› Enable efficient energy generation	› Higher power density thanks to optimized package and extremely low losses	› High power per volume using less power blocks per turbine to reduce system cost & optimize the levelized cost of energy (LCOE)
› Meet quality standards to withstand extremely harsh conditions	› Reliable and robust modules	
› Achieve the highest availability in order to contribute to grid stability	› Package families (PrimePACK™ & EconoDUAL™) are excellent building blocks for higher power ranges	› Longer lifetime leading to reduced maintenance cost
› Extended lifetime		› Enabling excellent system efficiency

Commonly used wind converter topologies

DFIG / Partial converter

Power ratings from 1,5 to 6 MW

Doubly-fed induction generator

Gear

Transformer

Grid

Filter

Filter

AC-DC converter

DC-AC converter

1/3 scale power converter
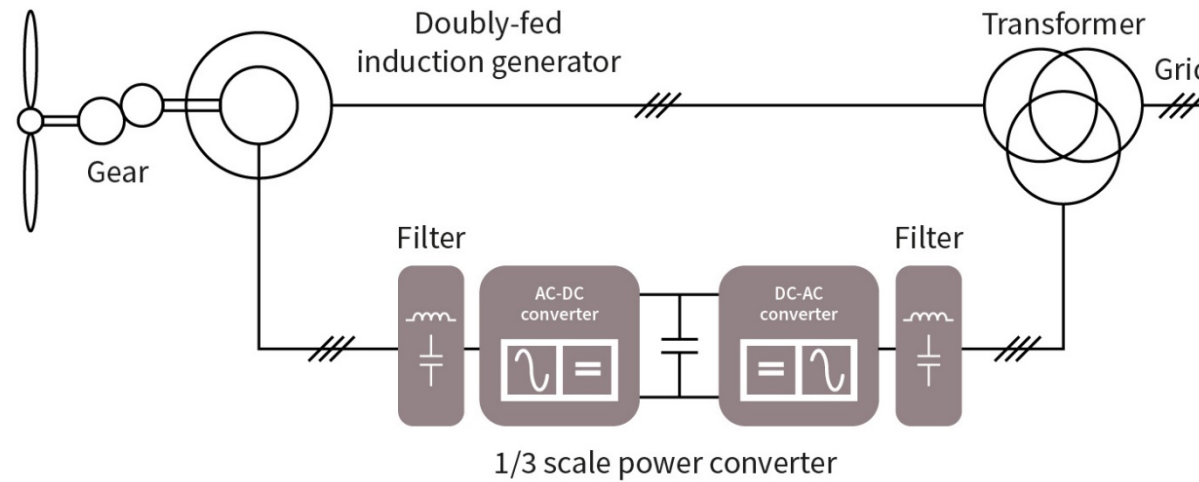
Full converter

Power ratings from 1MW to 10 MW

Gear

Asynchronous/ Synchronous generator

Filter

Filter

AC-DC converter

DC-AC converter

Full scale power converter

Transformer

Grid
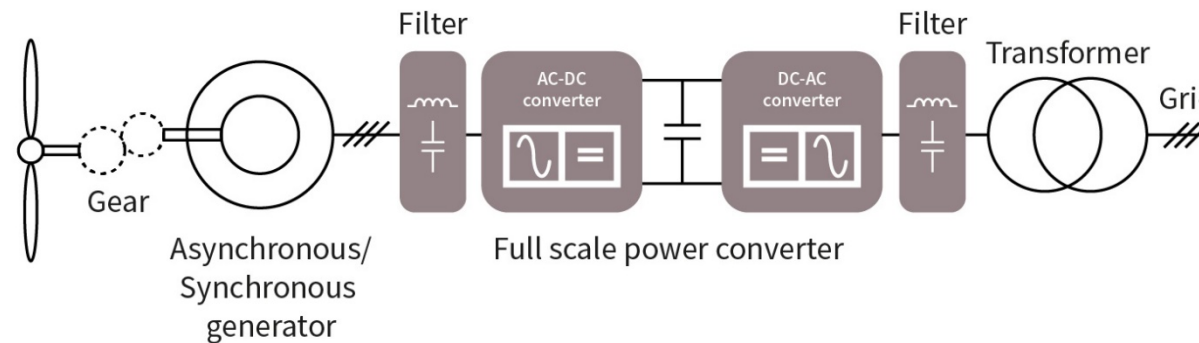
Infineon's product offering for wind power

