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Inverter Explained 2.0

Strengthening Europe's inverter industry



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Introduction

As solar and renewables boom across Europe, the role of the solar inverter is becoming ever more critical. Inverters are the components that connect the solar module to the electricity grid and convert direct current (DC) into alternative current (AC). But inverters offer much more. They operate as the brain of PV power plants, directly linking plants to the electrical architecture and controlling the output depending on system needs. Inverters operate and produce data by putting them at the core of a digital energy system, integrating solar PV with decentralised energy assets like batteries, EV chargers, and heat pumps. In larger building management systems utilising DC-to-DC coupling, and within utility infrastructures, inverters serve as the backbone of electrolysis processes that produce green hydrogen from wind or solar energy.

Europe has a strong industrial base in inverter manufacturing. Europe hosts more than 82 GW of yearly production capacity and employs 35,000 direct and indirect jobs, representing 72% of all jobs in the solar manufacturing supply chain in Europe. SMA, Power Electronics, Fronius, Fimer, and Kaco are among the leading European manufacturers of inverters.

But it should not be taken for granted. Inverters are power electronic components, and like other electronic industries, they have been severely impacted by the semiconductor crisis that has shaken Europe's economy. Due to their increased functionalities, inverters are made up of thousands of components, making them particularly vulnerable to supply chain issues. At a time when the world is taking a fresh look at global manufacturing, and newer, more robust industrial programmes are proliferating, manufacturing in Europe becomes increasingly challenged. Countries like China and the US are supporting domestic production of PV inverters, while European support lags, putting European producers at a competitive disadvantage with these products on the market. High-volume inverter products for the solar rooftop segment are particularly affected.

As a result, and while some EU inverter companies keep growing and announcing reinvestment plans, **their relative market share in Europe is shrinking**. It is estimated that EU inverter manufacturers are only able to capture 20% of the market currently.

To **compete with the fierce competition, European inverter manufacturers need a tailored industrial strategy** embedded into a strong innovation agenda which is focused on reducing the cost of integrating solar in the electricity system.

As solar PV's role in electricity generation grows, Europe expects more from its inverters in terms of services to the grid, integration with electrified loads and batteries, and cyber-security. This paper is an updated version of SolarPower Europe's 2023 Inverter Explained paper. This new edition provides a complete overview of the European inverter markets and technologies (section 1), as well as laying out an energy policy vision for EU inverters (section 2).

In an increasingly electrified world, we hope this report serves the solar industry and policymakers in planning our way forward.

Abstract

The EU remains a technological leader in the field of PV inverters and still maintains large production capacities. However, due to global pressure on competition, EU production sites are facing serious challenges. Existing production capacities in the EU are not fully utilised and new production sites are increasingly planned in countries outside the EU.

Given inverters' importance for grid integration and energy security, the EU must take urgent action to ensure EU's competitiveness in this critical technology. We call on EU leaders to develop a policy vision for EU inverters to ensure a thriving and innovative inverter eco-system in Europe that reaches the Net Zero Industry Act objectives. Specifically, we call for a new Important Project of Common European Interest (IPCEI) for solar inverters.



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1.1. Solar inverters: The brains of our solar PV systems

1.1.1. Introduction: What are inverters and why do they matter?

Aside from modules, the solar inverter is the most important component of a grid connected solar photovoltaic (PV) system. Its first function is to convert the direct current (DC) produced by solar panels into alternating current (AC), without which the electricity produced by solar PV would not be useable in electric appliances or the grid.

The second role of inverters is to generate data and control the quality of produced electricity. They are therefore indispensable for grid stability, as they hold

information on electricity demand and communicate with the grid within a network of millions of installed PV inverters. In large-scale solar power plants, they serve to stabilise the grid and provide the flexibility needed in our complex energy systems. Some inverters also include important physical (electrical) safety features.

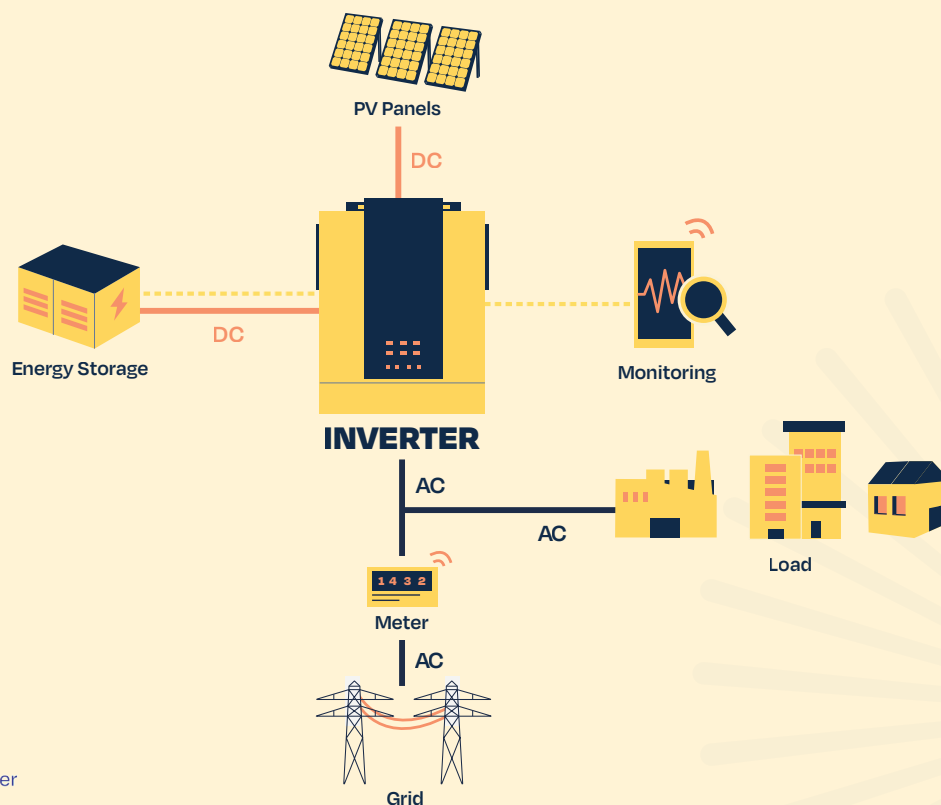
Inverters are also key for smart energy management solutions and sector-coupling in PV-powered systems (households, commercial buildings, or large-scale applications), as they connect renewable electricity production and storage with EV charging, electric heating/cooling, and the grid. They are therefore the backbone of the future European energy system based on renewables.

Box 1: How do they work?

Sunlight captured by PV panels generates a flow of electrons and creates a DC current. The inverter processes and transforms this DC into AC by sending the DC current through a system of **switches** (transistors) that are turned on and off at high speeds. The resulting output then imitates the behaviour of alternating current, which can be used in our electronic appliances and the grid.

Another key characteristic of solar inverters is their use of **Maximum Power Point Tracking (MPPT)**. Many modern solar PV inverters incorporate MPPT technology, which continuously tracks and adjusts the operating points of the system to ensure it is drawing the maximum power possible, based on factors such as sunlight intensity and temperature. MPPT in inverters therefore greatly improve the performance and efficiency of the solar power system.

FIGURE 1 INVERTERS: THE BRAIN OF THE SOLAR PV SYSTEM



1 Market & technology briefing / continued

1.1.2. What are the different types of inverters?

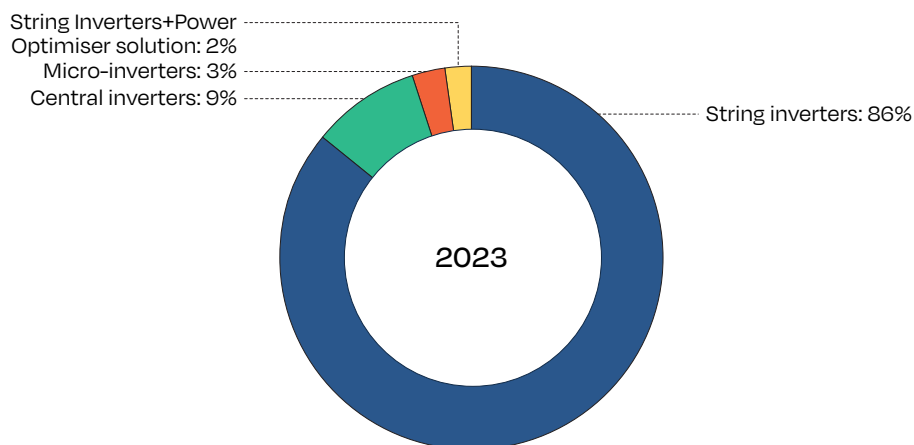
Each solar installation needs its own inverter, or set of inverters, which are the heart of the architecture of the PV power plant as they are adapted to different applications, capacities, grid-connections, and uses. Table 1 details the 4 main types of inverter solutions on the global and EU market, categorised by scale and application. Inverter capacity is generally expressed in watts of AC rated output (W_{AC}). Although there are variations, generally speaking, by segment:

- **Residential or Home PV** tends to favour lower-voltage string inverters or microinverters for rooftop applications.
- The **C&I segment** generally makes use of string inverter technology.
- **Utility scale** solar projects will generally use central inverters, with a recent increased use of high-power string inverters. A disruptive technology in this segment is the use of medium voltage for PV power collection and local distribution.

TABLE 1 MAIN INVERTER TYPES ON EUROPEAN AND GLOBAL MARKETS

TYPE	CAPACITY	APPLICATIONS	CHARACTERISTICS
Central inverters	500 kW AC – 5 MW AC	Large commercial and utility scale	• Collect and centralise electricity from several PV arrays • Floor or ground-mounted – housed in free standing electrical enclosures • Advantages: simple design and connection, low operational costs
String inverters	Few kW up to over 380 kW AC	Low-power inverters: Rooftop PV for residential and small-scale commercial High power inverters: large scale rooftop or ground mounted C&I, even utility scale	• Collect electricity from one or several strings of PV modules connected in series • Single-phase or three-phase string inverters convert DC current to either single-phase or three-phase power • Wall, ceiling or rack-mounted • Advantages: modularity, low upfront costs and flexible applications
Power optimisers	Module level	Mostly rooftop solar & small Distributed Generation	• MLPE (module-level power electronics) • Used in tandem with string or central inverters • Optimise the DC power output from each individual panel and send it to the inverter for DC – AC conversion, or for direct DC feeding into a storage system, or DC-EV charger • Enable solving mismatches between individual panels created by shading, manufacturing faults, soiling, clouds and other factors • Improved power yield, attractive LCOE, enhanced safety features
Micro-inverters	Module level	Rooftop solar & small Distributed Generation	• MLPE, converting DC to AC directly at the panel level • Provide panel-level monitoring capabilities and optimised power-output (ideal for shaded roofs) • Safe AC architecture • Modularity and no single point of failure

FIGURE 2 DIFFERENT INVERTER SOLUTIONS' SHARES ON THE EUROPEAN MARKET IN 2023



Source: S&P, 2024.

