

# IEEE y la Energía Renovable

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23 DE SEPTIEMBRE DE 2021



# IEEE & Energías Renovables, una relación simbiótica

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## Objetivos de la charla

- **VISIÓN** del panorama energético actual
- Mostrar los **RETOS** a afrontar
- ¿Cómo **AYUDA** IEEE a afrontarlos?



# Introducción. Aplicaciones



Energy Storage



Switched mode power supplies



Electrochemical process



Robotics & Automation



Hacia una "More Electrical Life"



FACTS



Alternative energies power converters



HVDC transmission



Lighting and air conditioning



Solid state protections





## Introducción. Ventajas



Del pasado al futuro



- Muy alta eficiencia comparando con los sistemas de potencia de décadas anteriores
- Convertidores de potencia que mejoran la prestación

Cada vez un rol más importante en la generación de energía potenciando medidas medioambientales durante el siglo XXI

- Los convertidores de potencia tienen una muy alta eficiencia
- En el área de la distribución eléctrica, la electrónica de potencia permite mejorar la estabilidad de la red



# European Energy Policy. 2030-2050



## Getting to Net-Zero Carbon Emissions by 2050

### 8 actions needed by 2030

The infographic is a grid of 8 panels, each with a number, a title, and an illustration. The panels are arranged in three rows: the first row has three panels, the second row has two panels, and the third row has three panels. The illustrations use various symbols like wind turbines, solar panels, power lines, and industrial buildings to represent different energy and infrastructure concepts.

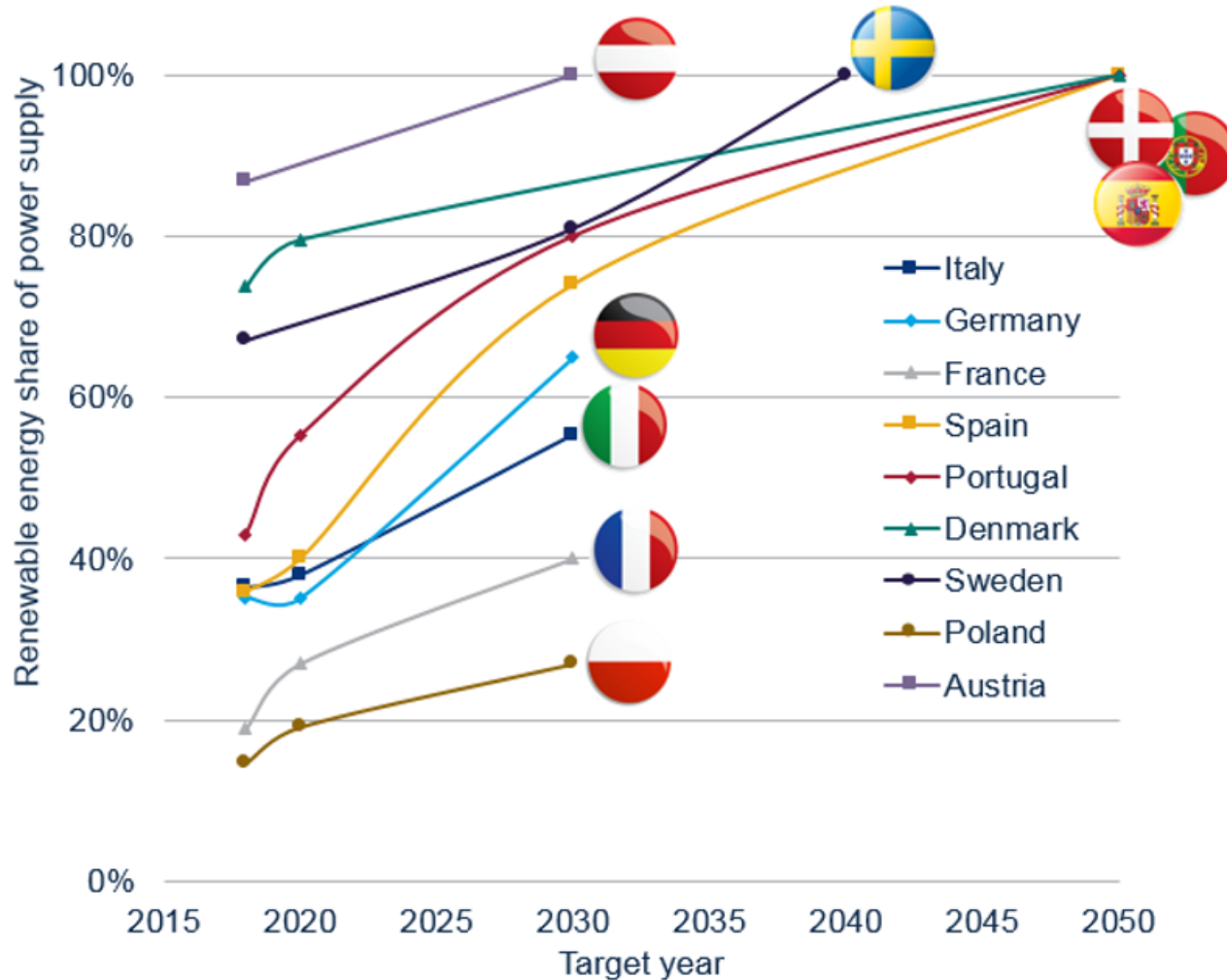
- 1 Increase solar and wind capacity 3.5 times, to 500 gigawatts**
- 2 Eliminate most electricity generation from coal**
- 3 Maintain current natural gas generating capacity for reliability**
- 4 Increase zero-emission vehicle sales share to 50%**
- 5 Increase sales share of building heat pumps to 50%**
- 6 All new buildings and appliances meet strict energy efficiency goals**
- 7 R&D for carbon capture, sequestration, and carbon-neutral fuels**
- 8 Build electricity transmission and pipelines for carbon dioxide and hydrogen gas.**





# European Energy Policy. 2030-2050

### Targets for renewable energy in power supply



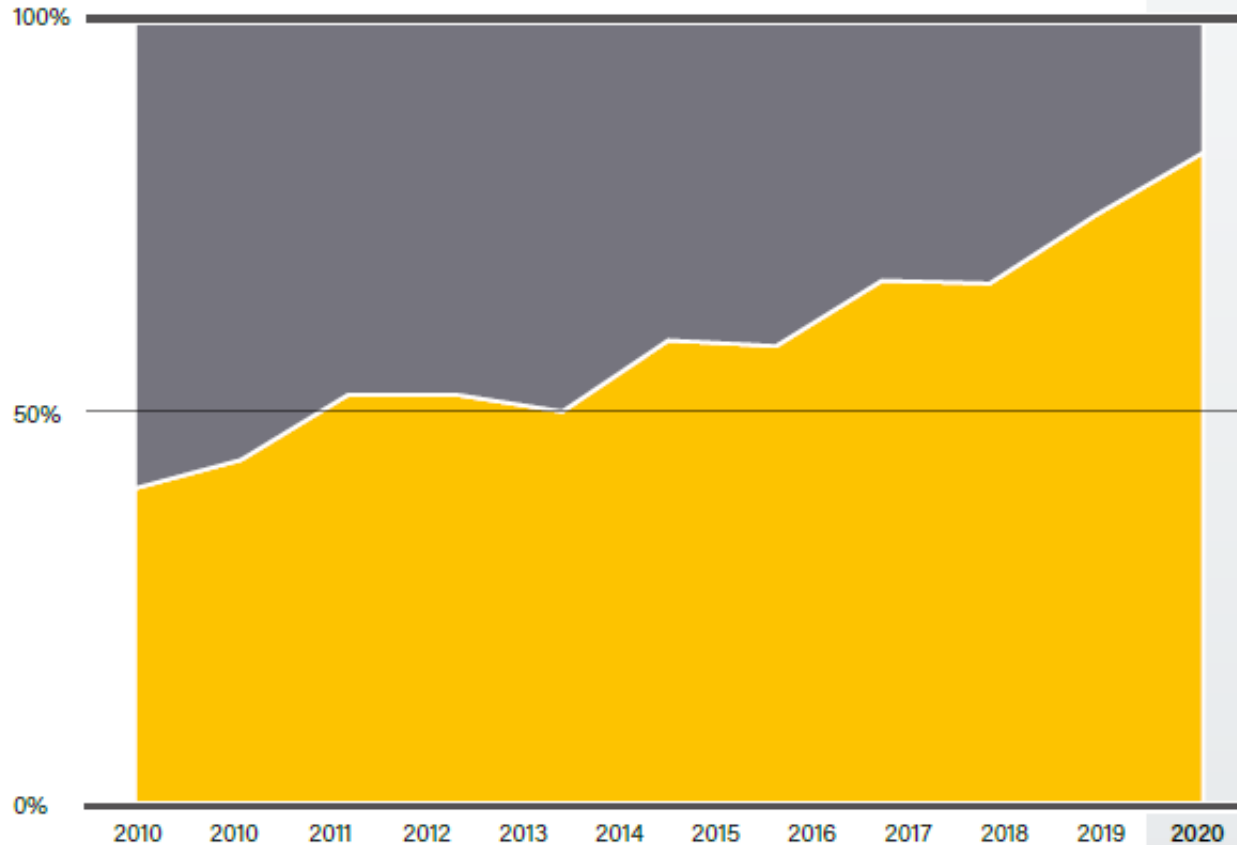
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# Nuevas plantas de energía instaladas

Share in Additions to Global Power Capacity



**83%**  
renewables in  
net additions

■ Non-renewable share  
■ Renewable share



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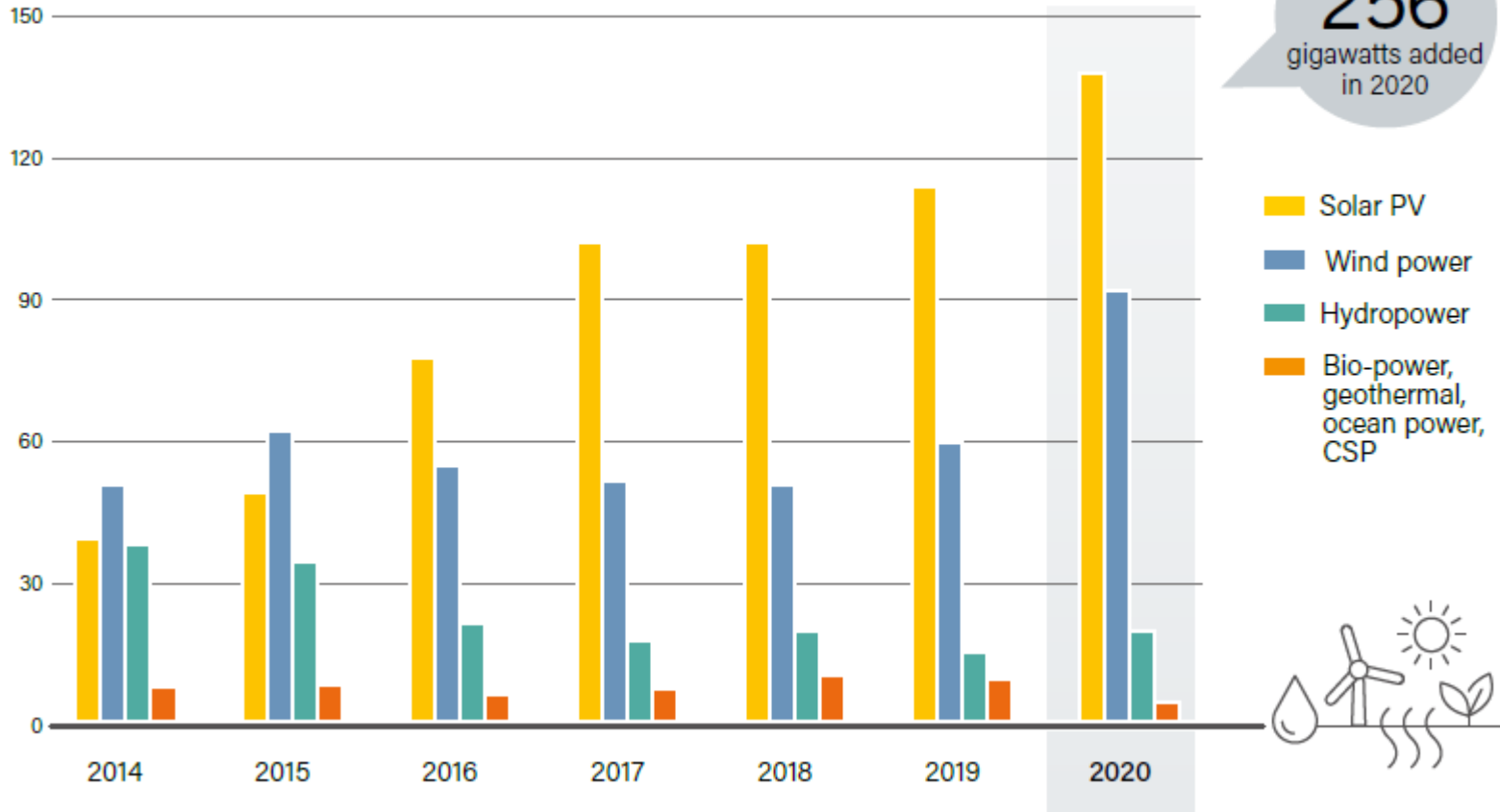






# Nuevas plantas de energía instaladas

Additions by technology (Gigawatts)