EconoDUAL™

EconoPACK™+

µC XMC™ family

Gate driver

PrimePACK™3

PrimePACK™3+

AC-DC converter

DC-AC converter

Generator

Gearbox
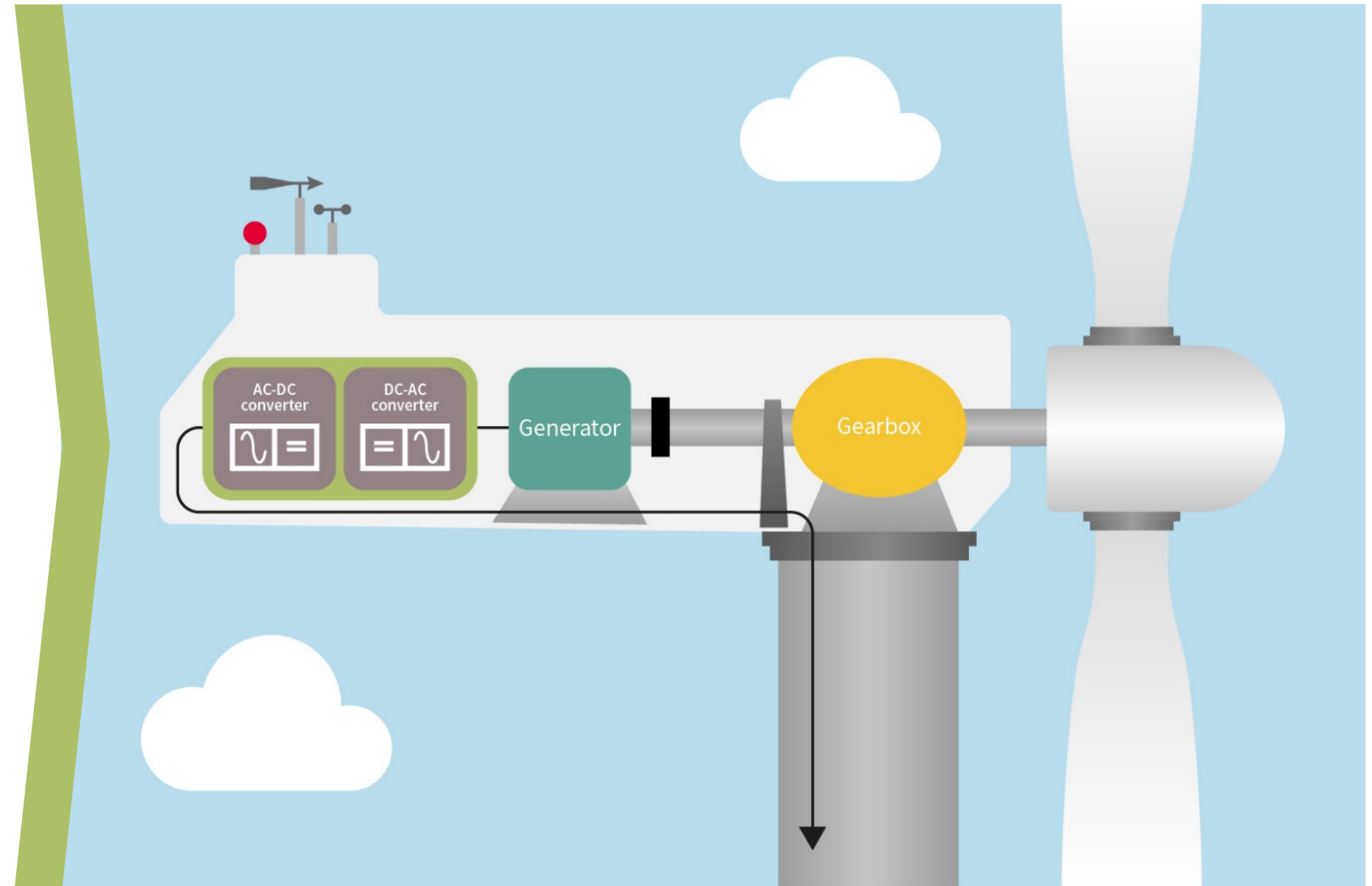
Broad segmentation of ESS along the energy supply chain