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Central inverters

Central inverters, with 9% market share on the European market in 2023 (Fig. 2), are used for utility and large-scale commercial applications, in ground-mounted installations. They have rated capacity ranging between 500 kW up to 5 MW. Due to their complexity, size and weight, they are often housed outdoors in free standing electrical enclosures.

Central inverters collect the DC current produced by several PV module arrays. As they are generally used for utility applications, they often feed electricity directly to the medium voltage (MV) power distribution network. They are sometimes packaged with transformers, to harmonise voltages between DC input and grid-compatible AC output, which together are referred to as 'central solutions'. They present several advantages for large-scale applications, such as simple design and connection, along with lower operation and maintenance costs.

A central inverter typically has a maximum input voltage of 1,000 V. However, one emerging trend in the high-power inverter landscape is a move to even higher voltages. 1,500 V solar systems are becoming

more popular as they can reduce system costs and improve end-to-end efficiency, by reducing power losses and material use as they require fewer BOS (balance of system) components. In July 2023, a 2,000 V inverter system developed by Chinese market leader Sungrow was connected to the grid for the first time, in China.

Although the projected trend in the next few years is for rising demand from the C&I and utility segments, today, EU developers of utility-scale projects have a preference for string inverters, rather than central inverters. One analysis from S&P forecasts shipments of central inverters to decline slightly up to 2030, at a compound annual growth rate (CAGR) of -2% between 2023 and 2030. However, central inverters will maintain some market share due to their suitability to certain projects and lower price.

Moreover, utility inverters with grid forming capabilities are key for grid stability. Due to their size, above 1 MW they are directly connected to the high voltage grid and are easily managed by the grid operator. Together with utility storage, they are able to build an energy "island" without having to manage thousands of households on the low power level.

1 Market & technology briefing / continued

String inverters

String inverters are the most common type of solar inverter, with a 86% market share on the European market in 2023 (88% when counting string inverters + power optimiser solutions) (Fig. 2). They convert the DC output from a string of PV panels connected in series into single phase or three-phase AC current. Each string of modules in a PV installation has its own string inverter, meaning a PV plant can have one or several string inverters, depending on its size. String inverters have a wide range of capacities, with single phase inverters in the 1-6 kW_{AC} range, and the latest high power three-phase inverters reaching up to 380 kW_{AC} and over, making them suitable for all kind of applications, from small-scale residential rooftop installations to C&I and even utility-scale. Key advantages of string inverters generally include modularity, low upfront costs, flexible applications, their relatively small size and weight, and lower production losses when an inverter goes down or when working in non-uniform conditions such as partial shading.

There are two main types of string inverters on the market today: high power string inverters for large commercial, industrial and even utility applications, and inverters for smaller-scale residential and commercial rooftop applications. Historically, string inverters are typically installed in residential and small to medium-sized commercial PV systems, for rooftop

PV or small ground-mounted installations of under 1 MW. However, developments such as cost decrease, voltage and capacity increase, higher energy yields, easier installation, O&M and other benefits, have led to string inverters becoming increasingly common in utility scale plants. While EU developers increasingly favour high power string inverters for large scale utility projects, this trend is also visible on the US market and as a global trend.

In addition to this driver from utility solar applications, major suppliers are also promoting 300 kW+ string inverters in place of inverters in the 100-250 kW range, as they offer a lower price per watt, and involve fewer units per MW, reducing labour and installation time.

As a result, S&P expects shipments of 251-500 kW high-powered string inverters to grow at a CAGR of 31% between 2023 and 2030

Module-Level Power Electronics: Power Optimisers and Microinverters

Module-Level Power Electronics (MLPEs) are devices that can be incorporated into a solar PV system at the panel level, to improve its performance in certain conditions (especially where shade is present). They also improve rapid shutdown and electric arc detection. There are two types of MLPEs: DC power-optimisers and microinverters.



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Data from S&P indicates that the EU MLPE market is expected to grow steadily over the next few years. The main drivers for this predicted growth include optimisation, building on a favourable context of falling costs, supportive policies, increasingly innovative business models, and a general trend towards rooftop solar and smaller distributed generation systems with complex orientations and/or areas of shading. Notably, balcony solar in Germany and potential markets such as France, Italy, and Poland, show growth opportunities for MLPE products. Apart from the residential segment, MLPE suppliers continue to push into larger commercial applications by releasing multimodule and higher-powered products.

- **Power Optimisers**

DC optimizers are not inverters but operate in conjunction with a central or string inverter to convert DC to AC current. Power-optimisers optimise the voltage output of each individual panel, using MPPT technology, before sending it to the inverter. This design avoids power output being restricted by the PV string set-up, where the power production of all modules is determined by the weakest performing solar module in that string. If one solar panel produces less energy, all the solar panels in that string will produce less energy to send to the string inverter. With the power optimiser, each solar panel produces energy, and when that energy reaches the optimised threshold, the power optimiser sends it to the inverter, therefore improving output.

As well as improving PV system output in complex set-ups, for instance with varying panel orientations, power optimisers offer another advantage through their monitoring capabilities, as they provide real-time data on the performance of individual panels, allowing for easier maintenance and troubleshooting. They also provide enhanced safety.

Power optimisers are mostly used for residential and commercial rooftop PV but are increasingly used in dedicated ground-mount installations, mainly in the small utility-scale market. Used in tandem with an inverter solution, they hold a 2% share of the EU inverter market in 2023.

- **Microinverters**

Microinverters are a distributed architecture, i.e. they operate at the panel level and therefore have no single point of failure. Each solar panel is paired

with its own microinverter, which converts DC to AC. They are used in similar applications to power-optimisers, notably for rooftop PV.

As well as improved system performance and monitoring capabilities, microinverters are also considered to provide better fire safety, as there are no points with high DC voltage in the system.

In 2023, microinverters held a 3% EU market share. Additionally, microinverters are the only relevant solution for 'plug-in' balcony solar systems. Finally, microinverters play the leading role in the residential sectors in France and the Netherlands and show substantial growth opportunities in Germany, Italy and Poland.

1.1.3. Hybrid inverters: the all-in-one energy solution

One key development on the inverter market in recent years has been the emergence and increasingly overwhelming presence of hybrid inverters, which intelligently manage power from multiple sources: PV modules, batteries and the grid. Positioned as the all-in-one energy solution, they allow for flexibility and resilience of solar PV systems everywhere.

What is a hybrid inverter?

Inverters have different applications depending on the PV system's integration with the electricity grid. Grid-tied inverters used for grid-connected solar PV are specifically designed to match phase with the electrical grid. In off-grid standalone systems which rely on batteries, battery inverters are used to convert the DC current stored in batteries into AC current.

Hybrid inverters, whether in the string, central, or MLPE configuration, combine the functions of traditional inverters with those of a battery charger and a grid-tied inverter, combining the energy generated by solar panels with energy stored in batteries and power from the grid. The inverter manages the flow of energy between the different power sources, used interchangeably depending on factors such as energy demand, solar availability, and battery state of charge. This ensures efficient and reliable power management, enabling solar systems to operate effectively as both on-grid and off-grid solutions, and even as back-up solutions. Choosing a hybrid inverter for a PV installation, even without battery storage, provides added flexibility and retrofitting possibilities, for instance if the consumer wishes to add battery storage in the future.

1 Market & technology briefing / continued

They are used in residential and commercial applications, including in areas with unreliable grid supply or high electricity costs. However, given their many advantages, notably increased energy efficiency, cost savings, improved power reliability, and removing the need to have two separate inverters for

PV installations with storage, they have become a leading product on the market, including where grids are reliable. For the residential segment, up to 65% of inverters sold on the EU market are now hybrid, with signs that this upward trend will only increase.

Box 2: Innovation trends

- **Smart communication and interconnection**

Inverters increasingly have added capabilities beyond DC/AC conversion: one hallmark characteristic of the latest generation of inverters, or advanced 'smart inverters', include built-in communication and monitoring and control capabilities. They allow, for example, the connection to smart meters for measuring and visualising self-consumption, or the integration of additional consumers such as air conditioners or heat pumps.

- **Grid forming technologies**

Grid-forming inverters are an emerging technology which improve the resilience of our power systems. While conventional power plants have been responsible for maintaining stable voltage and power line frequency in the past, the increase of renewable energy systems requires grid-forming inverters to take over this task to ensure grid stability and energy security for homeowners. By 2050, more than 60% of renewable energy sources will be inverter-based power. Therefore, it is necessary to build an EU roadmap for grid-forming inverters as a backbone of our energy systems.

In Germany, for example, the Federal Cabinet recently adopted the **System Stability Roadmap**, which defines necessary measures and regulations for a renewable energy supply, and grid-forming inverters were among the key issues.

- **Inverter sustainability**

Another important development relates to sustainability as an added value in the inverter market: EU producers can maintain leadership on sustainability, promoting the durability, reparability, and recyclability of their products. Optimised generation also creates a sustainability advantage, by increasing the generation efficiency of each PV system, and with it the associated GHG reductions for the overall energy market. By prioritising sustainability, EU inverter manufacturers can differentiate themselves in a competitive market and meet the growing consumer demand for environmentally responsible products.

Leading EU inverter companies already advance strong sustainability performances of their products, for instance by publishing life cycle assessments (LCAs), Carbon Footprint analyses (CFPs) or Environmental Product Declarations (EPDs) of their inverters. From raw material extraction to end-of-life disposal, these documents provide detailed insights into the environmental impact of their products, which help to improve resource efficiency, reduce carbon footprints, and drive innovation and market appeal for sustainable inverters.

Circular design practices and the provision of repair and conditioning services are other key product sustainability strategies carried out by inverter companies, which are driving the emergence of the sustainable inverter market. Meanwhile, sourcing 100% of their electricity from renewables, developing transparency through sustainability reports, or establishing clear supplier sustainability frameworks are among the key strategies leveraged for instance by European market leaders like SMA and Fronius to set the way on sustainable practices on the inverter market.

Box 3: Single-Phase or Three-Phase inverters

What is the difference between a single-phase inverter or a three-phase inverter?