More than  
**256**  
gigawatts added  
in 2020

- Solar PV
- Wind power
- Hydropower
- Bio-power, geothermal, ocean power, CSP



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**REN21** Renewable Energy Policy Network for the 21st Century



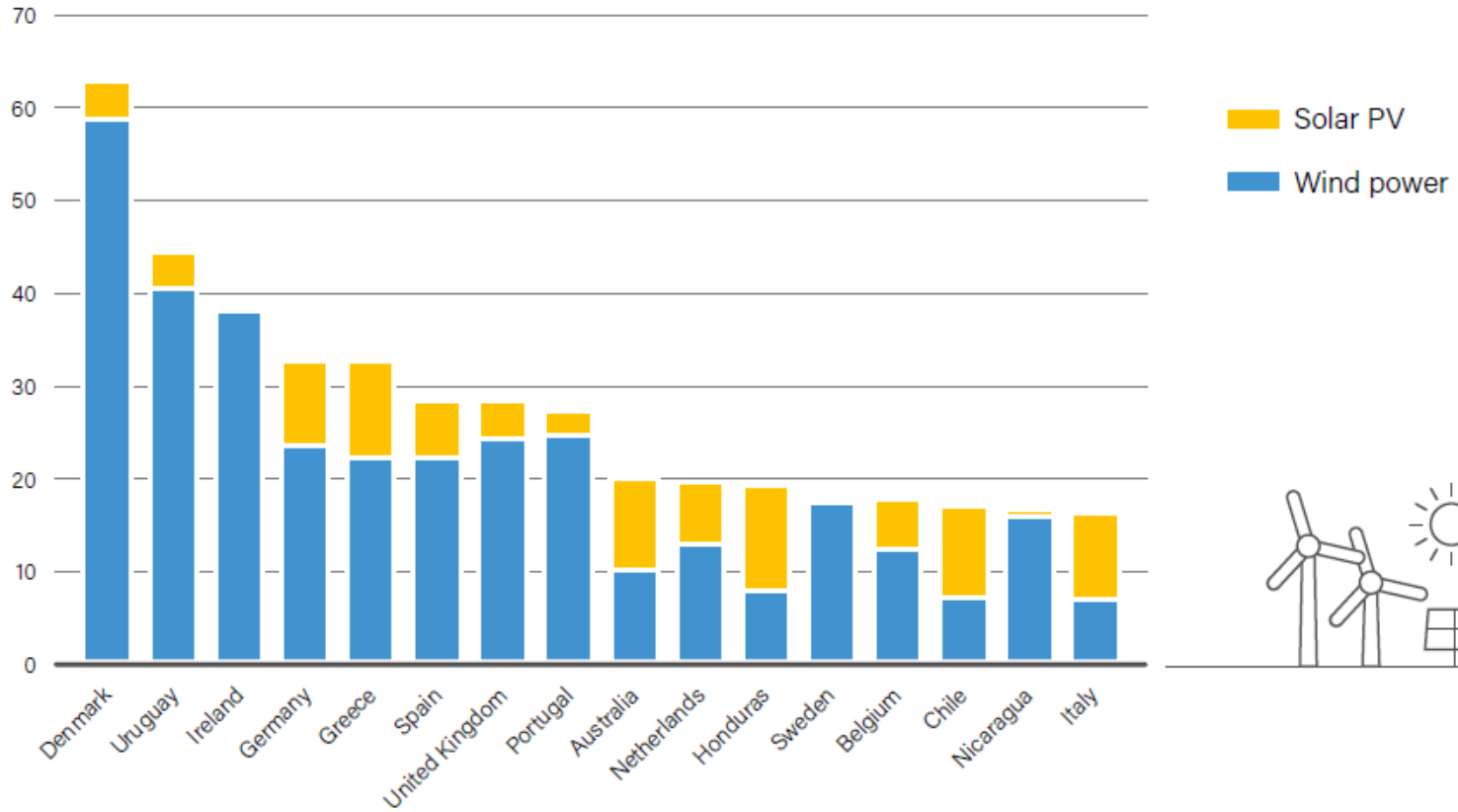
**ENGREEN**  
LABORATORIO DE INGENIERÍA PARA LA SOSTENIBILIDAD ENERGÉTICA Y MEDIOAMBIENTAL - UNIDAD DE EXCELENCIA DE LA US








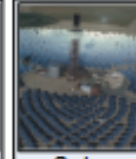





# Penetración de energías renovables en 2020

Share of total generation (%)



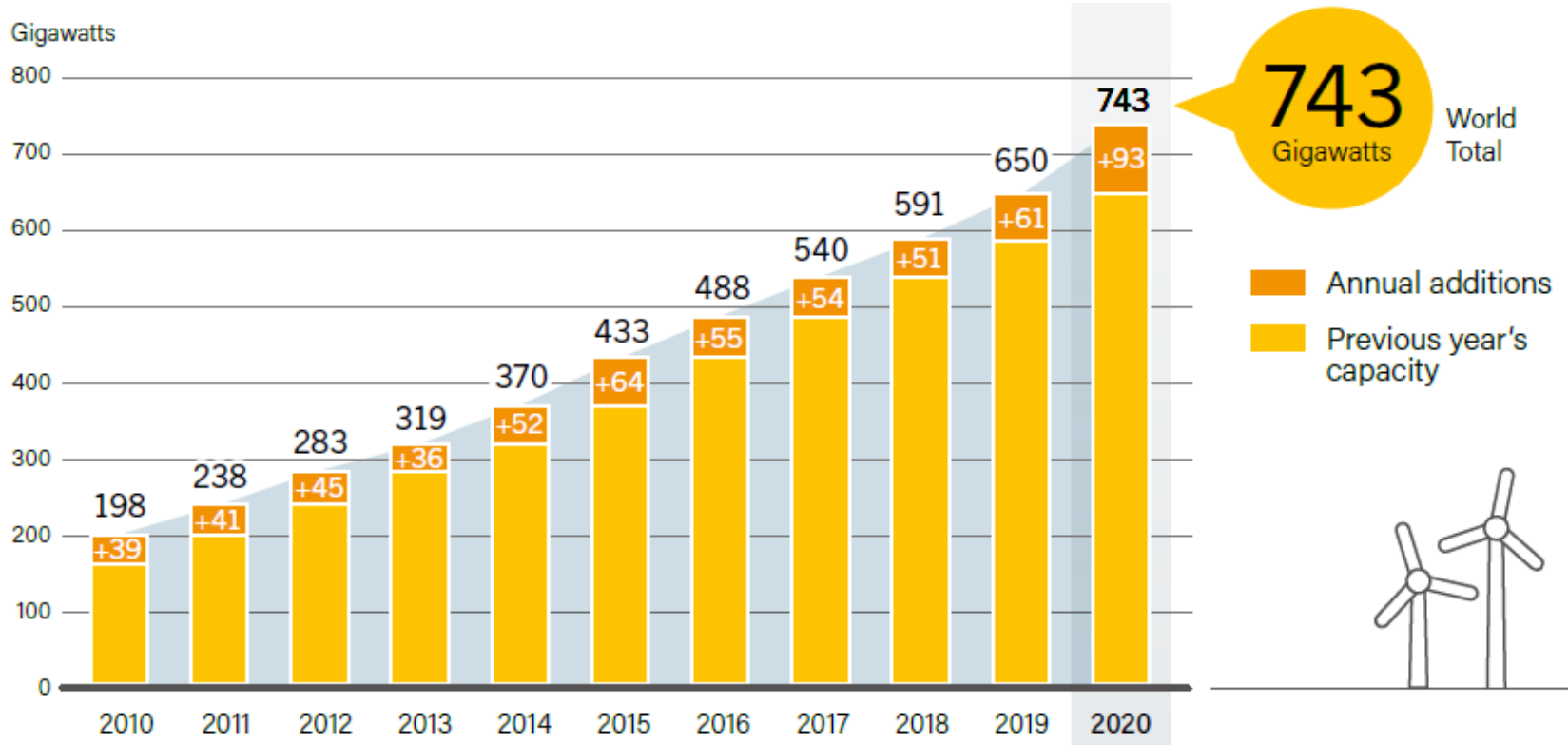


# Tipos de Fuentes de Energía Renovable

	Housing applications		Solar Energy		Marine/Fluvial Energy			Wind Energy	Geothermal Energy	
<b>Renewable Energy Systems</b>										
	RoofPV	Solar Thermal Roof	PV Plants	Solar Thermal	Wave Energy	Tidal Energy	Hydroelectric	Wind Energy	Geothermal	
<b>Maximum nominal power</b>	1kW–10kW up to 16MW	50 kW	2 GW	500 MW	62 MW	250 MW	22.5 GW	8.8 MW per Turbine	120 MW per power plant	
<b>Usual converter topologies</b>	DC/AC DC/DC	- -	DC/DC DC/AC	- -	AC/DC, DC/DC, DC/AC			-	Back-to-back	-
<b>Typical power semiconductors</b>	MOSFET	- -	IGBT IGCT	- -	IGBT, IGCT			-	IGBT IGCT	-
<b>Availability</b>	Solar irradiance dependance				Random	Intermittent	Seasonal	Intermittent	Constant	
<b>Technology trend</b>	↑ Power Density ↑ Efficiency		↑ Nominal Power ↑ Efficiency		↑ Robustness Under Storms		-	Gearless, Offshore, ↑ Power	↓ Development cost	