Before-the-Meter		Behind-the-Meter
› Conventional and renewables generation combined with ESS (stationary ESS)	› Transmission and distribution system with bulk ESS (stationary / mobile ESS)	› Roof top PV, UPS, V2G (stationary / mobile ESS)

Generation

Transmission

Consumption
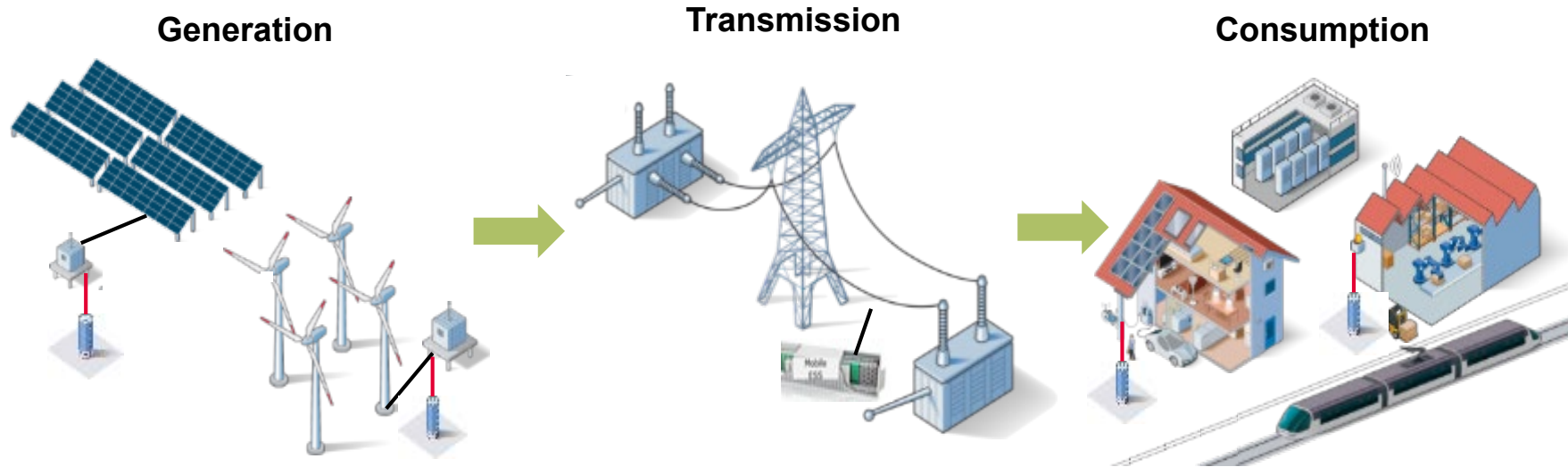
Bulk storage, substation, utility wind & utility photovoltaic (PV)	Commercial, residential PV & charging stations

Value of energy storage systems in before-the-meter

Grid reliability & stability

› Unstable grids and full-blown blackouts due to natural disasters and technical problems in ageing infrastructures

› Through ESS grid reliability and stability can be ensured even

Transmission capacity constraints

› Growing demand on electricity, especially during peak periods (e.g. aircon use at noon etc.), stretching grids to the limit

Intermittent renewables

› Boom in wind and solar PV leading to massive weather-dependent fluctuations and distributed generation, hence mismatch of supply and demand is growing

› ESS is needed to smooth-out this fluctuations

Bulk storage 1 MW – 10 MW	Substation 500 kW – 10 MW	Utility wind 500 kW – 10 MW	Utility PV 500 kW – 5 MW

Value of ESS in Behind-the-Meter

Commercial & residential

› Installed in offices, factories and supermarkets mostly for self consumption

› Excessive non self consumed energy generated by rooftop PV is stored in batteries for later consumption

Commercial & residential PV
up to 250 kW

Electric vehicles & others

› Electric cars require low-cost, high-density and safe battery storage and could become part of smart grid ("vehicle-to-grid")