- A **single-phase inverter** converts the DC input from PV modules into single-phase AC power
 - Single-phase power is distributed through one active wire to other single-phase equipment.
 - Single-phase inverters are typically used in residential or **small-scale commercial PV systems**, where the electrical load is typically single-phase and power demand is relatively low.
 - They are often **simpler in design and less expensive** than three-phase inverters.
- A **three-phase inverter** converts the DC input from PV modules into three-phase AC power,
 - Three-phase power is distributed through three active wires to other three-phase equipment and the grid, providing a more balanced load and improving the efficiency of energy transmission.
 - Three-phase inverters are typically found in larger installations, **commercial and utility scale applications** where the power demand is higher and more balanced across multiple phases, although they are also often used in residential systems.
 - They are generally more complex and expensive compared to single phase inverters due to the additional circuitry required to generate and control three phase output.



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1 Market & technology briefing / continued

1.2. Supply chain for solar inverters

1.2.1. What's in an inverter?

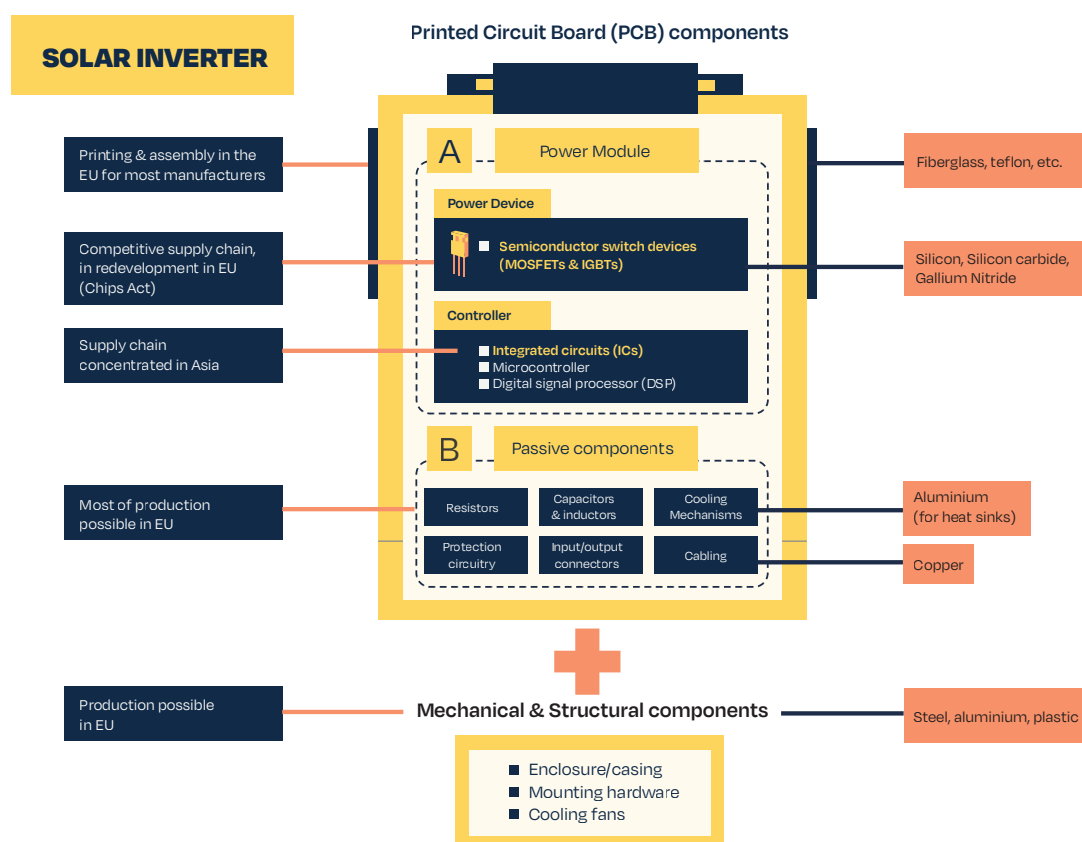
A typical string inverter consists of hundreds of different components, manufactured and assembled in different locations, which makes for a complex global supply chain.

PV inverters are composed of power electronic semiconductors, power circuits, mechanical and structural parts.

To simplify, the key elements of a solar inverter can be separated into two main 'groups' (Fig. 3):

- Components typically assembled onto the Printed Circuit Board (PCB), including:
 - The Power Module or Power block (A), which hosts key semiconductor components, namely:
 - Power semiconductor switch devices (transistors, typically IGBT¹ or MOSEFT²)²
 - Integrated Circuits (ICs), or "microchips," used in the controller
 - Other passive electronic components (B), used for example to filter and smooth the waveform: inductors, resistors, capacitors, transformers, cabling, etc.

FIGURE 3 INVERTER COMPONENTS, SUPPLY CHAINS AND MATERIALS



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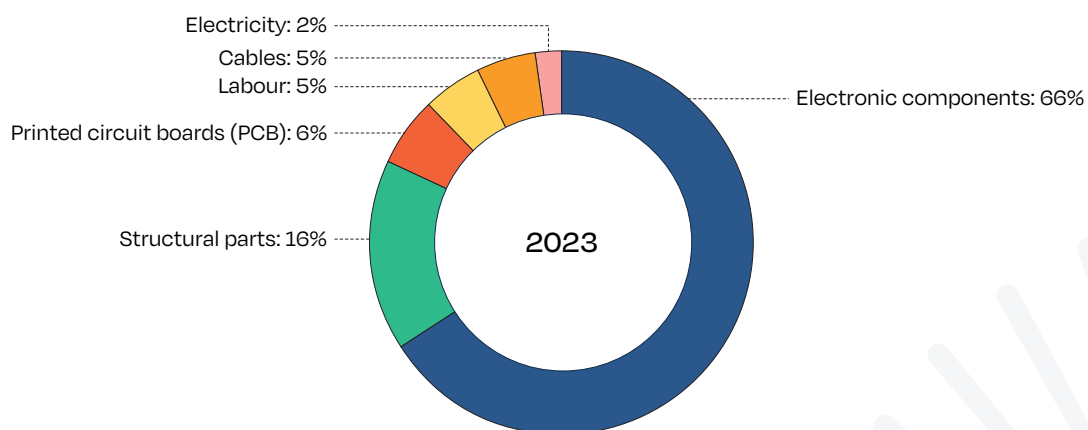
1 IGBT: Insulated-gate bipolar transistor.
2 MOSEFT: Metal-oxide-semiconductor field-effect transistor.

- **Mechanical and structural parts**, including:
 - Thermal management systems, required as semiconductor components generate a lot of heat:
 - Cooling fans/ventilation, or liquid cooling systems
 - Aluminium heat sinks (sometimes assembled onto the PCB)
- Casing
- Mounting structure

One analysis by Rystad (Fig. 4) shows that most of the costs for inverter manufacturing lies in the production of electronic components, representing 66% of costs, with structural components such as the casing, generally made of aluminium, steel, or plastic, coming in second with 16% of overall costs.

Specifically, semiconductor components like transistors and ICs, are the most strategic/important electronic components of a solar inverter.

FIGURE 4 2023 SOLAR INVERTER COST BY COMPONENT, IN USD/WATT-PEAK



Note: . Note that this is data from inverter production in China.
Source: Rystad, 2023.

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Box 4: Strategic semiconductor components: transistor switches and ICs

1) Semiconductor switches, or transistors, are semiconductor power electronics used to convert DC into AC current. They are a key component of the inverter supply chain.

The most commonly used are **MOSFETs** (Metal-oxide-semiconductor field-effect transistor) and **IGBTs** (Insulated-gate bipolar transistors). In general, high voltage, high current and low switching frequencies favour the IGBT, resulting into a wide application into larger scale applications. By contrast, low voltage, medium current and high switching frequencies are the domain of the MOSFET, which are typically used for smaller-scale systems. They are both usually made with silicon.

As the inverter market is highly dynamic and competitive, with strong cost pressure, market players constantly search for more efficient, miniaturised, and cost-optimised components – this applies to inverter switches. New innovative semiconductor technologies are emerging on the market as they provide optimised efficiency, by improving heat

resistance, reducing losses at high switch frequencies, reducing material use, and increasing power density.

The emerging trend on the inverter market on this front is for increased use of wide bandgap (WBG) semiconductors. The two leading technologies, silicon carbide (SiC) and gallium nitride (GaN), are already largely taken up by the electric vehicle (EV) sector and represent a key upcoming development on the solar inverter market. For instance, GaN has already been adopted as a key strategic technology by US inverter producer Enphase Energy for their microinverters. SiC is gaining traction in the high voltage, 1500 V scale and some projections have been made for it to become the industry norm in the next few years.

2) Integrated Circuits (ICs): ICs, sometimes called semiconductors, chips or microchips, are fundamental to the functioning of all modern technology. In solar inverters, they hold the intellectual property of the solar PV system: this is where manufacturers can implement control algorithms, protection features, communication interfaces, and other functionalities that enhance the performance and reliability of inverters (through the use of MPPT, for instance). ICs are therefore an integral component of most advanced inverter designs and are a key component of the solar inverter supply chain.

1.2.2. The solar inverter supply chain

A global supply chain – dominated by Asia

According to data from Rystad Energy, 77% of global inverter production capacity in 2023 was located in Asia, with 68% in China. Although a small number of companies, such as EU-headquartered ABB and Infineon, have some vertical integration along the value chain, starting at the semiconductor device level all the way through to an inverter, most inverter manufacturers buy components to assemble them into a finished product. This means that components are typically manufactured in separate locations from where they are eventually assembled, providing the opportunity for a global supply chain.

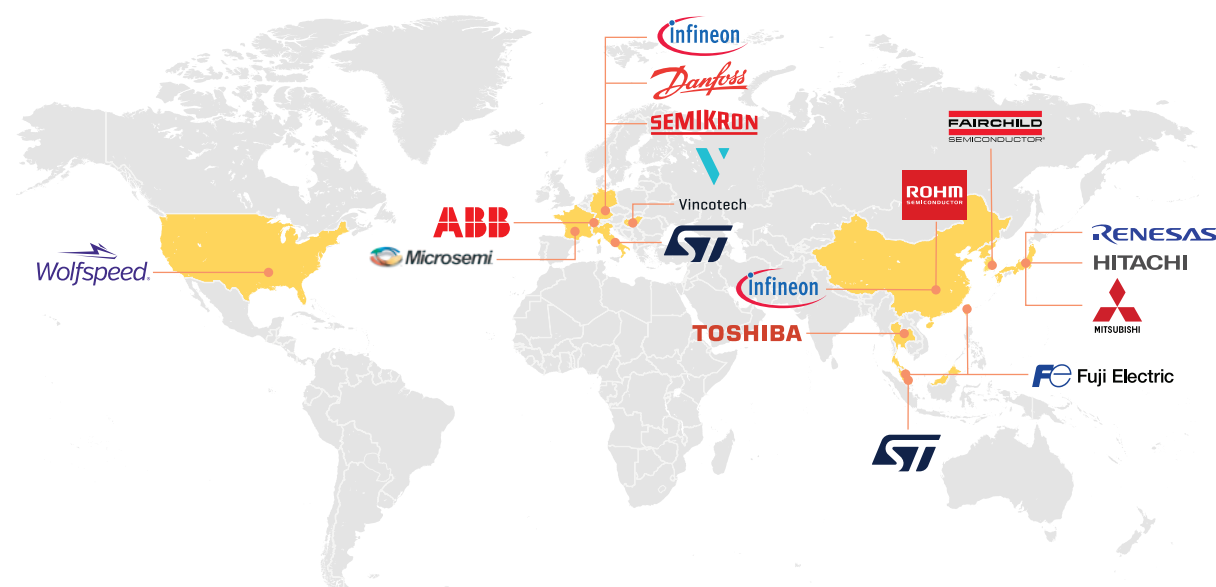
In particular, when looking at semiconductor components, the U.S., Europe, and Japan have many

large semiconductor companies, but crucially, the majority of the manufacturing takes place in Asia.