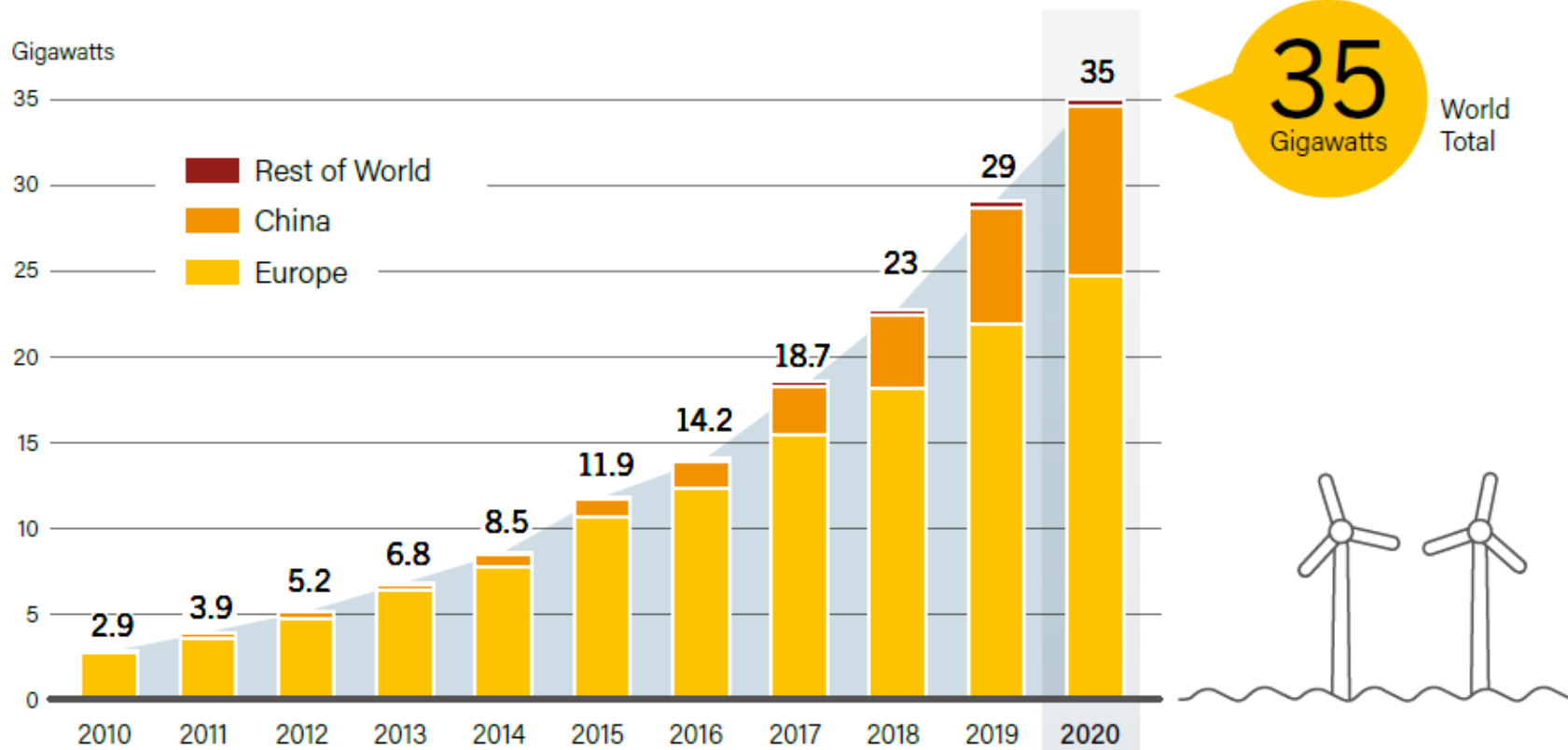


# Instalaciones de Energía Eólica



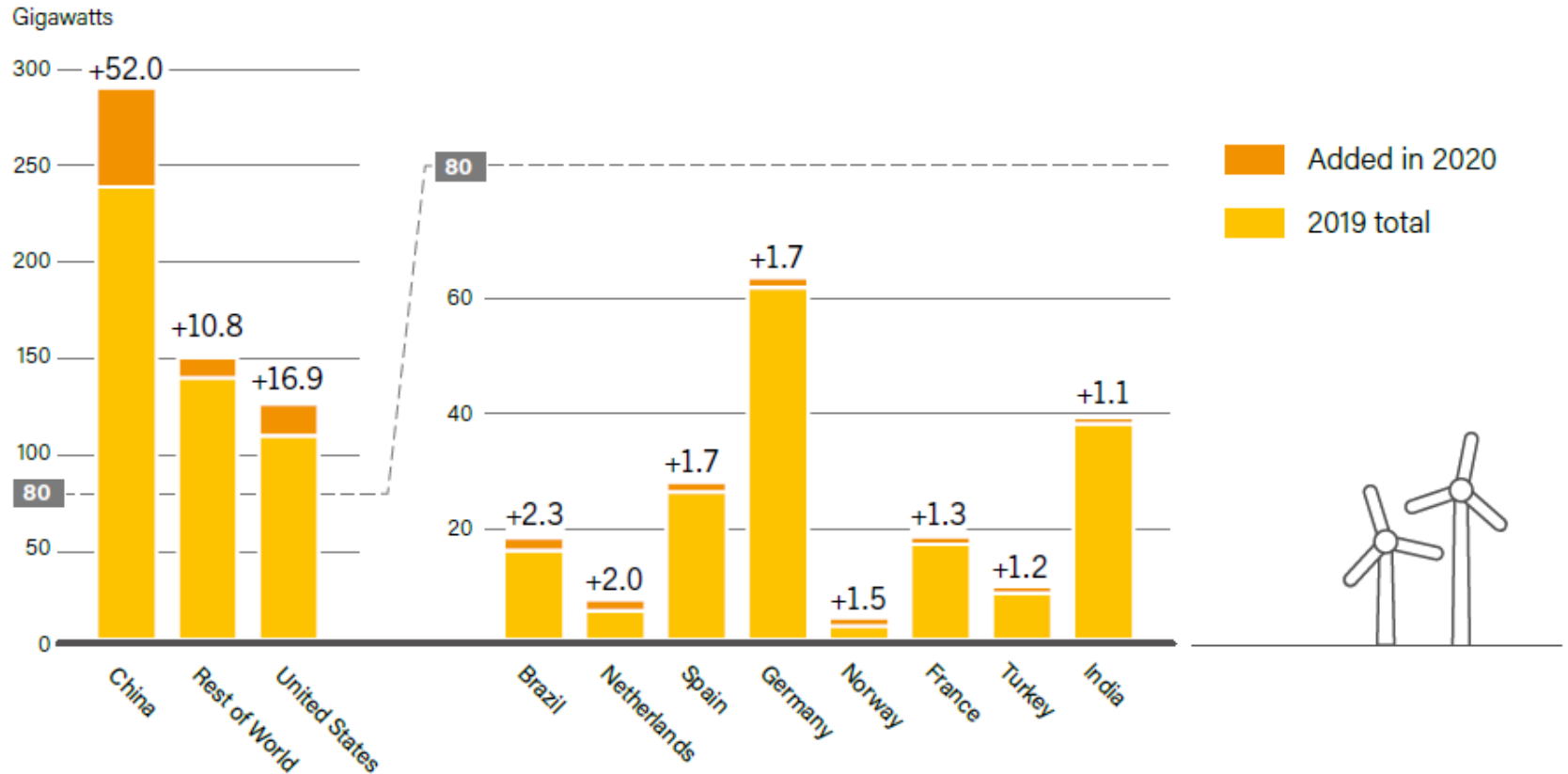


# Energía eólica offshore





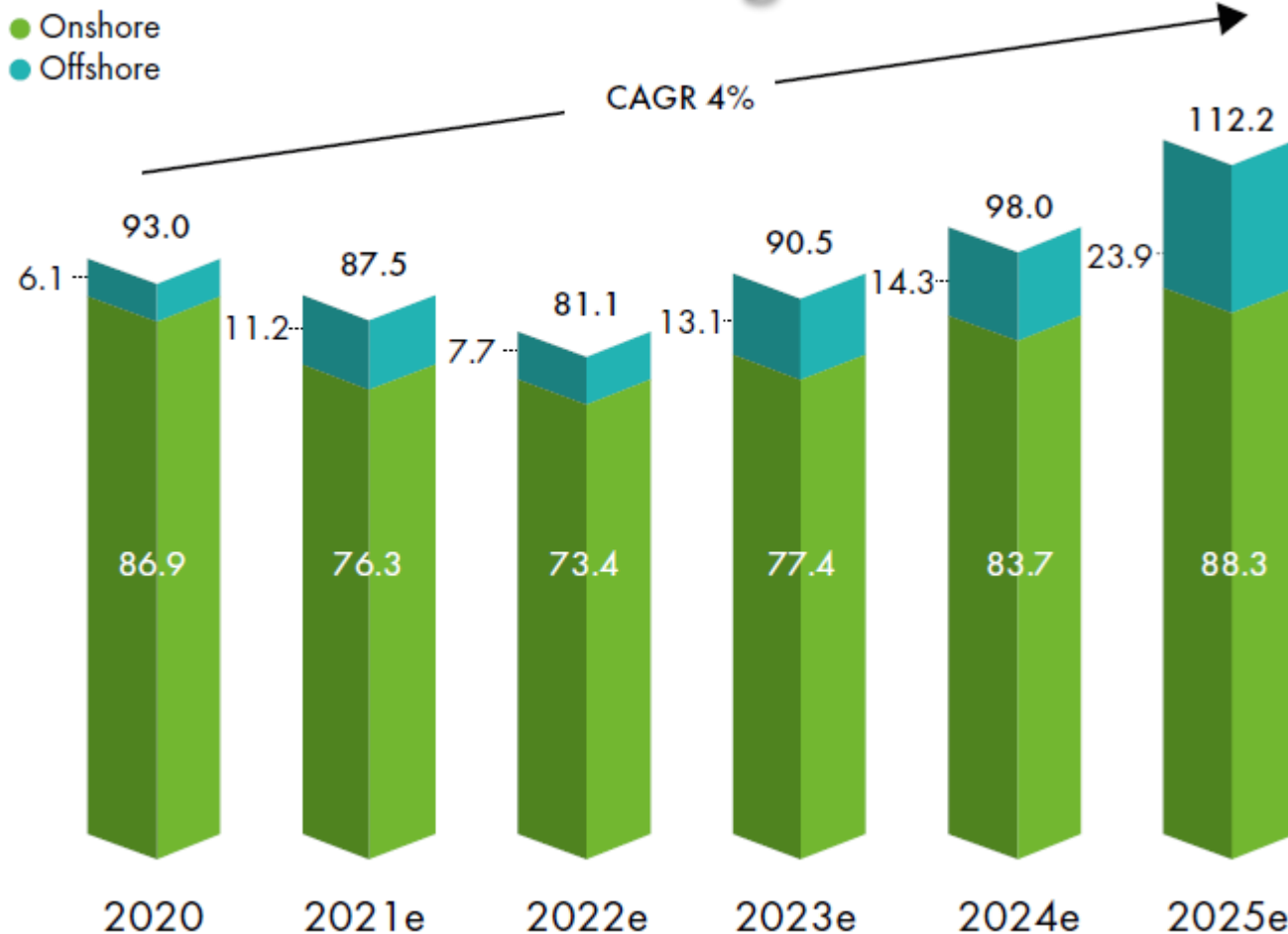
# Nuevas instalaciones de energía eólica







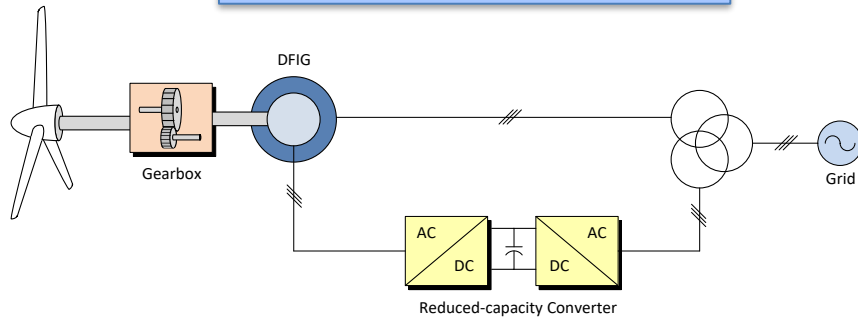
# Predicción de nuevas instalaciones de energía eólica



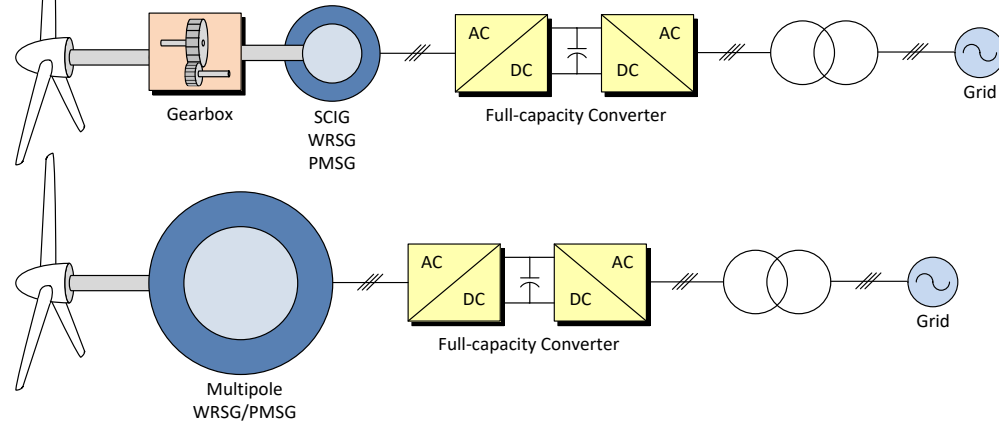


## Sistemas de conversión de energía eólica

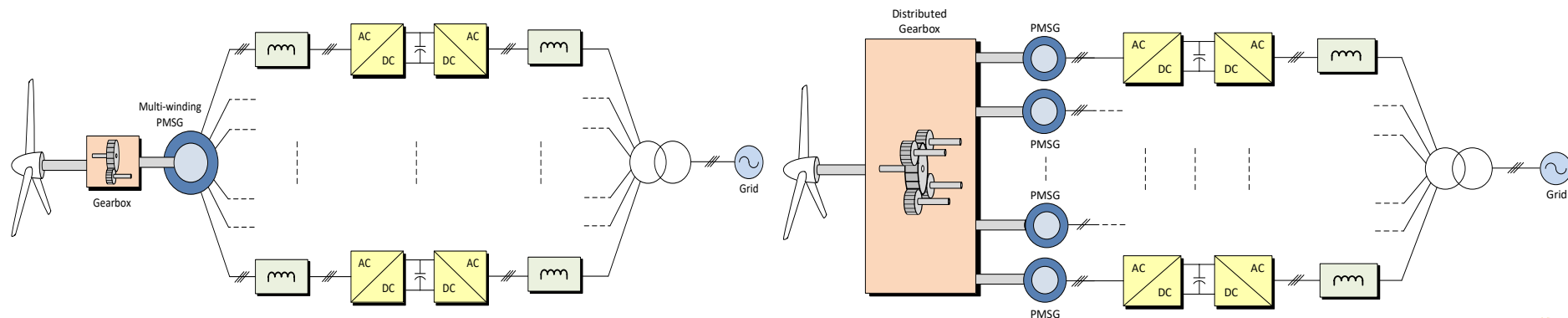
### Doubly-fed converter



### Full-converter (with or without gearbox)



### Distributed back-to-back converters





## Wind Energy Systems

This paper reviews application of power electronics in wind energy systems.

By FREDE BLAABJERG, Fellow IEEE, AND KE MA, Member IEEE

**ABSTRACT** | Wind power now represents a major and growing source of renewable energy. Large wind turbines (with capacities of up to 6–8 MW) are widely installed in power distribution networks. Increasing numbers of onshore and offshore wind farms, acting as power plants, are connected directly to power transmission networks at the scale of hundreds of megawatts. As its level of grid penetration has begun to increase dramatically, wind power is starting to have a significant impact on the operation of the modern grid system. Advanced power electronics technologies are being introduced to improve the characteristics of the wind turbines, and make them more suitable for integration into the power grid. Meanwhile, there are some emerging challenges that still need to be addressed. This paper provides an overview and discusses some trends in the power electronics technologies used for power generation. First, the state-of-the-art technology and global market are generally discussed. Several important wind turbine concepts are discussed, along with power electronics solutions either for individual wind turbines or for entire wind farms. Some technology challenges and future solutions for power electronics in wind turbine systems are also addressed.