Charging stations
up to 350 kW

Overviews of Energy Storage Systems (ESS)
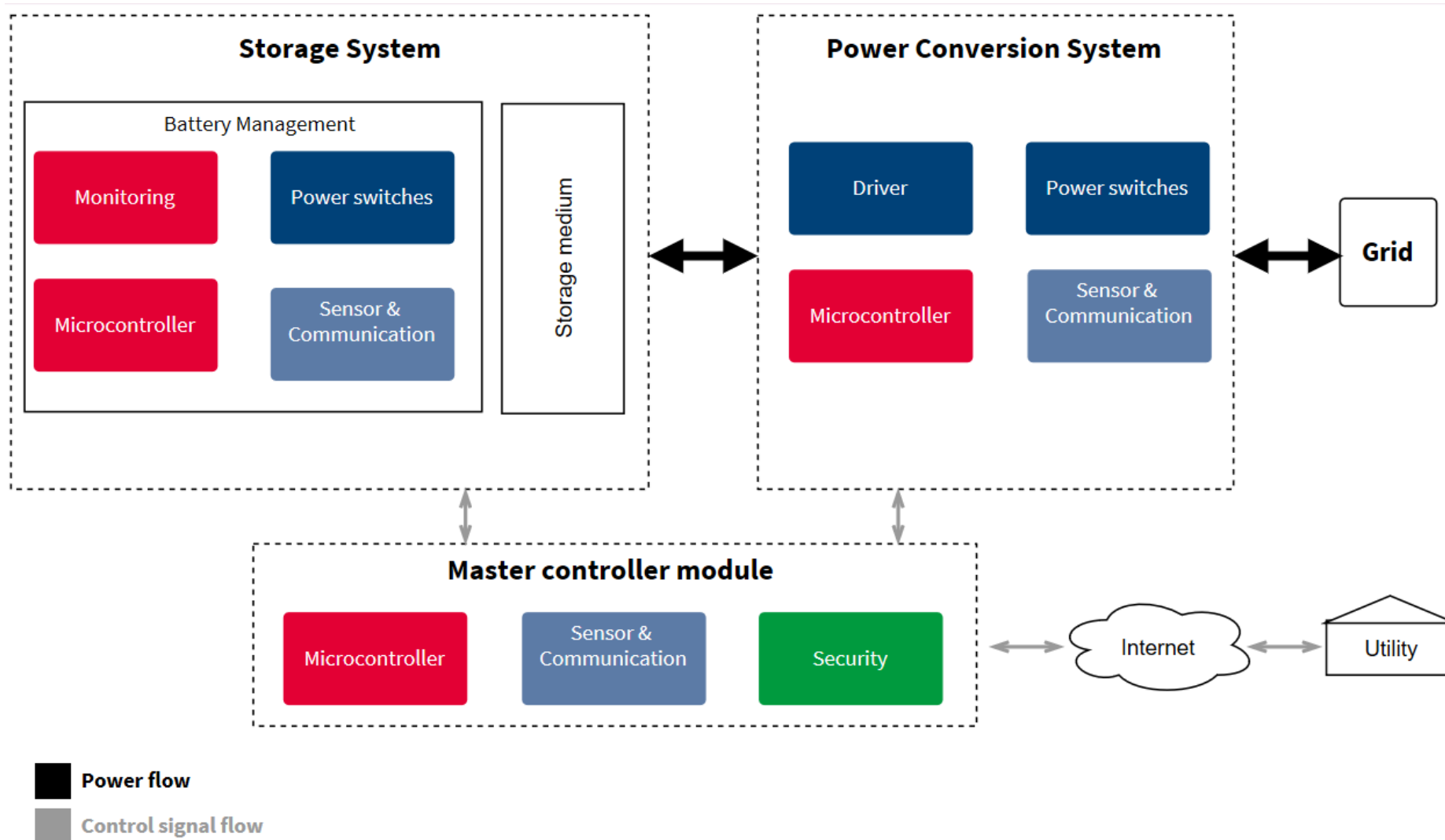
Topologies and key features for <10 kW