Although Taiwan is home to 60% of all semiconductor manufacturing and 92% of advanced chip production, with the Taiwan Semiconductor Manufacturing Company (TSMC) alone producing around 50% of the world's semiconductors, the solar inverter industry does not depend on these chips. TSMC chips mostly serve the mobile sector and advanced applications, which do not include the solar inverter industry.

A 2022 analysis of PV supply chains from the US Department of Energy highlights that despite a large geographic distribution of semiconductor power electronic companies, manufacturing capacities for inverter power blocks are still concentrated in Asia, with some significant capacity in Europe as well (Fig. 5).

FIGURE 5 GEOGRAPHICAL DISTRIBUTION OF MAIN MANUFACTURING POWER BLOCK LOCATIONS



Source: US Department of Energy, 2022

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The landscape of passive electronic components manufacturing displays a similar picture, with a strong presence of production facilities in Asia. The same report refers to a database of 542 unique passive components (e.g., cathode, wire, die, terminals), 35 manufacturers-built parts in 31 different countries. While the quantity of products built is not well known, 43% of the individual products were manufactured in China, 5% in Japan, and another 33% in the rest of Asia, with 11% from Europe.

In terms of raw materials, aluminium used to produce heat sinks, steel for electronic or structural components, copper for cabling, and silicon for semiconductor components are key materials of concern in the supply chain.

1.3. EU solar inverter industry and market

An established industry, under stress from global competition.

The EU inverter value chain

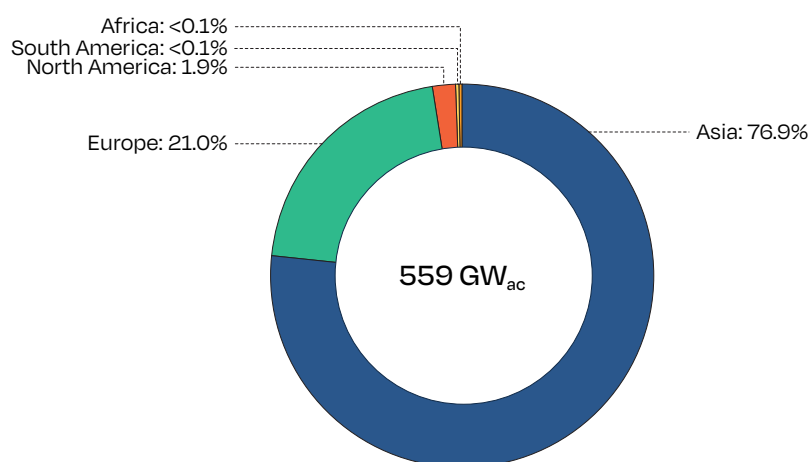
Solar inverters have been designed and made in Europe since the early 1990s, and EU companies are global pioneers in solar PV inverter technology. For example, Fronius, based in Austria, successfully launched the first PV inverter on the European market back in 1995. Today, EU production capacity exceeds 82 GW, which represents a 14% growth in 2023 from 2022 (72 GW). However, production capacities are no longer being fully utilised, and companies' investment decisions are increasingly being made in favour of non-European locations.

1 Market & technology briefing / continued

According to data from Rystad Energy (Fig. 6), in 2023 the European continent holds 21% of global aggregated production capacity for solar inverters, with the majority of production capacity located in Asia, specifically China (similar to the solar module supply chain).

The inverter industry holds a prominent position in the EU solar manufacturing sector, employing a significant majority of the manufacturing workforce (Fig. 7).

FIGURE 6 2023 INVERTER MANUFACTURING CAPACITY PER REGION (GW_{AC})



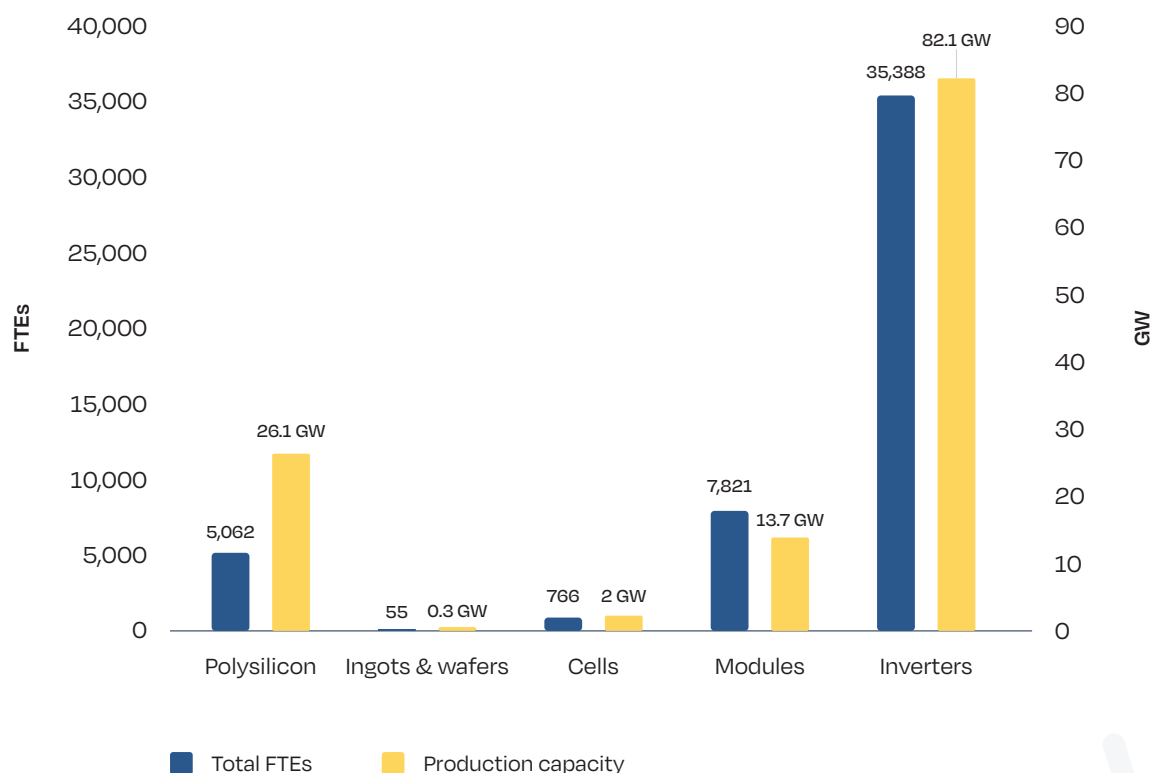
Note: Some numbers may vary from SolarPower Europe's EU data.
Source: Rystad, 2023.

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FIGURE 7 SOLAR MANUFACTURING JOBS AND PRODUCTION CAPACITY IN 2023



Note: Production capacity values based on SolarPower Europe's EMO 2023, solar manufacturing jobs based on the Medium Scenario for 2023 from SolarPower Europe's EU Solar Jobs Report 2023.

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In 2023, the inverter manufacturing sector employed 72% of all full-time equivalents (FTEs) in EU solar manufacturing across the supply chain, which translates to over 35,000 direct and indirect jobs.

While inverter manufacturing jobs are a minor portion of total solar job creation in the EU – where over 80% is found in deployment, they are strategically important for developing a resilient solar inverter industry and for maintaining know-how. According to SolarPower Europe's EU Solar Jobs Report 2023, under a Medium Scenario, inverter manufacturing jobs are projected to grow from 35,000 FTEs in 2022 to 48,000 FTEs in 2027.

Many steps of the solar inverter value chain are contributing to manufacturing value and industrial jobs in the supply chain in the EU, from the production of many hardware components and their assembly to software development, R&D, service and repair jobs.

As highlighted in Figure 3, inverter manufacturing in the EU currently integrates the following steps in production:

Production:

PCB/Electronic parts:

- A big share of **power modules**.
- Microcontrollers
- Sheet metal parts (e.g. EMC cage)
- Inductors (chokes, coils)
- DC-disconnector
- Heat sinks

Structural components

- Housing components (injection moulding, e.g. base shell, front cover, etc.)

1 Market & technology briefing / continued

- Assembly:

- Cable assemblies
- PCB assembly
- Packaging (cardboard, inserts)

However, there is a growing footprint of competition from outside the EU on 'mature', legacy semiconductors, where the EU is currently strongest. This could represent a future dependency challenge, as the EU already depends on outside players for processors used for data processing and generation.