**KEYWORDS** | Control; grid codes; power electronics; power semiconductor devices; topology; wind farms; wind power generation; wind turbine system

### I. INTRODUCTION

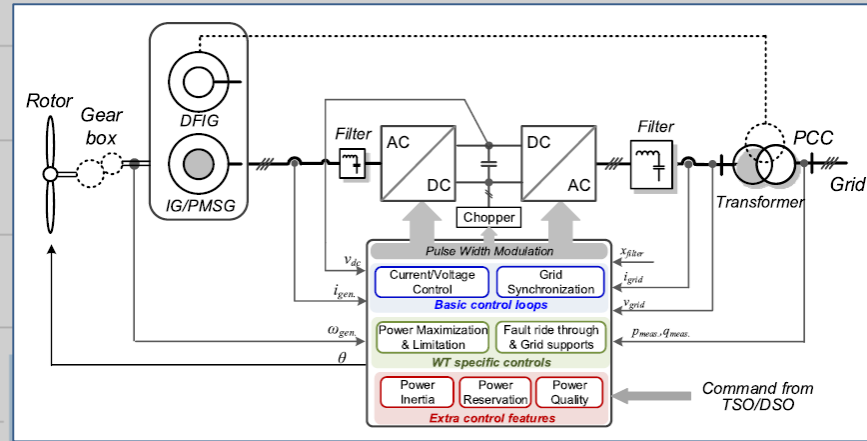
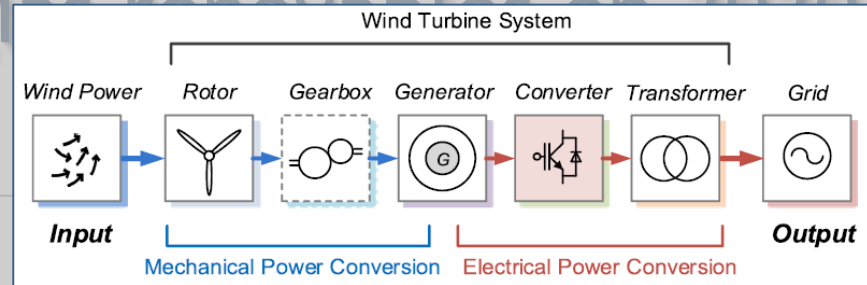
The cumulative installation of wind turbines has grown at a fast pace over the last two decades. Installed wind power generation, which is currently larger than 440 GW, is expected to exceed 760 GW by 2020, making this form of renewable energy a significant component of the modern and future energy supply systems [1]–[3]. Along with the fast-growing capacity, the power electronics technologies used for wind turbine systems (WTSs) have also changed dramatically in the last 30 years [4]–[12].

In the 1980s, the power electronics in wind turbines was simply a soft-starter, which is used to initially interconnect a

squirrel-cage induction generator (SCIG) with the power grid when the wind turbine starts to produce power. Because power electronics did not need to carry power continuously, simple power semiconductor device such as thyristors were applied. In this solution, the rotational speed of the generator is fixed; thus, the wind-speed fluctuations are directly reflected as mechanical-torque fluctuations and then current fluctuations of the generator. Therefore, this solution requires a “stiff” power grid, and its mechanical construction must be able to support the high mechanical stress caused by wind gusts. Moreover, the wind turbine cannot operate at its maximum efficiency in a broad range of wind speeds, and thereby has reduced energy yield.

In the 1990s, power electronics technology was mainly used for rotor resistance control of wound-rotor induction generators (WRIGs), in which more advanced power electronics devices such as diode bridges and choppers were used to control the rotor resistance for the generator. In this solution, the rotational speed of the wind turbine can vary in a limited range, especially at the nominal power operation of the wind turbine (typically 0%–10% above the generator’s synchronous speed); thus, the mechanical stress in the system can be relieved.

Since 2000, even more advanced voltage source converters with bidirectional power flow have been introduced; the power electronics started to handle the generated power from the wind turbine continuously, first, by partial scale of power capacity for doubly fed induction generators (DFIGs), and then by the full scale of power capacity for asynchronous or synchronous generators (ASGs) [5]–[7]. By introducing power electronics converters, it is possible to fully control the rotational speed of the generator and acquire many benefits: First, the wind-speed fluctuations can be smoothly converted into mechanical torque and electrical power with certain inertia by utilizing the kinetic energy in the blades. Moreover, wind turbine efficiency can be optimized over a broader range of wind speeds. Meanwhile, some ancillary services can also be provided for the grid thanks to the extra power control flexibilities introduced by power-electronics converters.



F. Blaabjerg and K. Ma, "Wind Energy Systems," in **Proceedings of the IEEE**, vol. 105, no. 11, pp. 2116-2131, Nov. 2017, doi: 10.1109/JPROC.2017.2695485.

Manuscript received February 03, 2017; revised March 27, 2017; accepted March 29, 2017. Date of publication May 04, 2017; date of current version October 04, 2017. (Corresponding author: Frede Blaabjerg.)  
 F. Blaabjerg is with Aalborg University, Aalborg, Denmark (e-mail: fbl@et.aau.dk).  
 K. Ma is with the department of electrical engineering, Shanghai Ao Tong University, Shanghai, China (e-mail: kema@atuu.edu.cn).

Digital Object Identifier 10.1109/JPROC.2017.2695485

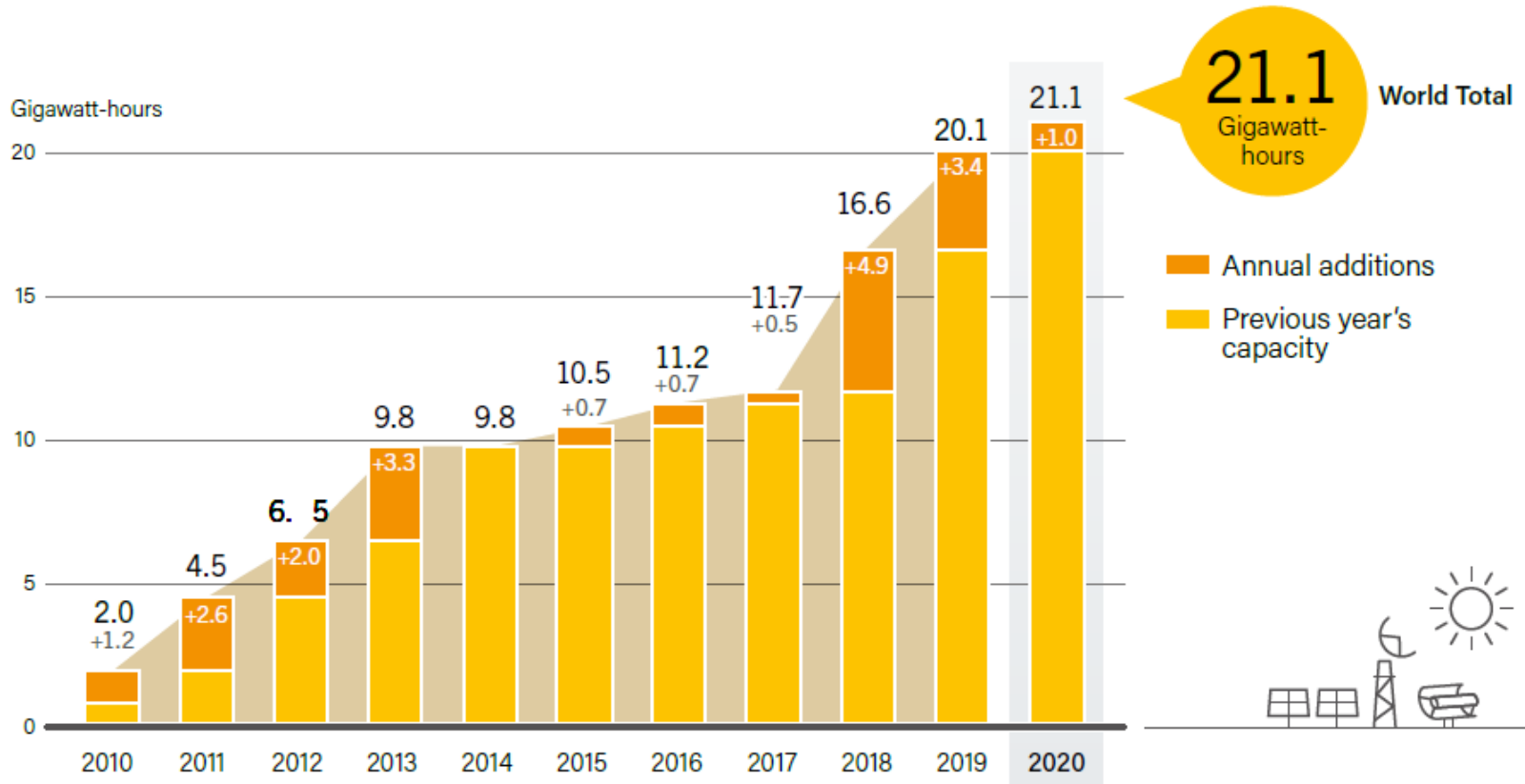
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2116 PROCEEDINGS OF THE IEEE | Vol. 105, No. 11, November 2017