ACDC stage	DCDC stage

650 V CoolSiC™   600 V CoolMOS™ S7   600 V CoolMOS™ CFD7   60 - 150 V OptiMOS™
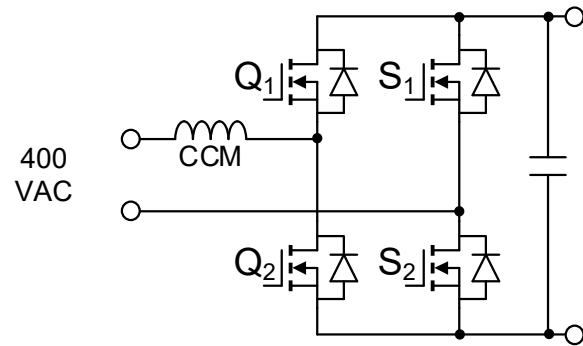
Q_1 S_1 Q_1 Q_3 L_r C_r C_s Q_5 Q_7

400 VAC   CCM   400 VDC

Q_2 S_2 Q_2 Q_4 Q_6 Q_8
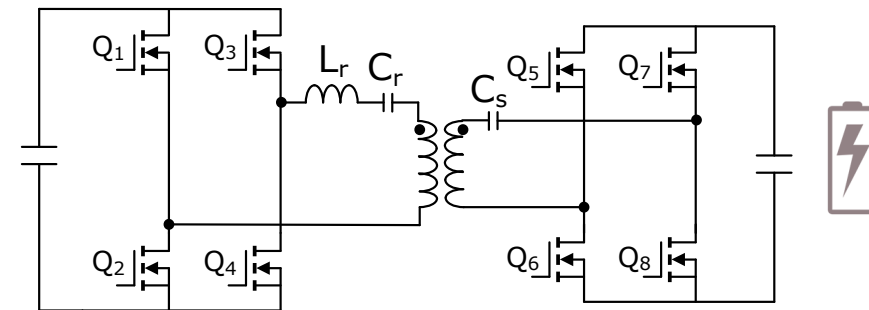
Key features and benefits

› Highest efficiency and power density for systems using low and high voltage batteries

› Bi-directional power flow

› Full system solution enabled by SiC and Si MOSFET design paired with best-fit Gate Drivers

› DCDC stage allows stack connection for serving three-phase PFC stage high output voltage

› Low ripple inductor current and reactive power capability

Topologies and key features for >10 kW & <125 kW

1x 1200 V Module with CoolSiC™ MOSFET
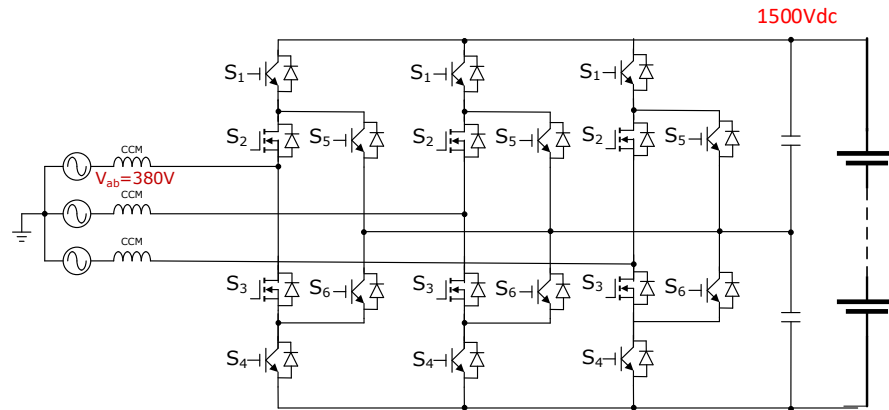
650V CoolSiC™ MOSFET / 600V CoolMOS™ MOSFET
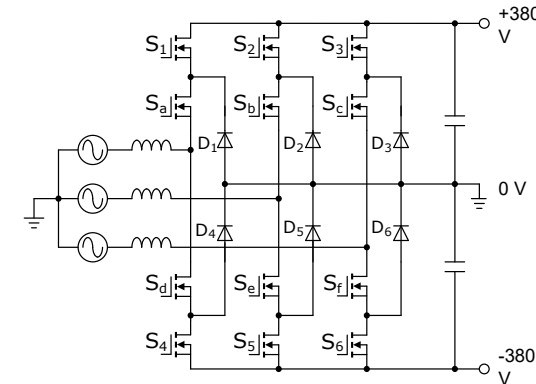
Key features and benefits