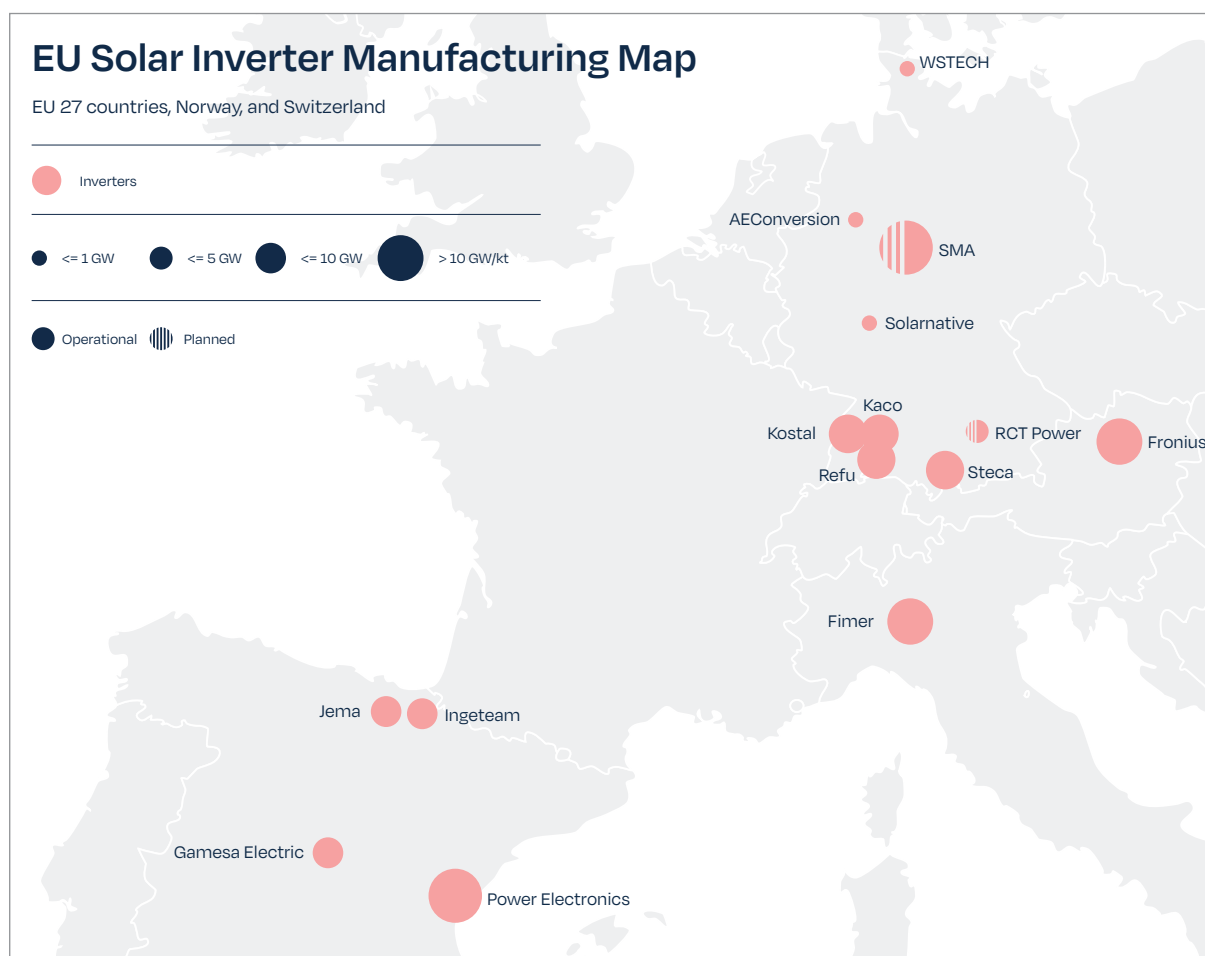
Focus: Semiconductor components in the EU

Despite a global concentration of manufacturing capacity for semiconductors in Asia, the EU has significant production capacities for power modules and microcontrollers, and solar inverter producers can source these components directly in the EU today.

The EU inverter industry – a rich landscape of established actors

Figure 8 below displays a map of the solar inverter manufacturing landscape in the EU from EU companies, based on the latest developments and planned capacity expansions (Fig. 8). In addition, there

FIGURE 8 EU INVERTER MANUFACTURING MAP



Note: Due to limited data, the capacity indication for all points may not be fully accurate.

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are a number of EU-headquartered inverter companies which do not produce in the EU, but still actively contribute to the segment's activity and the growth of the industry through R&D and deployment. As this map only displays manufacturing that is located in the EU, they have not been included in the analysis. Some EU manufacturers also use significant amounts of re-branded Asian inverters in their product portfolio.

With at least **14 companies operating in the EU**, the inverter manufacturing industry is a critical part of the overall EU solar manufacturing eco-system. The top countries for inverter production are Spain and Germany, with Spain providing almost half the total EU manufacturing capacity from 4 companies, while Germany hosts almost a third of EU manufacturing capacity, from at least 8 inverter producers.

Several EU inverter companies are international leaders on the global market. SMA from Germany, and Power Electronics from Spain, were ranked 6th and 7th for 2022 global market shares in a 2023 study by WoodMackenzie. This can be attributed to their strong international reach: SMA, for example, is leading in utility-scale applications on the Australian market, and Power Electronics has long-standing presence on the US market.

SMA is an EU inverter leader across all segments, providing a full portfolio of inverter solutions. With annual production capacity of 21 GW in 2023, they reached high utilisation rates with 20.5 GW output for the same year. SMA plans to double their production capacity in the EU to 40 GW in 2024, with the construction of a new gigawatt factory at their headquarters in Niestal, although the opening was postponed. SMA is also expanding their production of electromagnetic components for inverters in Poland in 2025, adding further integration to the inverter value chain.

Power Electronics has 30 GW annual production capacity from their plant in Valencia, Spain. They specialise in inverter solutions for utility-scale solar and energy storage plants.

Fronius has 7 GW of annual inverter production capacity in Austria. As they are specialised in rooftop systems, this represents manufacturing capacity of over 600,000 inverters per year, making them the top

EU producer in terms of number of inverters manufactured in the EU in this segment. Fronius also produces their own inductive components at their plant in the Czech Republic. Although they were expecting their capacity to increase to 10.5 GW thanks to a new contract manufacturing facility in Hungary, these plans were scrapped due to challenging industrial and market conditions in the EU. Fronius also has a considerable presence on the global market: in Australia, for example, Fronius has the largest rooftop market share of any European manufacturer.

Fimer from Italy and **Kaco** (a Siemens subsidiary) from Germany, are among other leading EU inverter producers today. Fimer acquired ABB's inverter branch in 2020 and produce inverters in 2 sites in Italy.

While some of the biggest EU producers offer a full portfolio of solutions, including microinverters, a few notable EU companies specialise in MLPE production. Established player **AEConversion** develops and manufactures microinverters in Bad Sessendorf, Germany, while **Solarnative**, a new player on the market, also from Germany, opened their factory in Hohheim am Taunus in May 2023, with plans to gradually reach 1 GW manufacturing capacity for their innovative microinverter product.

Generally speaking, most companies present in the sector either maintained their 2022 production levels in 2023, or even increased their manufacturing scale in the EU. However, while production expansions in the EU indicate positive growth, notably for larger inverter companies with strong leadership in high power inverters for larger-scale applications, many manufacturers are currently facing serious challenges on the EU market due to difficult market conditions and strong price pressure.

The majority of PV inverters manufactured in the EU are produced for large PV systems. A large proportion of these are exported from Europe to countries such as the USA, where framework conditions prevent them from being massively displaced by cheap products from Asia. The question arises as to how long EU production capacities can be operated competitively compared to products that benefit from the IRA.

1 Market & technology briefing / continued

Against this background, it is worth noting that the top 3 largest EU manufacturers – Power Electronics, SMA, and Fronius – all plan to expand their production in the US in the next few years. Although some of these expansions were planned before the implementation of the US Inflation Reduction Act (IRA), these new attractive market conditions have at least encouraged the acceleration of US based developments.

Furthermore, some inverter companies headquartered outside the EU also have manufacturing capacity on EU soil. Notably, leading MLPE producer **SolarEdge** has historically manufactured in Europe. US based **Enphase**, market leader for microinverters, conduct manufacturing through 3rd party company Flex Energy in Hungary and Romania respectively, although they announced in December 2023 that they will stop manufacturing in the EU due to challenging market conditions.

Aside from manufacturing, the EU also holds strong R&D capabilities for inverter hardware and software, both from leading inverter companies and from research institutions, such as CSEM in Switzerland, CEA-INES in France or Fraunhofer ISE & CST in Germany, among others.

EU market dynamics

Despite this rich landscape of EU based companies, there is a growing entry of non-EU product manufacturers on the European market. Although this has been supporting the growth of the EU inverter market, it is now leading to a massive displacement of inverters produced in Western countries away from the EU market.

The EU market for inverters is increasingly dominated by companies based in Asia. During the boom phase in 2021-23, European production capacities for inverters could not be fully utilised due to severe supply bottlenecks for components from Asia. Inverter manufacturers from China (established and new) were significantly less affected; combined with their comparatively lower costs per watt, they were thus able to take over large market shares in Europe.

S&P Commodity Insights estimates that, in terms of MW shipped, European headquartered solar inverter suppliers only shipped 20% of all solar inverters in the European market in 2023. The remaining share was mostly dominated by Chinese companies.

These companies have extremely low priced products on the EU market. The reasons for lower manufacturing costs and product prices of non-EU producers include the ease of doing manufacturing business outside of Europe, larger economies of scale, the availability of lower labour and energy costs than in Europe, and an industrial strategy in support of domestic manufacturers.

Some EU producers are concerned that inverter prices are decreasing due to these distortions of the level playing field.

In the face of this price pressure from outside competitors, EU companies often advance data security, durability, product sustainability, service quality including after-sale, avoidance of remote controllability of European power supply by foreign entities, and the importance of European manufacturing and suppliers for jobs and future innovation potential, as key added value for their products. However, product price is still the primary decision factor for buyers.

The price pressure is particularly challenging for EU producers with high added manufacturing value in the EU. There is a growing risk of deindustrialisation in the EU on the inverter front as some producers are already facing utilisation rates of 50% and lower in their EU production facilities. Investment decisions for new inverter production capacities are increasingly being made in favour of non-EU locations.

Outside players who recently started producing in Europe are faced with the same challenging conditions: in December 2023, the California-based leading microinverter manufacturer Enphase Energy announced it will stop manufacturing at their production facility in Timisoara, Romania, run by contract manufacturer Flex, and laid off 10% of its workforce, after only 12 months of production. Enphase cited deteriorating market conditions and higher inventories in Europe as the key reason for this closure.

2

Increasing Europe's inverter market resilience

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An EU energy policy for inverters should combine measures to support manufacturing with measures to support a thriving solar and inverter market - clear regulatory frameworks that enable and value inverter technologies.

2.1. Five measures to support manufacturing conditions

2.1.1. Ensure right conditions for inverter manufacturing in Europe

While Europe takes pride in a strong track record in inverter research and development, translating those innovations into a thriving manufacturing sector requires setting the right manufacturing conditions in

Europe as well as the right investment tools to ensure regular reinvestment into the industrial apparatus. A European industrial policy for inverters must ensure EU manufacturers can rely on a level playing field with other geographies.

This includes reliable and cost-effective supply chains for the critical materials that inverter manufacturers need, in particular electronics-related components, such as semiconductors and controllers.

The inverter industry requires access to specialised semiconductor switches with increased isolation and blocking voltages, but at relatively lower power levels. Utility-scale inverter manufacturers need smaller power level semiconductors with high insulation voltage.

Five measures to support manufacturing

1. Ensure right conditions for inverter manufacturing in Europe.
2. Promote a continuous innovation cycle in the industry: and IPCEI for solar inverters.
3. Support a level-playing field in environmental and sustainability requirements.
4. Reward diversification and EU added value.
5. Grow the pool of specialised skills.