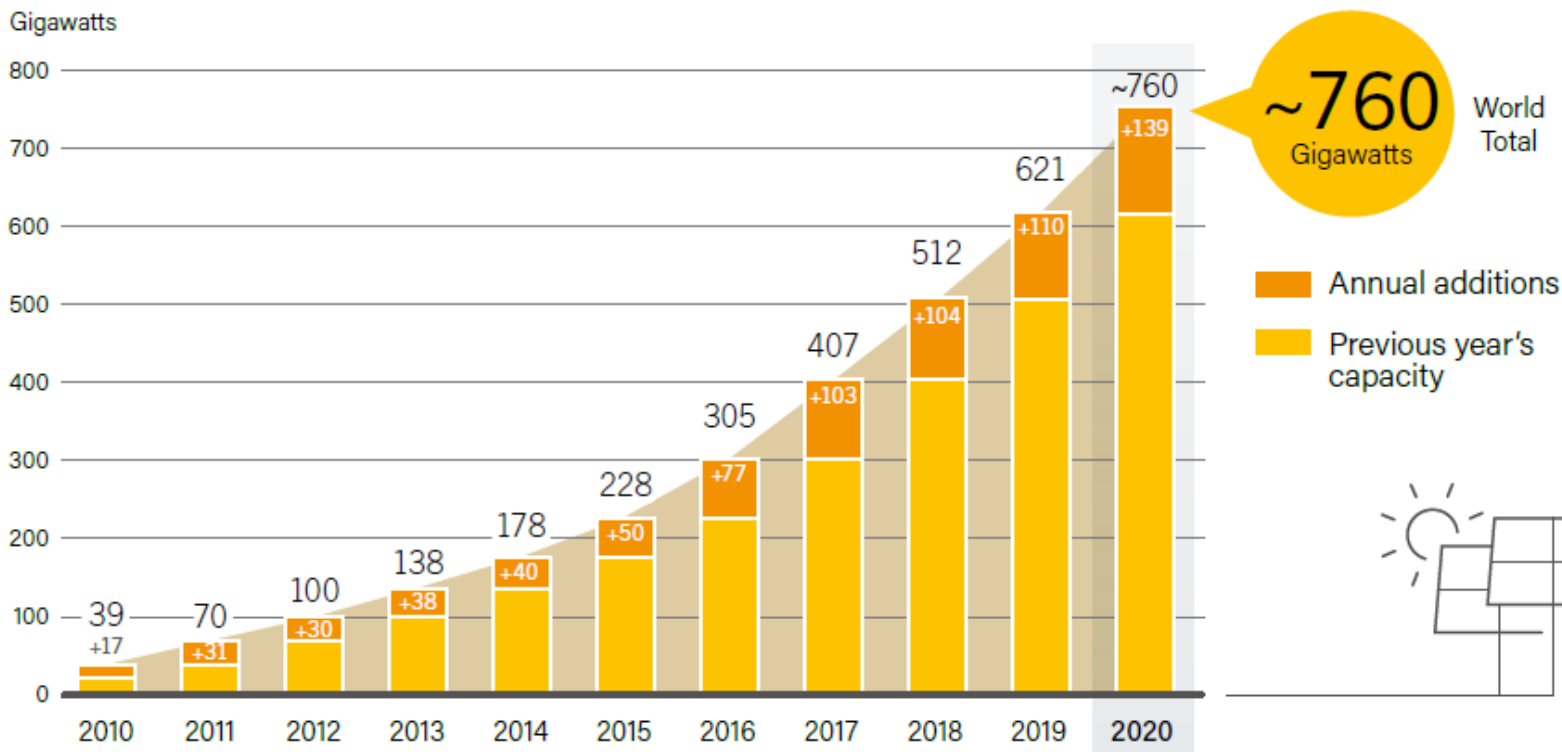


# Concentrated solar power (CSP) Potencia instalada



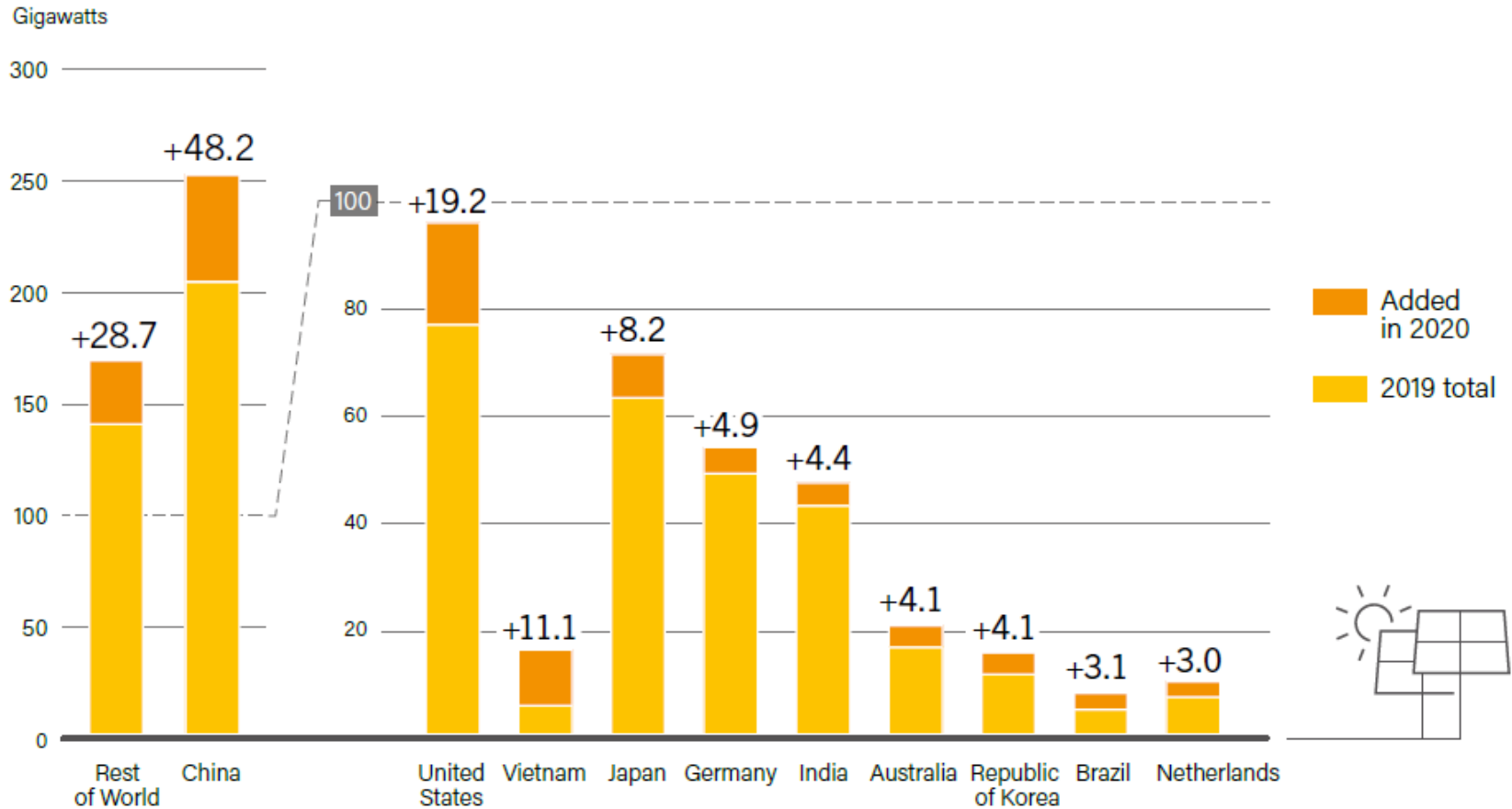


# Solar Fotovoltaica Potencia instalada





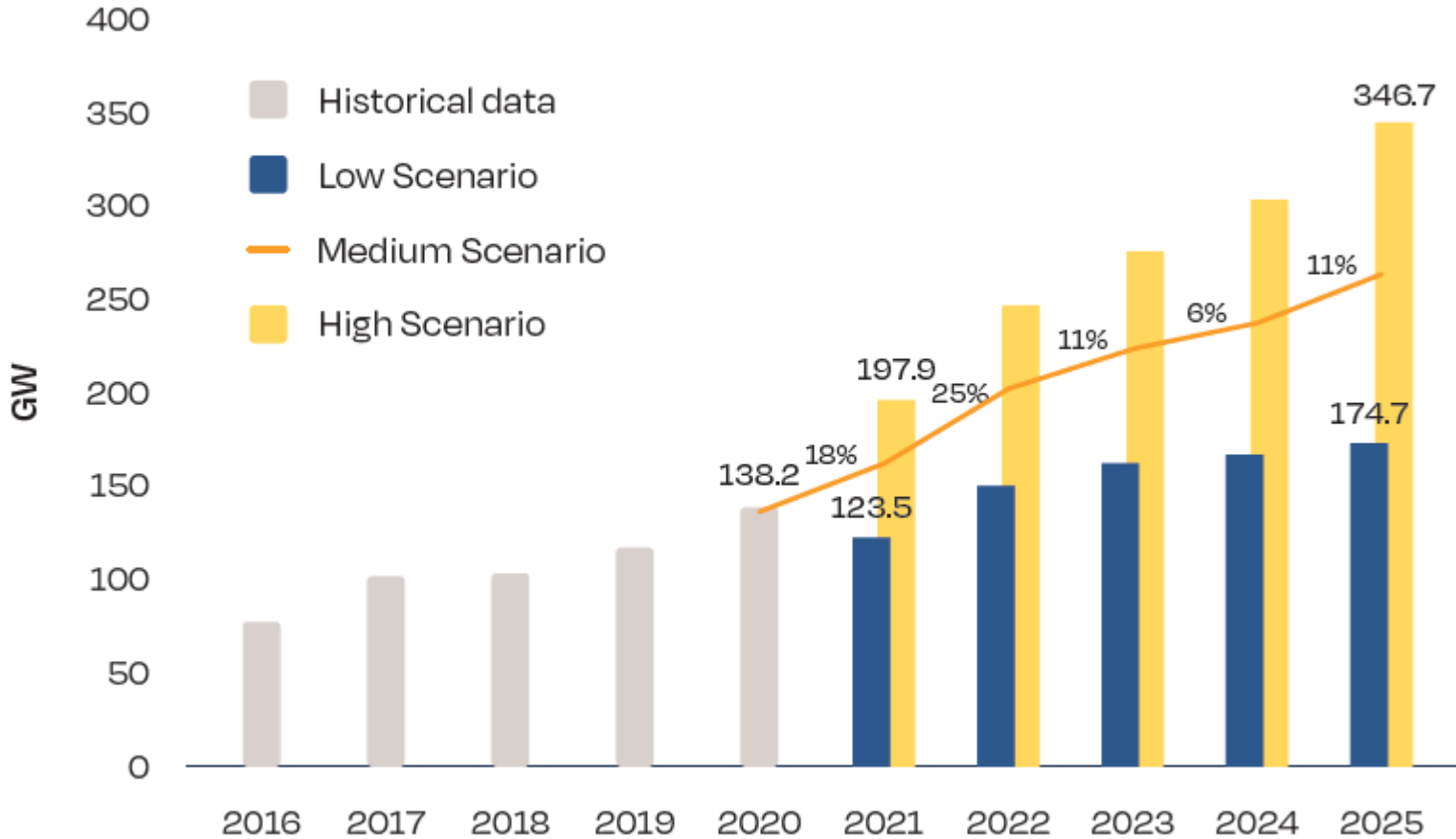
# Nuevas instalaciones de solar fotovoltaica





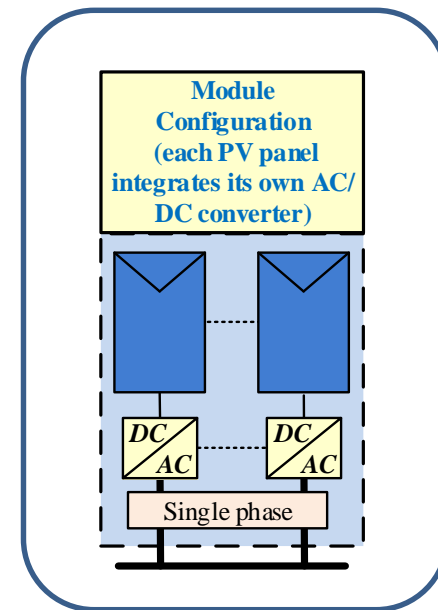
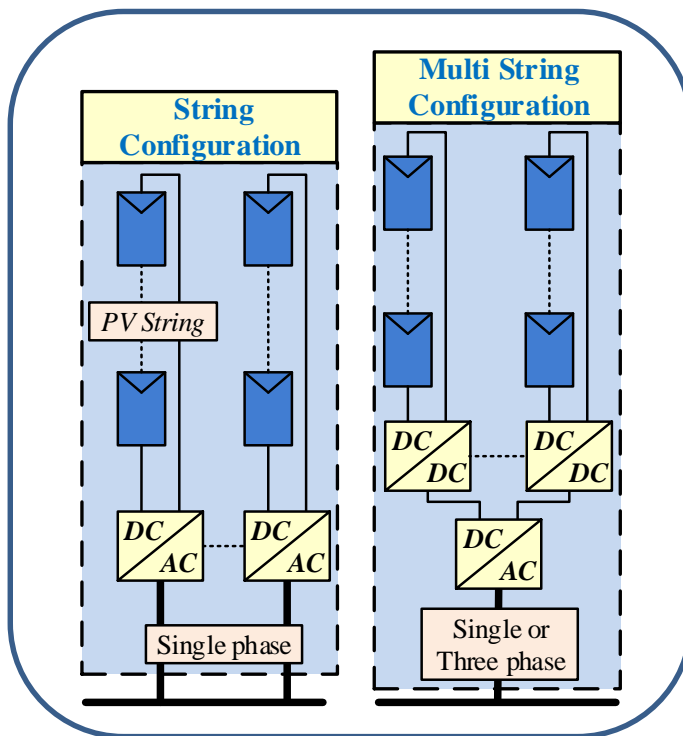
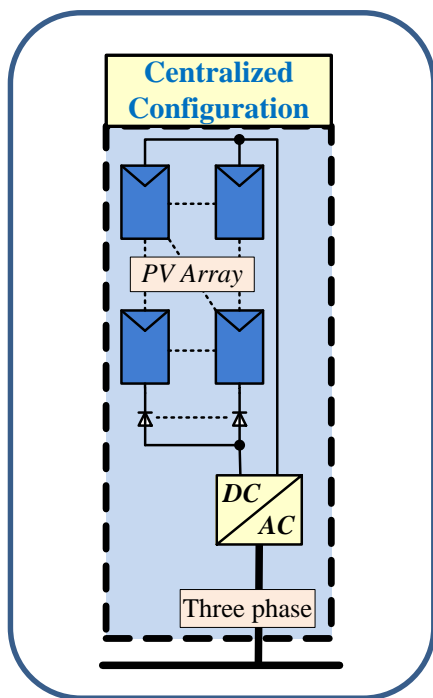


### Predicción de nuevas instalaciones de solar fotovoltaica





# Sistemas de conversión para sistemas PV



## Inversores centrales

- 150 kW- 1MW, trifásico, varios strings PV en paralelo
- **Alta eficiencia**, bajo coste, **MPPT global (no óptimo)**
- Usado a nivel de planta PV

## Inversores String/Multistring

- 1.5kW - 150 kW, típica **aplicación residencial**
- Cada string PV tiene su algoritmo MPPT específico obteniendo mayor rendimiento

## Inversores domésticos

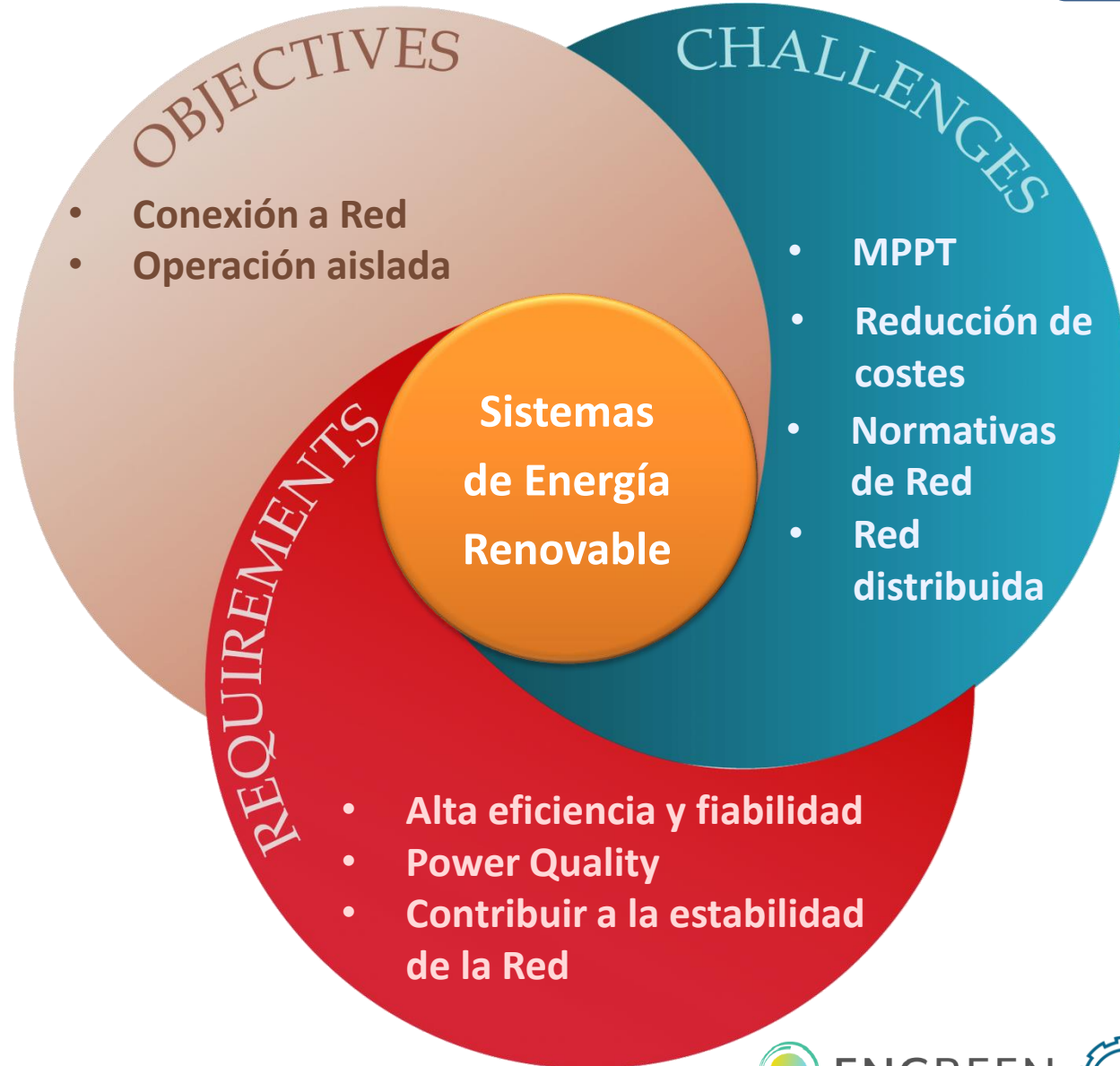
- 50W-1kW, cada panel PV tiene su propio inversor permitiendo un **MPPT óptimo**
- Mayor coste por kWp