› ANPC allows optimal integration of CoolSiC™ MOSFET (M2, M3) with EiceDRIVER™ isolated gate driver 1ED Compact

› T1…T4 are optimized for lowest conduction losses

› Highest round trip efficiency

› Power losses independent of power factor

› Full 1500 Vdc capability & up to 75 Arms output power

Topologies and key features for >125 kW & up to 2 MW
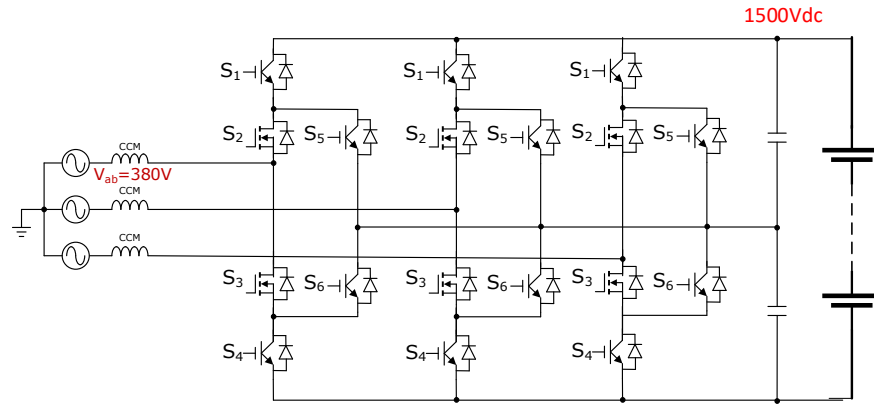
1x 1200 V Module with CoolSiC™ MOSFET	3 x 1700 V PrimePACK™ Module with IGBT4
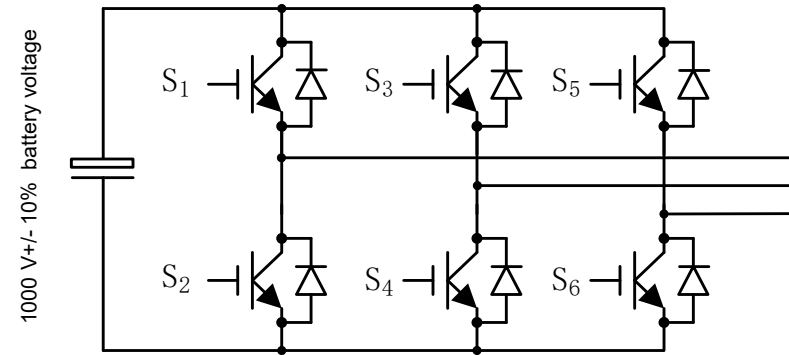
Key features and benefits

› Paralleling of many 125 kW ANPC topology units to address higher power level such as 500 kW and 1 MW

› Key advantage of paralleling 125 kW units is economy of scale

› Also 500 kW up to 2 MW can be addressed by 1700 V PrimePACK™ modules based 2-level inverter

› Both topology provides highest round trip efficiency

Infineon's solution positioning for ESS application

	PCS		BMS
	Discrete solutions	**Module solutions**	
> 1 MW module solutions	Module solution	PrimePACK2™ PrimePACK3™	
250 .. 1000 kW	Multilevel solution OptiMOS™	Easy CoolSiC™ Easy 1B / 2B EconoDUAL™	Monitoring IC
100 .. 250 kW	Multilevel solution OptiMOS™	Easy CoolSiC™ Easy 1B / 2B	OptiMOS™
10.. 100 kW	CoolMOS™ 7 CoolSiC™ IGBT TRENCHSTOP™ 5/6 HighSpeed3	Easy CoolSiC™ Easy 1B / 2B	CoolMOS™ 7
≤ 10 kW	CoolMOS™ 7 OptiMOS™ CoolSiC™	Discrete solution is recommended	

Every Li-Ion battery needs a "Battery Management System"