Five measures to support market deployment of inverters

1. Enhance the cybersecurity baseline in the solar sector.
2. Unlock the value of inverters for system integration and flexibility.
3. Develop a joint roadmap for advanced capabilities of inverters with the industry.
4. Develop novel standards for medium voltage PV power plants.
5. Promoting EU-level standards for inverters in the Single Market.

2 Increasing Europe's inverter market resilience / continued

However, the semiconductors currently available in Europe are primarily designed for high-voltage applications like trains, which are too high for solar inverters, posing a constraint on inverter manufacturers. This challenge extends to other industries as well, including electrolyzers, wind turbines (especially in the production of smarter turbines), and batteries. Despite this widespread issue, rooftop PV inverters are less affected, as they do not directly source semiconductors or require increased voltage levels.

With the implementation of the European Chips Act by the European Union, effective as of September 2023, semiconductor manufacturing in Europe stands to receive a significant boost. This initiative holds promise for the inverter industry within the region, potentially resulting in increased availability of semiconductor components, decreased supply chain vulnerabilities, and advancements in inverter technology. The solar inverter sector should be included into the appropriate collaborative frameworks within EU semiconductors manufacturers, as part of the Chips Act.

Additionally, fostering access to growth capital and long-term operational support will be crucial. Financing support should be accessible through the InvestEU facility, either directly accessible through the European Investment Bank or through public bank

partners. SolarPower Europe has welcomed the creation of the Temporary Crisis and Transition Framework for State Aid that allowed to support investment into the solar industry. At the same time, the TCTF framework should be improved, mainly by reducing complexity and conditions and allowing for OPEX-related support. It will also be critical to prolong the TCTF framework beyond the end of 2025.

By creating these conditions, Europe can maintain its R&D edge while ensuring it has the industrial muscle to translate those innovations into real-world products. This dynamic is essential for continued reinvestment in cutting-edge manufacturing apparatus.

- Include the solar inverter sector into the appropriate collaborative frameworks within EU manufacturers semiconductors manufacturers, as part of the Chips Act Pillar I.
- Foster crucial access to growth capital and long-term operational support.
- Prolong and allow for OPEX support through the TCTF framework beyond end of 2025.



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2.1.2. Promote a continuous innovation cycle in the industry: an IPCEI for solar inverters

Industrial policy for inverters must be rooted in innovation, especially to serve new uses linked to electrification and system integration as well as electrolyser-based hydrogen production. For this reason, we suggest the creation of an Important Project of Common European Interest for inverters.

The European inverter industry boasts several crucial prominent players that dominate a significant portion of the inverter value chain. Within this supply chain, Europe holds a strong position in the pivotal realm of power electronics and European products excel in quality and grid efficiency, owing to extensive experience in power electronics.

However, the industry falls short on two points. The first point concerns the operation voltage of PV power

plants that needs to be increased to medium voltage levels for cost reduction and direct coupling of PV with electro intensive industries. The second point concerns monitoring and data access, where non-EU competitors excel, leveraging telecommunications and ICT expertise to offer robust capabilities for monitoring, comprehensive detection, and seamless integration with operator software tools.

To ensure European solar inverter industry continue to have an innovative competitive advantage we propose an Important Project of Common European Interest (IPCEI) aimed at advancing the solar inverter technology such as transistor scalability, critical component efficiency, grid forming capabilities, and cybersecurity in solar inverters.

The IPCEI should therefore focus on areas as seen in Table 2. (See in annex a detailed concept note for a solar inverter IPCEI).

TABLE 2 IPCEI FOCUS AREAS

AREA	GOAL	DESCRIPTION	IPCEI CATEGORY
Transistors	- Scale production - Higher blocking voltages	- Finance industrial lines - Develop next generation of control	Manufacturing
Critical components	- Decrease material needs - Improve connectivity and control of components - Develop local production	- Identify and facilitate sourcing of critical comp - Design for reuse and materials recovery	R&D Manufacturing
Grid forming	- Improvement of capabilities - Software control automatization	Co-creation of technology with grid operators and system integrator for improvement of grid forming capabilities with grid operators	R&D
Cybersecurity & Digitalisation	- Improvement of cybersecurity - Strengthen interoperability and system integration	Develop a roadmap of improvement of cyber-preparedness	R&D
Disruptive Architectures for PV systems	Develop a novel disrupting architecture for PV system with a focus on medium voltage applications	- Research and Development at the System Level - Engage in comprehensive R&D to innovate the overall system architecture for PV systems, specifically targeting medium voltage applications and global innovation fields	R&D

2 Increasing Europe's inverter market resilience / continued

2.1.3. Support a level playing field in environmental and sustainability requirements (PV Ecodesign)

EU inverter manufacturing must be on a level playing field with production that takes place outside of the EU when it comes to minimum environmental and sustainability requirements. The upcoming PV Ecodesign rules on inverters, setting minimum standards on environmental and sustainability performance for products entering the EU market, will play a critical role in this regard.

Ecodesign rules on inverters will include minimum performance requirements, reliability requirements, repairability requirements including availability of spare parts, and material content disclosure of a list of relevant materials. Ultimately, these requirements will support the efforts of the manufacturing industry towards circularity, increasing product reliability, lifetime, performance and repairability. It will also lay the foundations to establish a circular approach towards raw material recovery and use in EU manufacturing processes.

- Ensure a swift adoption of the Ecodesign rules for solar inverters.

2.1.4. Reward diversification and EU added value

Creating a level playing field for inverters also requires rewarding products that make the EU more resilient. The consolidated document of the Net Zero Industry Act³, which was adopted in the EU Parliament on 24 April 2024, includes several measures relevant for the solar PV sector. It sets the goal to reach at least 30 GW of operational solar PV manufacturing capacity by 2030 across the full PV value chain including inverters.

NZIA also includes a goal for the EU to have 40% of net-zero technologies deployed manufactured in Europe by leveraging public demand. To do so, NZIA aims at the leveraging of public demand through public procurement (Art. 25), renewable energy auctions (Art. 26) and other forms of public intervention (Art. 28 using resilience and sustainability criteria to favor the diversification of the sourcing of net-zero technologies away from the dominant single source of supply).

Resilience is defined as (Art. 26.2):

(a) contribution to resilience, taking into account the proportion of the net-zero technologies or its main specific components that originate from a third country accounting for more than 50% of the supply of that specific net-zero technology or its main specific components within the Union; For the purpose of point (a), the country of origin shall be determined in accordance with Regulation (EU) No 952/2013 of the European Parliament and of the Council. For inverters it is important to detail how to assess the contribution to resilience in the sense of the NZIA target (40% of components of EU demand in 2030).

SolarPower Europe calls on Member States to act swiftly to reduce the dependency on a single source of supply. Germany and Austria have attempted to implement resilience principles inspired by the NZIA, before the NZIA came into force, with limited success so far. The EU Solar Charter signed in April was a commitment from 23 EU countries to reshore solar manufacturing.

- Ensure inverters are included in the list of key solar PV components in the NZIA Annex, as defined by the Delegated Act that will be published.

3 TA (europa.eu)

2.1.5. Grow the pool of specialised skills

Inverter manufacturing is based on significant R&I and power electronics engineering. An industrial policy for inverters therefore requires developing a strategy to attract the right skills in the field. Yet, it is currently very difficult to find the appropriate skills to meet the industry requirements, in the field of power electronics and applied physics.

It is therefore important to leverage the EU strategy on skills to attract and retain students and engineers to power electronics field.

- Create a dedicated workstream under the newly created Solar Academy, in particular fostering partnerships between the industry and the research community.
- Skills in power electronics are crucial for aerospace, automotive and the energy sector: joint forces are needed to have a competitive advantage on innovation.

2.2. Five measures to support market deployment of inverters

2.2.1. Enhance the cybersecurity baseline in the solar sector

We propose additional procedures to ensure that inverters comply with the Cyber Resilience Act (CRA). To achieve this, the Commission should issue a Delegated Act to include these products in the category "important products with a digital element, class I" under Annex III of the CRA.⁴ This categorisation would subject manufacturers to more rigorous conformity assessment procedures, suitable for devices with a high impact on critical infrastructure. The current categorisation allows manufacturers to demonstrate compliance simply by issuing an EU declaration of conformity.

In its standardisation request following the CRA, the European Commission should request the development of a dedicated standard for distributed energy resources such as inverters. It should build on existing standards, where possible e.g. ETSI 303 645 (2020-06), IEEE IEC 62443-4-1 and 2 or UL 2941).



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⁴ The Commission is required to issue a Delegated Act to amend the assignment of conformity assessment procedures for products incorporating digital elements, as stipulated in Article 6(2) of the CRA.

2 Increasing Europe's inverter market resilience / continued

While it should cover all infrastructure that is capable of controlling power generation, it should start by developing a standard for inverter-based resources. This new standard should describe elements unique to Distributed Energy Resources (DERs), going beyond Internet of Things (IoT) characteristics. These include, for example, the DC to AC ratio, changes to grid code configuration, and capabilities to operate without a cloud connection. The existing standards only cover software development best practices (SDL) or corporate cybersecurity baselines for all IoT devices or automated control systems.

Inverter fleets face cybersecurity risks from centralised control points, which authorised entities such as manufacturers, VPPs, and Demand Response Entities use to interact with individual inverters. These interactions include running updates, optimising generation and consumption, and responding to signals from the power grid or markets. Importantly, these actions can occur at the fleet level, provided the devices support this functionality and have an active internet connection.

Similar challenges exist in other industries, such as EV chargers, heat pumps, and both offshore and onshore wind energy⁵, and the automotive industry. To address these vulnerabilities, some players in these industries operate centralised Security Operation Centers (SOCs). In the automotive industry, these centres are known as Vehicle Security Operations Centers (VSOCs). VSOCs continuously monitor data streams and risks across computers, servers, connections to other devices, individual control units inside vehicles, and entire fleets. Their purpose is to detect and respond to threats 24/7. VSOCs can be operated in-house or outsourced.^{6, 7, 8}

To mitigate the risks associated with centralised control points, we propose introducing a monitoring/control layer between product or service providers and individual devices. This layer should be

aware of relevant commands that affect a critical number of devices simultaneously. There are several possibilities to implement this.

- National Computer Emergency Response Teams (CERTs) or Computer Security Incident Response Teams (CSIRTs) can manage this layer by accessing logs and telemetry from the inverters. Product and service providers can develop the relevant APIs.
- Alternatively, a decentralised approach, similar to South Australia's not yet fully developed model, could be adopted. Following South Australian draft guidelines, Distribution Network Service Providers (DNSPs) can certify a Relevant Agent. The Relevant Agent would have control capabilities over PV plants, subject to customer agreement. Manufacturers must comply with specific requirements and develop necessary APIs to facilitate this control.
- Further possibilities exist but require additional reflections.