# Fuentes de Energía Renovable

visión





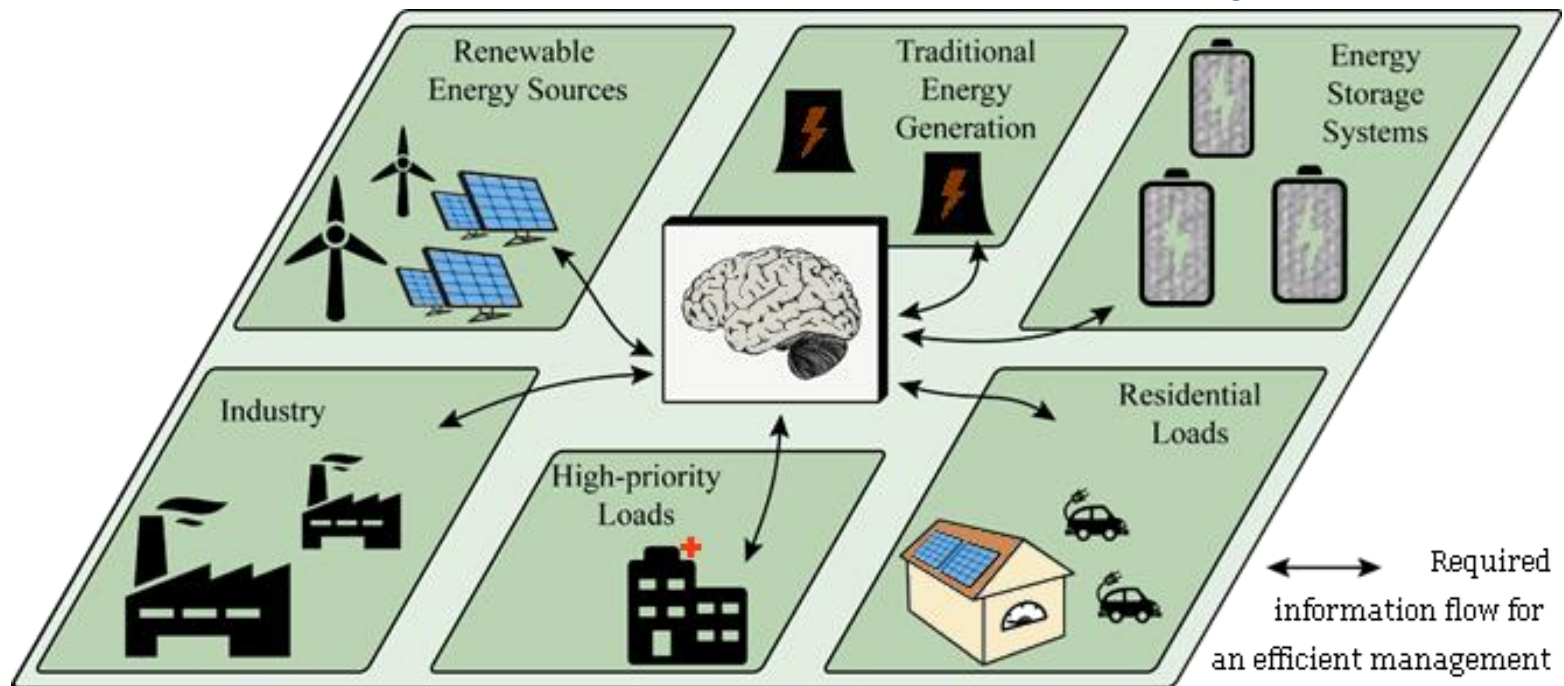


# Smart Grids

- ¿Qué es una Smart Grid?

“A smart or intelligent grid is basically the advanced electric power grid of tomorrow using state-of-the-art technologies in power systems, power electronics, computers, communications, information, artificial intelligence, cyber, etc., that will improve system availability, reliability, power quality, energy efficiency, and security with optimum resource utilization and economical electricity to the consumers.”

Prof. Bimal K. Bose, Proceedings of the IEEE Nov. 2017





# Retos de la Energía Renovable



J. M. Carrasco et al., "Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey," in **IEEE Transactions on Industrial Electronics**, vol. 53, no. 4, pp. 1002-1016, June 2006, doi: 10.1109/TIE.2006.878356.

## Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey

Juan Manuel Carrasco, *Member, IEEE*, Leopoldo García Franquelo, *Fellow, IEEE*,  
 Jan T. Bielašewicz, *Senior Member, IEEE*, Eduardo Galván, *Member, IEEE*,  
 Ramón C. Portillo Guisado, *Student Member, IEEE*, Ma. Angeles Martín Prats, *Member, IEEE*,  
 José Ignacio León, *Student Member, IEEE*, and Narciso Moreno-Alfonso, *Member, IEEE*

**Abstract**—The use of distributed energy resources is increasingly being pursued as a supplement and an alternative to large conventional central power stations. The specification of a power-electronic interface is subject to requirements related not only to the renewable energy source itself but also to its effects on the power-system operation, especially where the intermittent energy source constitutes a significant part of the total system capacity. In this paper, new trends in power electronics for the integration of wind and photovoltaic (PV) power generators are presented. A review of the appropriate storage-system technology used for the integration of intermittent renewable energy sources is also introduced. Decisions about common and future trends in renewable energy systems based on reliability and maturity of each technology are presented.

**Index Terms**—Direct drives, doubly fed induction generator (DFIG), hybrid, hydrogen, multilevel converter topologies, supercapacitors, superconducting magnetic energy storage (SMES), wind diesel.

These factors together have led to the development of cost-effective and grid-friendly converters.

In this paper, new trends in power-electronic technology for the integration of renewable energy sources and energy-storage systems are presented. This paper is organized as follows. In Section II, we describe the current technology and future trends in variable-speed wind turbines. Wind energy has been demonstrated to be both technically and economically viable. It is expected that current developments in gearless energy transmission with power-electronic grid interface will lead to a new generation of quiet, efficient, and economical wind turbines. In Section III, we present power-conditioning systems used in grid-connected photovoltaic (PV) generation plants. The continuously decreasing prices for the PV modules lead to the increasing importance of cost reduction of the specific PV converters.

Energy storage in an electricity generation and supply system enables the decoupling of electricity generation from demand. In other words, the electricity that can be produced at times of either low-demand low-generation cost or from intermittent renewable energy sources is shifted in time for release at times of high-demand high-generation cost or when no other generation is available. Appropriate integration of renewable energy sources with storage systems allows for a greater market penetration and results in primary energy and emission savings. In Section IV, we present research and development trends in energy-storage systems used for the grid integration of intermittent renewable energy sources.

### I. INTRODUCTION

THE INCREASING number of renewable energy sources and distributed generation requires new strategies for the operation and management of the electricity grid in order to maintain or even to improve the power-supply reliability and quality. In addition, liberalization of the grids leads to new management structures, in which trading of energy and power is becoming increasingly important. The power-electronic technology plays an important role in distributed generation and in integration of renewable energy sources into the electrical grid, and it is widely used and rapidly expanding as these applications become more integrated with the grid-based systems.

During the last few years, power electronics has undergone a fast evolution, which is mainly due to two factors. The first one is the development of fast semiconductor switches that are capable of switching quickly and handling high powers. The second factor is the introduction of real-time computer

### II. WIND-TURBINE TECHNOLOGY

#### A. Variable-Speed Wind Turbines

Wind energy has matured to a level of development where generally accepted utility generation technology has undergone a dramatic change in the last 15 years, developing from a 70s to the wind turbine of the 2000s. Power electronics, aerodynamics, and mechatronics [1], [2]. In the last five years, market has been growing at over 30% annually, playing an increasingly important role, especially in countries such as Spain, where legislation in both countries favors installed capacity. Wind power is quite

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MARCO LISERRE,  
 THILO SAUTER,  
 and JOHN Y. HUNG

## Future Energy Systems

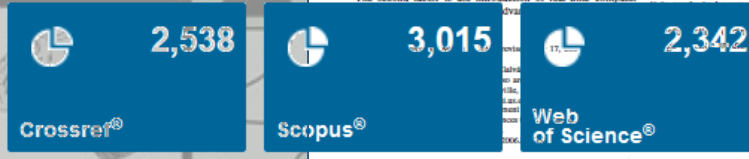
Integrating Renewable Energy Sources into the Smart Power Grid Through Industrial Electronics



Industrialization and economic development have historically been associated with man's ability to harness natural energy resources to improve his condition. Based on the distinctions, two industrial revolutions occurred in the 18th and 19th centuries, where natural resources such as coal (first revolution) and petroleum (second revolution) were widely exploited to produce levels of energy far beyond what could be achieved by human or animal muscle power.

Furthermore, modern power distribution systems made abundant energy reliably available and relatively independent from the plant location. More than two centuries of past industrialization exploited non-renewable energy resources, however, often with undesirable side effects such as pollution and other damage to the natural environment. In the second half of the 20th century, extraction of energy from nuclear processes grew in popularity, relieving some demands on limited fossil fuel reserves, but at the same time, raising safety and political problems.

Meeting the global demand for energy is now the key challenge to sustained industrialization. On the other hand, network and wireless communication systems have helped another modern economic and industrial revolution. New industries and economies based on communication services have sprung up from the widespread availability of information. Harnessing information continues to change the course of technological and social development [1]. In this article, the authors suggest that at the landscape or history of industrialization is a full circle: from energy



M. Liserre, T. Sauter and J. Y. Hung, "Future Energy Systems: Integrating Renewable Energy Sources into the Smart Power Grid Through Industrial Electronics," in **IEEE Industrial Electronics Magazine**, vol. 4, no. 1, pp. 18-37, March 2010, doi: 10.1109/MIE.2010.935861.

IEEE INDUSTRIAL ELECTRONICS MAGAZINE, 18 MARCH 2010

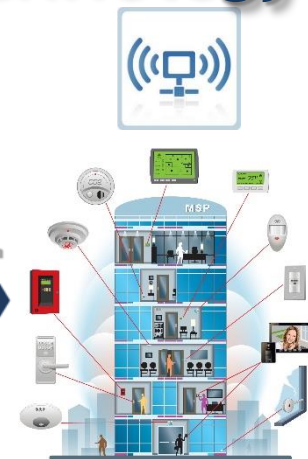
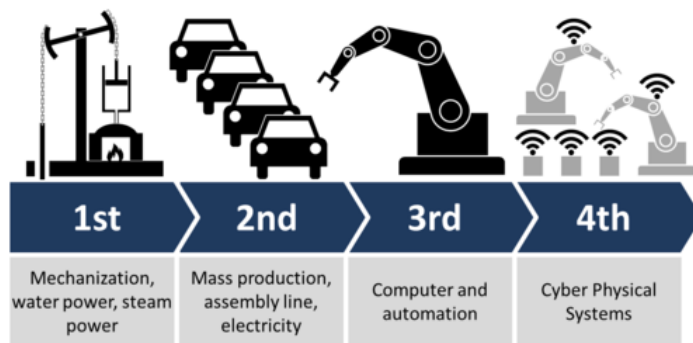
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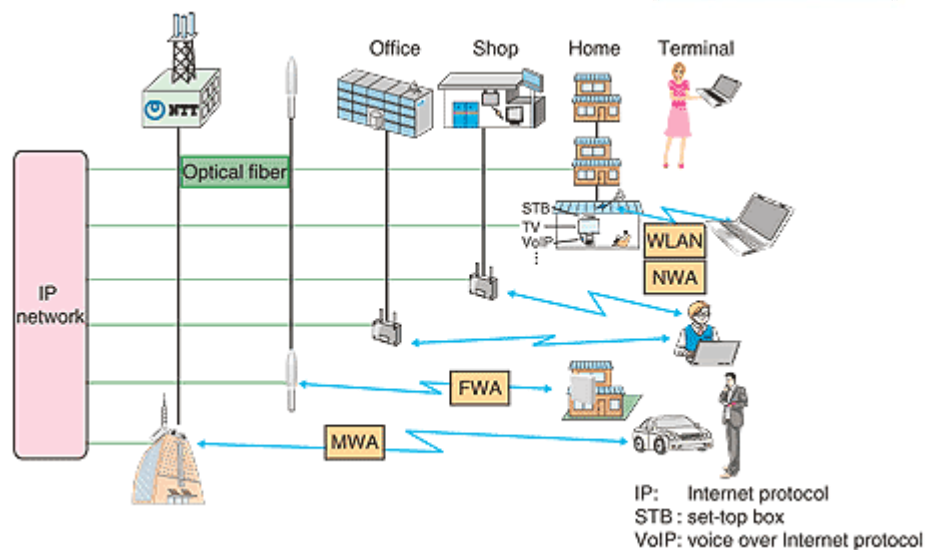




## Information & Communications Technology



- Building Automation, Control, and Management
- Cloud and Wireless Systems for Industrial Applications
- Factory Automation
- Industrial Agents
- Industrial Cyber-Physical Systems
- Industrial Informatics





S. E. Collier, "The Emerging Enernet: Convergence of the Smart Grid with the Internet of Things," in **IEEE Industry Applications Magazine**, vol. 23, no. 2, pp. 12-16, March-April 2017, doi: 10.1109/MIAS.2016.2600737.