Cell protection
From out of tolerance operating conditions

SOC (State of Charge)
Estimate capacity left in the battery, Range indicator

SOH (State of Health)
Estimate remaining useful lifetime of the battery

BMS

Cell balancing
Equalizing the charge on all the cells in the chain

Security
Authentication and battery usage recording

Charge control
Charging optimization, interface to charger

Battery management in ESS

› EiceDRIVER™

› Current sensor – TLI4970

› XMC™
› AFE: TLE9012 & TLE9015

› StrongIRFET™
› OptiMOS™ 3 & 5
› PROFET™
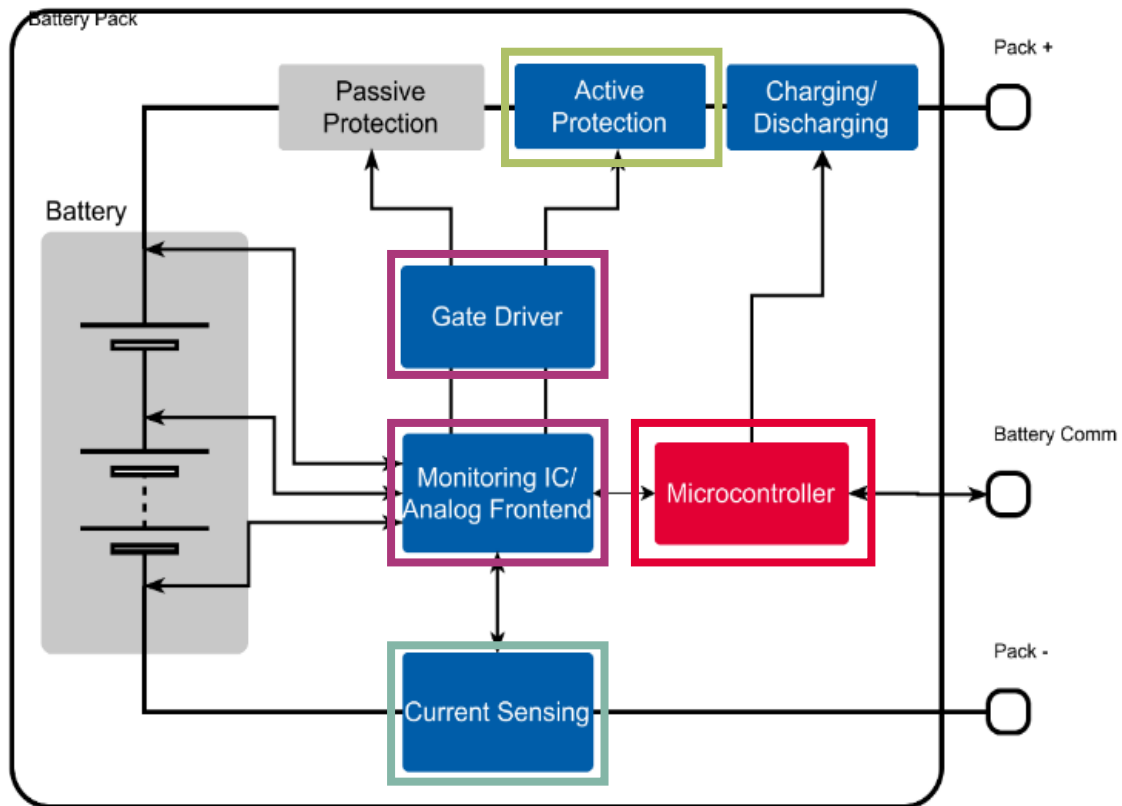
Battery protection	Over- / under- Voltage
	Inrush current
	Short circuit
	Reverse currents
Monitoring	State of charge (Fuel gauge)
	State of health
	Cell temperature
	Cell balancing
Security	Authentication
	Encryption