SolarPower Europe is committed to developing a proposal and providing feedback. We recommend that European stakeholders collaborate on technical solutions through legislation and standardisation. Any solution should allow manufacturers sufficient time to comply and establish necessary processes, avoiding costly retroactive requirements.

Finally, relevant operational, non-personal data of PV power plants and smart energy equipment should remain in the EU or countries which can ensure an equivalent level of security. This is already required for personal data in the GDPR. It should only be stored on servers, including cloud servers, under secure jurisdictions. No data storage provider outside of these jurisdictions shall effectively control this data storage infrastructure. The requirements should be aligned with relevant European certifications.

5 US Department of Energy. 2020. Roadmap for Wind Cybersecurity.

6 Vehicle SOC for OEMs | Upstream.

7 Why do automotive manufacturers need a VSOC? | Cybersecurity & Technology News | Secure Futures | Kaspersky.

8 Argus XDR Automotive Cyber Security for Fleets | Argus (argus-sec.com).

2.2.2. Unlock the value of inverters for system integration and flexibility

Inverters are uniquely positioned to support the energy transition. They can unlock the flexibility of demand by controlling devices (such as PV panels and batteries) based on system signals. Facilitating the integration of solar systems and optimising their use. To fully unlock the potential of inverters for system integration and flexibility, a multi-pronged approach is needed.

Firstly, developing clear price signals for demand response and flexibility is crucial. Despite this being a requirement from the previous Market Design legislation, ACER has recently found that only 13 countries have low price incentives and that 11 EU countries still have no price incentives for flexibility. This, combined with dynamic grid tariffs, self-consumption opportunities, and the removal of double taxation, will incentivise homeowners with solar and electric loads to participate in the market, ultimately driving growth for hybrid inverters and residential solar PV combined with storage.

Secondly, inverters can support demand response as metering devices, where smart meters are not installed or not adequate. They can control the quantity of energy exported from the devices into the grid. Yet, they are not sufficiently recognised as measurement devices to provide demand response, whereas smart meters are recommended. It will be critical to formally allow the solar inverter to be used as a dedicated measurement device in flexibility services or as a source of billing in collective self-consumption.

Finally, promoting DC connections between inverters and other technologies like battery storage at medium voltage level will streamline system integration and further enhance overall grid flexibility.

- Implement the provisions of the Electricity Market Design regarding flexibility and dedicated measurement device, and require the Commission to report to the Energy Council on implementation by 2025.
- Promote DC connections for high power systems and complete plants.



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2 Increasing Europe's inverter market resilience / continued

2.2.3. Develop a joint roadmap for advanced capabilities of inverters with the electricity industry actors

As the share of renewable energy sources in the grid continues to grow, the grid needs renewables to contribute new advanced capabilities known as 'grid forming.' Grid forming refers to the ability of an energy source to actively participate in maintaining the grid's stability. Traditionally, this responsibility has fallen to conventional power plants with large generators that provide a relatively strong and stable voltage and frequency signal (inertia) and which grid forming inverters can follow. Grid-forming inverters will have to address this by substituting the behaviour of conventional generators, electronically synthesising the necessary voltage and frequency signals to ensure grid stability even during fluctuations or outages.

This could be a significant opportunity for the inverter industry to innovate and develop new products and services. By collaborating with grid operators and developers, inverter manufacturers can create advanced inverters with grid-forming capabilities. This co-development approach is essential as it ensures the inverters not only meet technical requirements but also integrate seamlessly with existing grid infrastructure. On the contrary, the introduction of requirements too high, too early or too widely could endanger industry across the EU.

This should be reflected in the network code Requirements for Generators (RfG). In the first stage,

procuring those services by means of markets, as done in Great Britain, is the preferred approach as it allows to reveal only the right amount of services required by the system. As a second step, a real co-constructed roadmap should be developed with grid operators.

ENTSO-E has initiated relevant work in that regard, with HTW Berlin, through a first interim report on technical requirements for the Grid Forming Capability of the Power Park Module. While ENTSO-E aims to maintain the report technology-neutral, we believe it would be beneficial to assess the potential of different technologies in providing grid forming and to define the requirements based on this assessment. As per the requirements defined in the network code, it is also crucial to maintain harmonisation across the EU when defining the grid forming requirements in this report. This should be part of a mandated grid-forming roadmap with clear standards, essential for technological development across the EU. European standardisation and harmonisation are crucial for a cost-effective energy transition, especially concerning mass-market products such as inverters.

- Ensure that grid-forming requirements are procured market-based in a first place and as a principle.
- Develop a roadmap for the introduction of grid-forming requirement, standardised at EU level and technology-specific.



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2.2.4. Developing novel standards for medium voltage DC power plants and micro grids

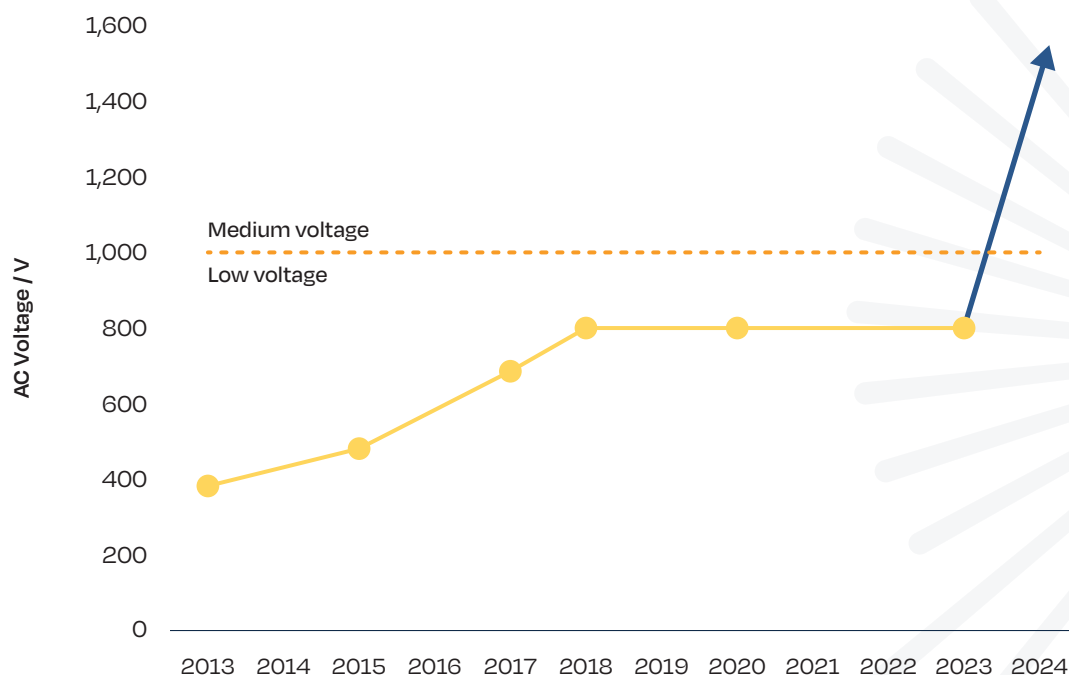
The solar industry has achieved a reduction of costs of solar systems by increasing the system voltage. Solar panels and solar inverters are traditionally low voltage assets (<1,500V), which results in excessively high currents in large-scale power plants. The resulting material consumption and high costs can be reduced by increasing voltage levels to medium voltage levels. The research sector has been working on this topic, which requires an update of solar modules, solar inverters, and all other PV system components.

This technical innovation would reduce the required amount of cable cross section, meaning a reduction of wires by 75%. It also means less transformers and switchgear, as the current will already be medium voltage, as the grid. In turn, this would free more space for more PV modules at a site. The international solar inverter industry is working on this technology change, and it is believed that medium voltage PV power plants will become standard in the future, for free field systems connected to the medium voltage grid.

The voltage of solar PV power plants has increased steadily in the past years, before plateauing. The main reason for this development is the definition of 'low voltage', which is limited to 1,500 V_{DC} or 1,000 V_{AC}. Above this value, the 'medium voltage' range begins, which is internationally part of the high voltage range. However, all PV-specific standards are currently only available for low voltage. A further increase is therefore associated with a significantly higher standardisation effort. This is because, not only do the PV-specific standards themselves have to be adapted, they also refer to other basic standards from the medium-voltage field of application.

It would be important to develop a roadmap on increasing voltage levels of solar components, in order to prepare the regulatory ground for this technological innovation. The industrial actors and the research community should contribute to the developments of novel standards dealing with medium voltage DC PV power plants and medium voltage DC micro grids. A first step has been made with the technical specifications IEC TS 63471:2023 which provides a recommended DC voltage series for HVDC grids with a DC voltage above 1.5 kV.

FIGURE 9 VOLTAGE LEVELS 2013-2023



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2 Increasing Europe's inverter market resilience / continued

For the development of such standards, intense research and development efforts are needed today to develop tomorrow's medium voltage level PV power plants and DC micro grids.

2.2.5. Promoting EU-level standards for inverters in the Single Market

The power grid is the new Single Market of EU companies – solar manufacturers, but also EV chargers, storage or heat pumps. Yet, too often, solar manufacturers are confronted with different rules, particularly when it comes to grid connection but also cybersecurity or digital rules. The reason is the lack of integration of grids.

SolarPower Europe supports the work initiated in the High-Level Forum on Standardisation. It must be pursued, and it should be ensured that there is a joint approach on key standards. These include:

- Standards for flexibility: power control systems (PCS) and communication between the SO and the DER asset.
- Standards for grid connection for each power level: recognition of CEN-CENELEC standards or development of a joint approach for low voltage assets (rooftop solar inverters, but also EV and building batteries).

- Standard for cybersecurity compliance + standard for advanced grid capabilities needs.
- Standards for building-level sector coupling (EV and heat pumps).
- Introduce protocol and interface standards between residential EMS and appliances, such as building-level sector coupling (EV and heat pumps).
- Standards for safety features.

- **Governance of an EU industrial policy for inverters**

Ensuring the effectiveness of industrial policy requires strong governance. To maximise its impact, the next mandate of the European Commission should prioritise continued support for this policy. In particular, close coordination with stakeholders across the entire value chain is crucial. Upstream collaboration with the semiconductor and electronics industries is essential to secure a reliable supply chain, for instance leveraging the structures of the Chips Act. Downstream engagement with grid operators will ensure the seamless integration of advanced inverters into the existing infrastructure.