## Autonomous Energy Grids

Controlling the Future Grid With Large Amounts of Distributed Energy Resources



THE DRASTIC PRICE REDUCTION in variable renewable energy, such as wind and solar, coupled with the ease of use of smart technologies at the consumer level, is driving dramatic changes in the power system that will significantly transform how power is made, delivered, and used. Distributed energy resources (DERs)—which can include solar photovoltaic (PV), fuel cells, micro-turbines, gensets, distributed energy storage (e.g., batteries and ice storage), and new loads (e.g., electric vehicles (EVs), LED lighting, smart appliances, and electric heat pumps)—are being added to electric grids and causing bidirectional power flows and voltage fluctuations that can impact optimal control and system operation. Residential solar installations are expected to increase approxi-

mately 8% annually through 2050. Customer battery systems are anticipated to reach almost 1.9 GW by 2024, and current forecasts project that approximately 18.7 million EVs will be on U.S. roads in 2030. With numbers like these, it is not unreasonable to imagine a residential electricity customer having at least five controllable DERs. In future

By Benjamin Kroposki, Andrey Bernstein, Jennifer King, Deepthi Vaidhyanathan, Xinyang Zhou, Chin-Yao Chang, and Emiliano Dall'Anese

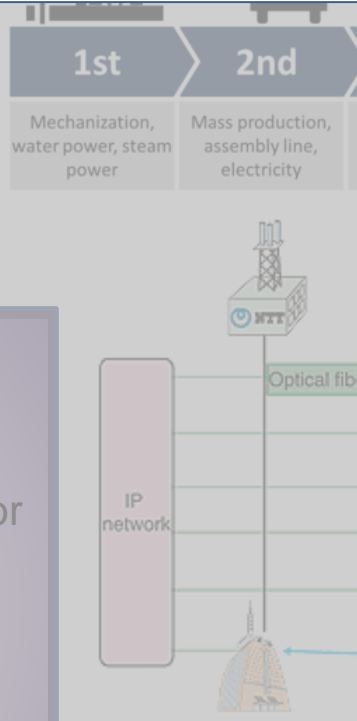
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 Date of current version: 16 October 2020

november/december 2020

1540-7177/20/2020IEEE

IEEE power & energy magazine 37

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## The Emerging Enernet



CONVERGENCE OF THE SMART GRID WITH THE INTERNET OF THINGS

By Steven E. Collier

BOB METCALFE, INVENTOR OF THE ETHERNET AND A well-known technology visionary, once said [8], "Over the past 63 years, we met world needs for cheap and clean information by building the Internet. Over the next 63 years, we will meet world needs for cheap and clean energy by building the Enernet."

The Internet has resulted from revolutionary advances in electronics, telecommunications and information technology, devices, and applications. Although it began as an Internet that connected people, by 2008 it connected more things than people. This exponential growth has primarily been as an Internet of Things (IoT). Cisco has predicted that 50 billion new connections will be made in this IoT by 2020. The U.S. electric utility grid has, until now, been a patchwork of monolithic, weakly interconnected,

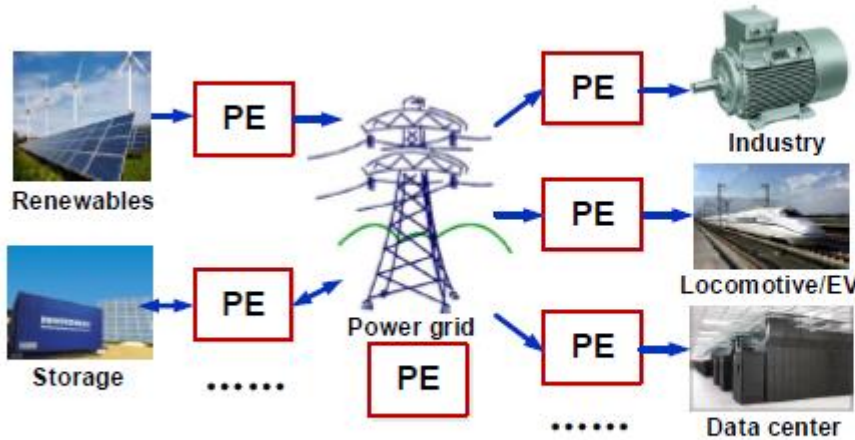
12 IEEE Industry Applications Magazine • MARCH/APRIL 2017  
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B. Kroposki et al., "Autonomous Energy Grids: Controlling the Future Grid With Large Amounts of Distributed Energy Resources," in **IEEE Power and Energy Magazine**, vol. 18, no. 6, pp. 37-46, Nov.-Dec. 2020, doi: 10.1109/MPE.2020.3014540.





# CAPEX & OPEX

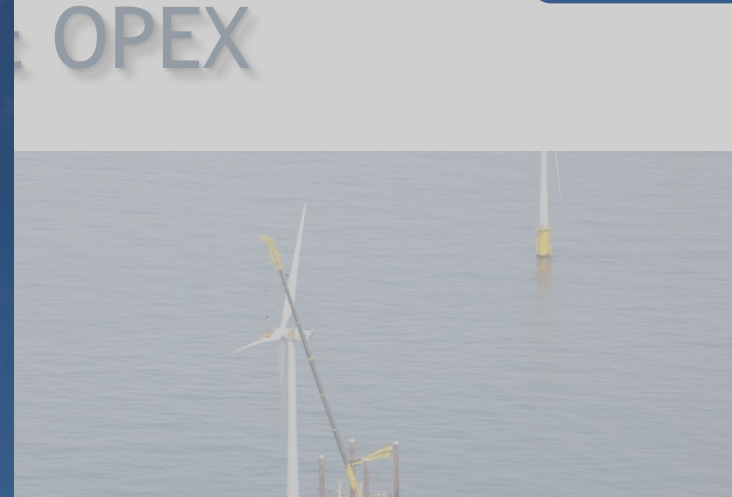


Modern energy supply structure



Maintenance of offshore wind turbine

- Mayor potencia instalada ➡ Importancia mayor de los fallos
- Coste de energía = (Instalación + O&M)/Tiempo en operación
- Mejora de la fiabilidad ➡ Reducción del coste de energía



## Power Routing

*A New Paradigm for Maintenance Scheduling*

MARCO LISERRE,  
GIAMPAOLO BUTICCHI,  
JOSE IGNACIO LEON,  
ABRAHAM MARQUEZ ALCAIDE,  
VIVEK RAVEENDRAN,  
YOUNGJONG KO,  
MARKUS ANDRESEN,  
VITO GIUSEPPE MONOPOLI, and  
LEOPOLDO FRANQUELO

**C**urrently, the necessity of efficient and reliable power systems is also increasing because of the strict requirements that standards and regulations impose, but still costs have to remain low. The monitoring and control of the components' lifetime can lead to reduce maintenance costs. However, overcoming the related challenges is not a straightforward task, as it involves knowledge of power device physics, smart management of electrical quantities, and optimal maintenance planning and scheduling. It represents a multidisciplinary issue being faced in the last decade. As a primary issue to



M. Liserre et al., "Power Routing: A New Paradigm for Maintenance Scheduling," in **IEEE Industrial Electronics Magazine**, vol. 14, no. 3, pp. 33-45, Sept. 2020, doi: 10.1109/MIE.2020.2975049.

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SEPTEMBER 2020 ■ IEEE INDUSTRIAL ELECTRONICS MAGAZINE 33

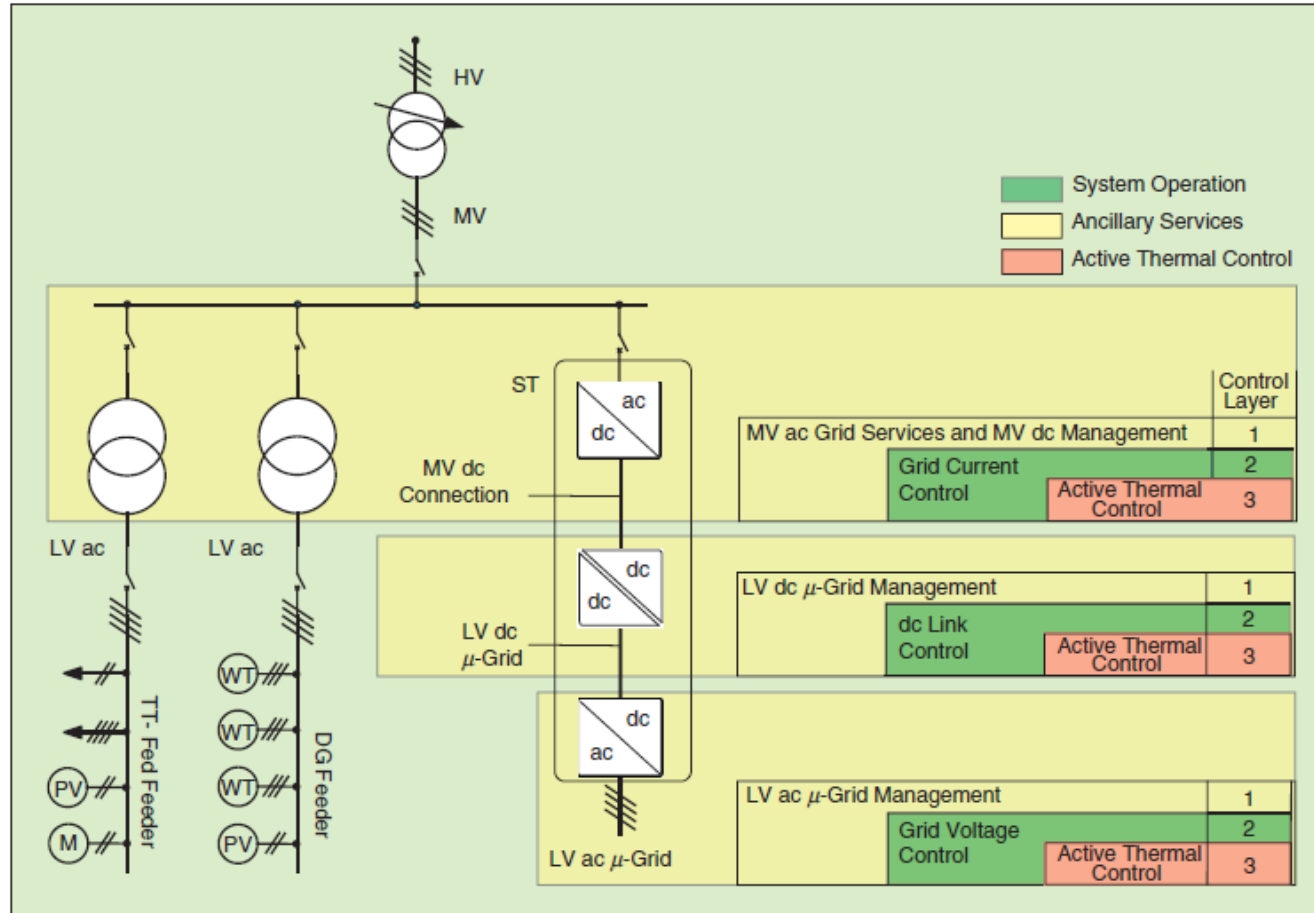
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## Smart Transformer como nodo de una Smart Grid

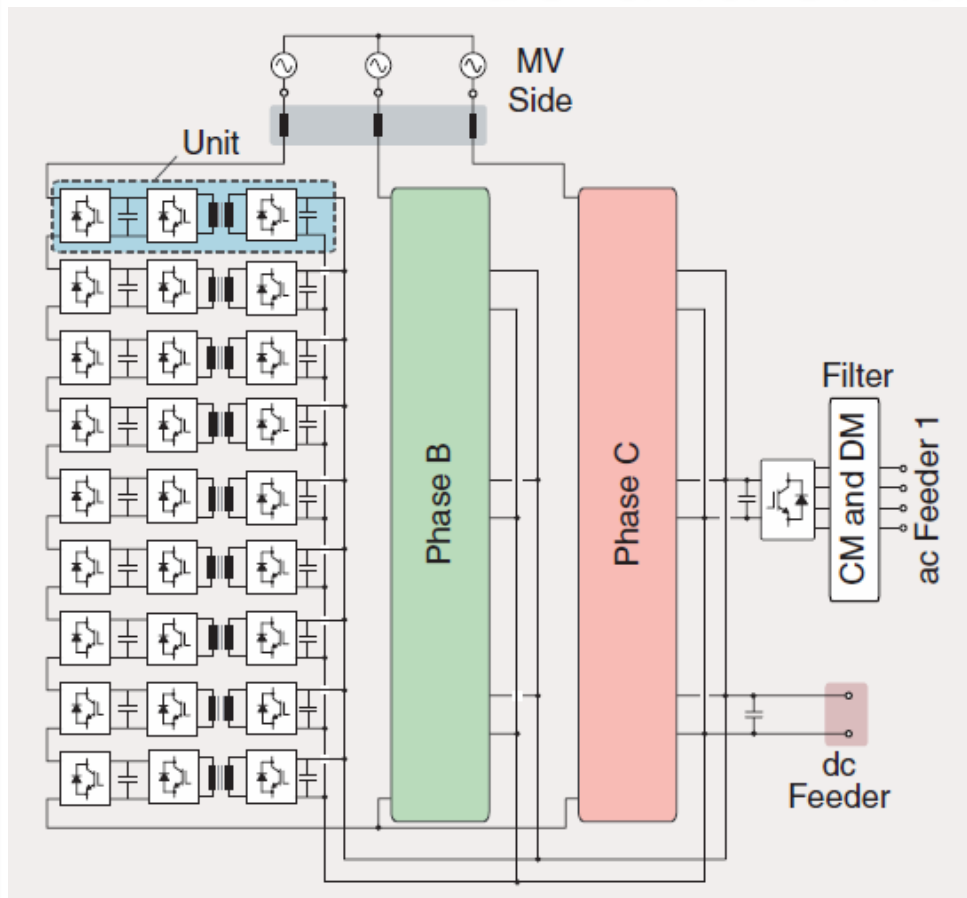
IEEE y Energías Renovables, una relación simbiótica