Infineon product offerings for ESS
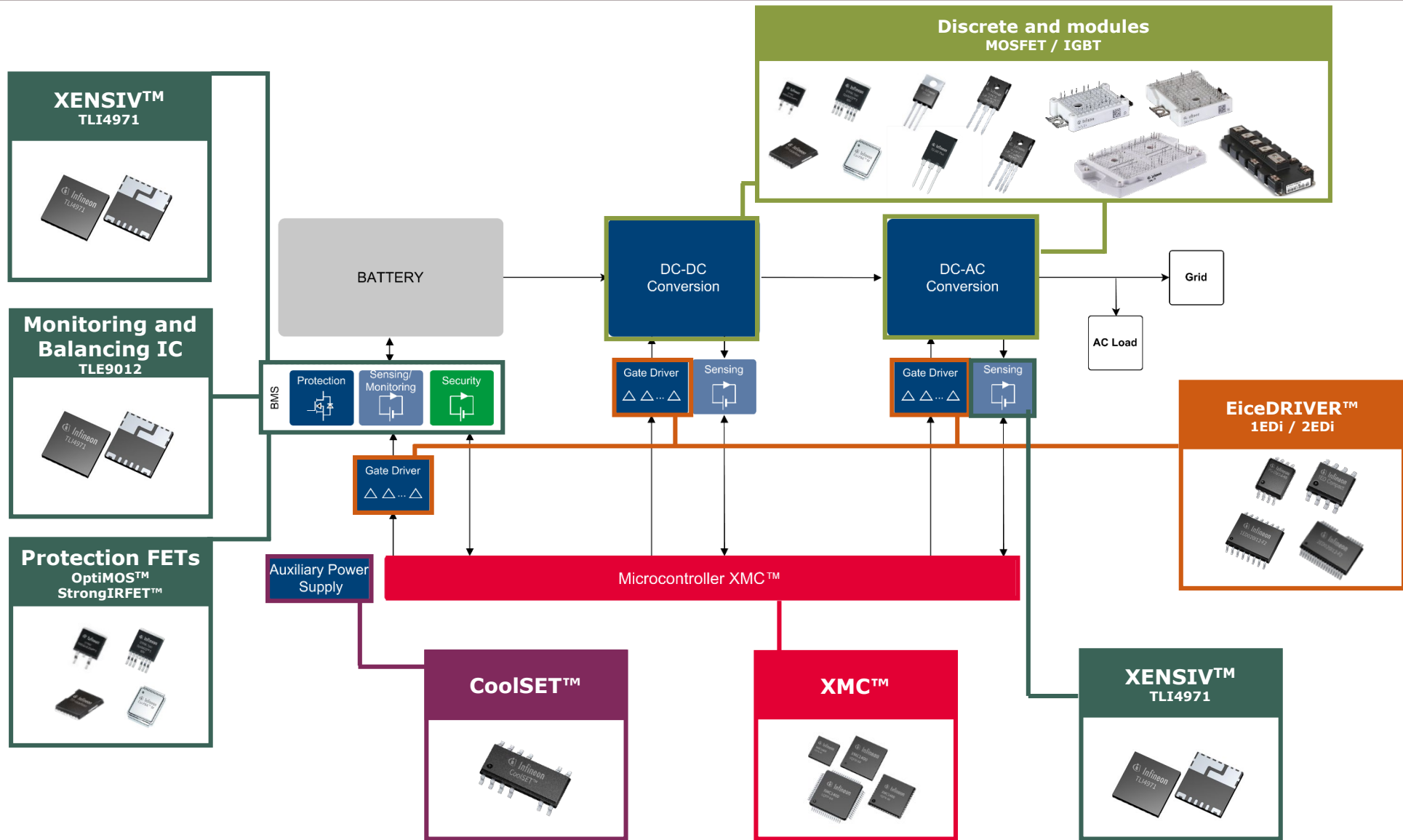
Summary

Solar

- The application can be categorized under three segments: Residential, commercial and utility scale

- String inverter is gaining popularity in utility scale application, and covers the complete range of application

- System cost and performance optimization are key driver, fast time to market and reliable delivery performance are key requirement.

- Our unique system expertise and unmatched capabilities in power semiconductors make us the natural choice for every solar inverter solution.

Wind

- The application can be categorized under two segments: On-shore and off-shore.

- Common used wind converter topologies are DFIG and full converter.

- Our offering is a perfect mix to get most out of the wind at optimal costs.

ESS

- Energy Storage is essential for further development of renewable and decentral energy generation.

- The application can be categorized under two segments: before the meter and behind the meter.

- Every Li-Ion battery needs a "Battery Management System"

- We provide easy-to-use products out of one hand to design efficient power conversion and battery management systems.

Part of your life. Part of tomorrow.