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IPCEI for Inverters

Scaling up a sustainable and innovative EU solar inverter ecosystem

Introduction

Inverters are the brain of the solar system. Today, the European inverter industry already has more than 80 GW of manufacturing capacity, and as of 2022 employed more than 35,000 people (representing 70% of the solar manufacturing jobs in Europe). We must ensure that the success story of European inverter companies continues.

The European inverter industry boasts several prominent players that dominate a significant portion of the inverter value chain. Within this supply chain, Europe holds a strong position in the pivotal area of power electronics, yet lags in capabilities concerning digital services, interoperability, and diagnostics. In the last years, while the total number of products has increased due to the growth of the global solar market, EU producers are facing fierce competition from non-EU players. The EU market for inverters is increasingly dominated by companies from Asia.

To ensure the European solar inverter industry continues to have an innovative competitive advantage, we propose an Important Project of Common European Interest (IPCEI) aimed at advancing the solar inverter technology. Such IPCEI could focus on enhancing key aspects in the European inverter supply chain such as magnetic components, critical component efficiency, grid forming capabilities, and cybersecurity in solar inverters.

Overall Objectives

The overall objective of the IPCEI projects is to ensure that the EU inverter ecosystem maintains an innovative edge by modernising technology to provide enhanced digital capabilities, mostly to support new uses linked to electrification and system integration as well as electrolyser-based hydrogen production. Equally, an IPCEI can improve access to critical components of inverters where there is over-concentration for the moment and make inverter supply chains more resilient.

This objective aims to leverage advancements in digitalisation and system integration to propel the European inverter industry forward, fostering its competitiveness, sustainability, and resilience in the global market, and to plug the funding gap in upscaling existing EU inverter production lines to that effect.

Timeline

The next Joint European Forum for IPCEI (JEF-IPCEI) Meetings are scheduled the following⁹:

- Q4 2024: 4th Technical level meeting.
- Q4 2024: 5th Technical level meeting.
- Q4 2024: 2nd High level meeting.

The JEF-IPCEI consists of representatives from the European Commission and Member States. High-level meetings are co-chaired by Kerstin Jorna, Director General for Internal Market, Industry, Entrepreneurship and SMEs, and Olivier Guersent, Director General for Competition in the European Commission. These meetings cover topics such as work plans and approving methodologies for identifying potential new candidate technologies and advanced materials. During technical meetings, they discuss a common methodology for evaluating and identifying new candidate technologies or infrastructures potentially relevant for an IPCEI, review potential candidate technologies, share best practices, and allow Member States to present areas for improvement.

Objectives in detail

The next Joint European Forum for IPCEI (JEF-IPCEI) Meetings are scheduled the following:

1. Power electronics:

- **Goal:** Scale production and increase blocking voltage. Renew of power electronic components.
- **Description:** Finance industrial lines to facilitate the scaling of power electronic production and enhance their blocking voltage capabilities and efficiency.

⁹ Joint European Forum for IPCEI - European Commission (europea.eu)

2. Critical components:

- **Goal:** Decrease material requirements, enhance component connectivity and control, and develop local production capabilities.
- **Description:** Develop the next generation of control systems for critical components, identify and facilitate sourcing of essential components, and design for reuse and materials recovery to reduce resource consumption (recycling).

3. Grid forming:

- **Goal:** Improve capabilities and automate software control for grid integration.
- **Description:** Collaborate with grid operators and system integrators to co-create technology solutions aimed at enhancing grid-forming capabilities and automating software control for better integration with grid infrastructure.

4. Cybersecurity & Digitalization::

- **Goal:** Enhance cybersecurity measures and strengthen interoperability and system integration.
- **Description:** Develop a roadmap for improving cyber-preparedness in solar inverters, focusing on enhancing cybersecurity measures and ensuring seamless interoperability and integration within the broader energy system.

5. Disruptive architecture for PV systems: :

- **Goal:** Develop a novel disrupting architecture for PV system with a focus on medium voltage applications.
- **Description:** Research and Development at the System Level. Engage in comprehensive R&D to innovate the overall system architecture for PV systems, specifically targeting medium voltage applications and global innovation fields.

Key projects

1. Advanced Inverter Hardware (covering point 1 and 2)

- High-Power Silicon Carbide (SiC) Implementation
- Gallium Nitride (GaN) for Low-Power Applications
- Laser-Welding Housing

2. Smarter Inverter (covering point 2 and 3 and 4)

- Turn-Key Solutions Manufacturing with MVPs
- Reduction of materials and cost for central inverter
- Optimisation of power electronic packaging to increase the capability to stabilise the grid

3. Disruptive Architectures for PV systems (covering point 5)

All proposals together have a budget estimate of around EUR 50 million.

Eligibility criteria

According to the European Commission Communication on IPCEIs¹⁰, the following criteria are important to select technologies for IPCEIs.

Definition of a project:

The aid proposal concerns single or integrated projects defined in objectives, implementation, participants and funding.

Common European interest:

• Specific criteria on innovation:

The Solar Inverters IPCEI promotes innovation through collaborative partnerships. By fostering collaboration rather than competition, the IPCEI creates a conducive environment for the exchange of ideas and the co-creation of innovative solutions. Cross-sectoral cooperation, bringing together expertise from various sectors such as energy, electronics, materials science, and software development. The IPCEI facilitates partnerships

¹⁰ Communication from the Commission — Criteria for the analysis of the compatibility with the internal market of State aid to promote the execution of important projects of common European interest (europa.eu)

between industry players and research institutions to leverage cutting-edge research and development capabilities. Collaborative research projects enable access to state-of-the-art facilities, expertise, and funding opportunities, accelerating the pace of innovation and technology transfer from lab to market. And knowledge sharing, by pooling resources and expertise, participants can collectively tackle technical challenges, develop new intellectual property, and bring innovative products and services to market more efficiently positioning Europe at the forefront of solar inverter technology development. By leveraging the collective expertise and resources of participating entities, the initiative drives advancements in solar energy conversion, grid integration, and digitalisation, paving the way for a sustainable and resilient energy future.

- **Positive spillover:**

By fostering innovation and collaboration, the IPCEI has the potential to generate positive spillovers for communities, such as:

- **Job Creation:** By promoting innovation and investment in the solar inverter industry, the IPCEI can create new job opportunities across various sectors, including manufacturing, research and development, engineering, and project management in the EU. For example, SMA estimates that IPCEI projects will directly add 150 Full-Time Equivalent (FTE) positions with an estimated 350 FTEs throughout the value chain. These jobs will not only contribute to economic growth but also provide employment opportunities for local communities, thereby enhancing livelihoods.
- **Skills Development:** The collaborative nature of the IPCEI fosters knowledge exchange and skills development among industry stakeholders, researchers, and workers. As an example, SMA partnered with Volkswagen and together they

will influence the transformation of the automotive industry. This leads to the acquisition of new skills, expertise, and technical know-how, which not only benefits individuals directly involved but also strengthens the overall workforce capacity in the region.

- **Local Economies:** The establishment of solar inverter manufacturing facilities and related infrastructure can stimulate local economies by attracting investment, supporting local businesses, and generating auxiliary services. This economic activity can lead to increased tax revenues, improved infrastructure development, and enhanced quality of life for residents in the surrounding communities.
- **Reinforcing EU Strategic Open Autonomy**
- **Technology Transfer:** Through partnerships and collaboration, the IPCEI facilitates technology transfer from research institutions and leading industry players to smaller firms and local businesses. This transfer of knowledge and technology enables smaller companies to adopt advanced manufacturing techniques, improve product quality, and expand their market reach, thereby fostering a more competitive and dynamic business environment.

Funding gap

Identifying the funding gap is essential for IPCEI projects. This is done on a project-by-project basis following an established methodology that is based on a counter-factual scenario. More details on the topic are available here.¹¹

In summary, the positive spillovers generated by the Solar Inverters IPCEI extend beyond the immediate objectives of the initiative, enriching communities through job creation, skill development, economic growth, technology transfer, and environmental sustainability.

¹¹ IPCEI_RDI_FID_funding-gap_template_2024.xlsx (live.com)

Partnerships

This IPCEI proposal will involve collaboration among industry stakeholders, research institutions, grid operators, system integrators, and government agencies across Europe. Partners will contribute their expertise, resources, and infrastructure to achieve the project objectives in a coordinated manner.

Given most inverter production capacity today is concentrated in Germany, Austria, Spain and Italy, these are the Member States suited to take leading roles:

- Germany
- Austria
- Italy
- Spain

Expected outcomes

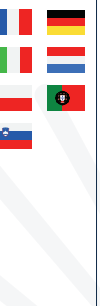
- Advancement in power electronics technology leading to increased production scalability and higher blocking voltage capabilities.
- Optimisation of critical components resulting in reduced material needs, improved connectivity and control, and enhanced local production capabilities.

- Development of grid-forming capabilities and software automation to improve grid integration and stability.
- Strengthening of cybersecurity measures and enhancement of interoperability to ensure the secure and efficient integration of solar inverters into the energy system.
- Reduced costs and material consumption for PV powerplants.

Conclusions

The European solar inverter industry stands at a critical juncture where maintaining its competitive edge necessitates constructive and concrete efforts in innovation, technology advancement, and collaboration. The proposed IPCEI is a strategic and vital initiative designed to address these challenges enabling the European inverter industry to stay innovative and competitive on the global stage. It is now the time to turn around the downward trend in EU inverter production capacity and plug the funding gap in upscaling existing EU inverter production lines to be the world's leading and innovative inverter technologies.

TABLE 3 APPROVED INTEGRATED IPCEIS

AREA	FIRST IPCEI ON MICRO ELECTRONICS (2018)	FIRST IPCEI ON BATTERIES (2019)	SECOND IPCEI ON BATTERIES - EuBATIn (2021)	FIRST HYDROGEN IPCEI - Hy2TECH (2022)	SECOND HYDROGEN IPCEI - Hy2USE (2022)	SECOND IPCEI ON MICRO ELECTRONICS AND COMMUNICATION TECHNOLOGIES (2023)	IPCEI ON NEXT GENERATION CLOUD INFRASTRUCTURE AND SERVICES (2023)	THIRD HYDROGEN IPCEI - Hy2INFRA (2024)	TOTAL
Participating companies	29	17	42	35	29	56	19	32	259 (226)*
Participating projects	43	22	46	41	35	68	19	33	307
State aid approved (EUR billion)	1.9	3.2	2.9	5.4	5.2	8.1	1.2	6.9	34.8
Expected private investments (EUR billion)	6.5	5	9	8.8	7	13.7	1.4	5.4	56.8
Participating Member States									22 Member States, UK and Norway participated in at least one IPCEI

Source: EU Commission.

* Excluding the companies that participated in more than one IPCEI.





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