Jose I. Leon - Univ. de Sevilla & Harbin Inst. Of Technology





# Smart Transformer como nodo de una Smart Grid



Smart Transformer:

- Compuesto por cientos de módulos simples conectados en serie
- Alta modularidad
- Tolerancia a fallos inherente
- Adquisición de datos y control complejo
- Conexión en media tensión dc, baja tensión dc, ó baja tensión ac permitiendo las microrredes en dc





M. Liserre, G. Buticchi, M. Andresen, G. De Carne, L. F. Costa and Z. Zou, "The Smart Transformer: Impact on the Electric Grid and Technology Challenges," in **IEEE Industrial Electronics Magazine**, vol. 10, no. 2, pp. 46-58, June 2016, doi: 10.1109/MIE.2016.2551418.

by Levy Ferreira Costa, Giovanni De Carne, Giampaolo Buticchi, and Marco Liserre

## The Smart Transformer

*A solid-state transformer tailored to provide ancillary services to the distribution grid*

The solid-state transformer (SST) was conceived as a replacement for the conventional power transformer, with both lower volume and weight. The smart transformer (ST) is an SST that provides ancillary services to the distribution and transmission grids to optimize their performance. Hence, the focus shifts from hardware advantages to functionalities. One of the most desired functionalities is the dc connectivity to enable a hybrid distribution system. For this reason, the ST architecture shall be composed of at least two power stages. The standard design procedure for this kind of system is to design each power stage for the maximum load. However, this design approach might limit additional services, like the reactive power compensation on the medium voltage (MV) side, and it does not consider the load regulation capability of the ST on the low voltage (LV) side. If the SST is tailored to the services that it shall provide, different stages will have different designs, so that the ST is no longer a mere application of the SST but an entirely new subject.

**Renewable Energy and the Power Distribution Grid**  
The integration of renewable energy systems and new loads, like electric vehicles (EVs), has changed the distribution grid. The grid, once passive and static with a limited number of distributed generators, is now active and dynamic. The LV grid hosts, together with residential and commercial loads, small generators in the range of hundreds of watts to a few hundred kilowatts. This generation capability consists of diesel generators, gas microturbines, photovoltaics, and micro wind turbines. Among these resources, there are the controllable ones (diesel and gas generators) and the ones called renewables that provide energy when available from natural sources (e.g., wind, sun irradiation, and tides). This last category has two main features: high power-injection variability and distributed presence in the distribution grid. These generation units vary their power-output with short-term forecast possibilities and at different times due to the different geographical distribution. The major challenges for the grid are the voltage control, frequency stability, reverse power flow, and protection systems coordination [1], [3].

The ST, an SST with control and communication functionalities, can represent a solution for many of the mentioned problems. The ST features cover a wide range of services, like the reactive power support in MV grids, dc connectivity at both the MV and LV levels, and load control in the LV side. The ST is designed following a three-stage solution, with the isolation stage in the dc-link converter. This solution enables the galvanic isolation between the two grids, guaranteeing the appliances' safety during abnormal conditions (e.g., faults or lightning strikes). The ST basic design does not differ substantially from the SST concept. However, unlike the SST, which is designed mainly for traction applications or as a mere one-to-one replacement of conventional transformers, the ST shall be tailored to provide those previously mentioned services.

This article presents the grid-tailored design approach (GITLA) for STs, taking in account the load requirements (e.g., unbalanced conditions) and the services that can be provided to the grid (e.g., reactive power support). This

phase  $k$  ( $k=a,b,c$ )  
power cell  $j$   
( $j=1,\dots,M$ )

Negative DC capacitor

$V_j(V_{Ckj} - V_{Ckj}^*)$   
per arm

IGBT current controllers

IEEE POWER ELECTRONICS MAGAZINE June 2017  
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of data  
signals  
focused  
waveforms  
ents

L. Ferreira Costa, G. De Carne, G. Buticchi and M. Liserre, "The Smart Transformer: A solid-state transformer tailored to provide ancillary services to the distribution grid," in **IEEE Power Electronics Magazine**, vol. 4, no. 2, pp. 56-67, June 2017, doi: 10.1109/MPEL.2017.2692381.

## The Smart Transformer

*Impact on the Electric Grid and Technology Challenges*

MARCO LISERRE, GIAMPAOLO BUTICCHI, MARKUS ANDRESEN, GIOVANNI DE CARNE, LEVY FERREIRA COSTA, and ZHI-XIAO ZOU

The increasing proliferation of renewable energy resources and new sizeable loads like electric vehicle (EV) charging stations has posed many technical and operational challenges to distribution grids [1]. Encouraged by attractive tax incentives and promotion policies, local grid and consumers are becoming not only consumers of electricity but, in many cases, also producers. The actual electric distribution system limits the use of renewable energy resources, offers poor EV infrastructure, and is based on a unidirectional information flow from sources to control centers.

Power electronics can play a significant role in the improvement of the electric grid. In fact, most of the actors, either sources or loads, are connected to the electrical distribution grid through power converters [2]. Moreover, many of the solutions proposed to improve the reliability and stability of the electric distribution grid are still based on power electronics, such as active filter, high-voltage (HV) dc, flexible ac transmission systems (FACTS), solid-state transformers (SSTs), and electronic breakers [3]. It is now possible to handle HV and high current power conversion with low losses, thanks to the latest generation of power semiconductor devices based on silicon (Si). Efficiency and power density will be further enhanced by the forthcoming power semiconductor devices that are based on compound materials like Si carbide (SiC) or gallium nitride (GaN) [4].

IEEE POWER ELECTRONICS MAGAZINE June 2016  
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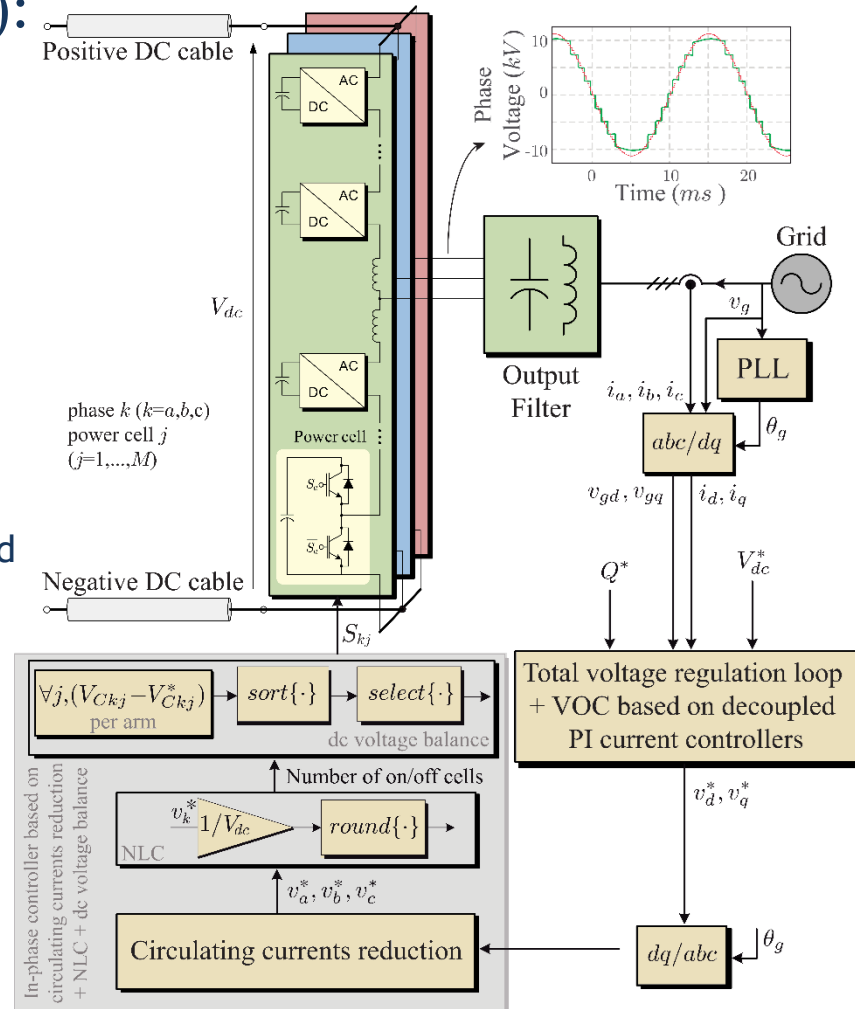




## Aplicación HVDC - Eólica offshore

### Modular Multilevel Converter (MMC):

- Compuesto por cientos de módulos simples conectados en serie
- Alta modularidad
- Tolerancia a fallos inherente
- Adquisición de datos y control complejo
- Objetivos de control:
  - Formas de onda de salida con alta calidad
  - Alta eficiencia
  - Minimización de corrientes circulantes
  - Reducción de la tensión modo común
  - Reducción del rizado de las tensiones dc
  - Mejora de las comunicaciones para no tener limitaciones por ancho de banda





H. Akagi, "Classification, Terminology, and Application of the Modular Multilevel Cascade Converter (MMCC)," in **IEEE Transactions on Power Electronics**, vol. 26, no. 11, pp. 3119-3130, Nov. 2011, doi: 10.1109/TPEL.2011.2143431.

## Circuit Topologies, Modeling, Control Schemes, and Applications of Modular Multilevel Converters

Marcelo A. Perez, *Senior Member, IEEE*, Steffen Bernet, *Member, IEEE*, Jose Rodriguez, *Fellow, IEEE*, Samir Kouro, *Member, IEEE*, and Ricardo Lizana, *Student Member, IEEE*

**Abstract**—Modular multilevel converters have several attractive features such as a modular structure, the capability of transformer-less operation, easy scalability in terms of voltage and current, low expense for redundancy and fault tolerant operation, high availability, utilization of standard components, and excellent quality of the output waveforms. These features have increased the interest of industry and research in this topology, resulting in the development of new circuit configurations, converter models, control schemes, and modulation strategies. This paper presents a review of the latest achievements of modular multilevel converters regarding the mentioned research topics, new applications, and future trends.

**Index Terms**—AC transmission systems, HVDC transmission, medium voltage machine drives, modular multilevel converters, power electronics converters.

### 1. INTRODUCTION

TODAY, multilevel converters receive wide acceptance in industry and energy systems because they enable the design of medium and high voltage systems with excellent output voltage quality. Compared to the two-level voltage source converter, the simple realization of redundancy, low filter expense, and the reduction of power semiconductor losses and common-mode voltages are important additional benefits [1], [2]. Among the different topologies for multilevel converters, as shown in Fig. 1, multilevel converters feature the highest degree of modularity and the lowest expense for redundancy due to the large number of cells they have, as well as the lowest harmonic content due to the large number of output voltage levels they produce. The large number of cells substantially increases the requirements of the converter controller, but each cell offers a simple structure, reducing the manufacturing costs. Currently, multilevel

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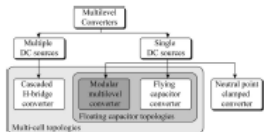


Fig. 1. Multilevel converter topology classification.

converters are used in applications like medium voltage drives (MVD), active filters, integration of renewable energy sources to the electrical grid, and in high-voltage dc (HVDC) transmission systems [3].

Modular multilevel converters (MMC) are a subfamily of multilevel converters which have additional features such as the option of a transformerless operation, a completely modular design, and a common DC-bus [4], [5]. The MMC was invented by Prof. R. Marquardt in 2001 [6]. Pioneering publications propose this converter as an interface between a three-phase and a single-phase systems, proposing the use of space vector modulation and a method for the capacitor design [7]. This converter has also been proposed for traction applications with a medium frequency transformer in [5], where technological aspects of the converter were addressed. The first reported prototype was implemented using the latter configuration [8]. Early publications describe an open-loop control strategy based on imposed modulation indices calculated by the required input and output voltages [5]. A closed-loop control strategy was published only a few years later [9]. During the last years, several alternative topologies, models, modulation techniques, and control schemes have been proposed for this converter [10], [11]. Furthermore, they have also attracted the attention of industry, being currently developed as a solution for HVDC transmission by four main vendors [12]–[15], as well as for MVD [16].

### II. MODULAR MULTILEVEL CONVERTER TOPOLOGIES AND MODELING

The main feature of MMCs is the cascaded connection of a large number of power cells. These cells are arranged in groups called arms, or branches, which can be connected in several configurations as shown in Fig. 2. In this figure, the interconnection of the arms between the input and output terminals is visible. Depending on the cell topology, as can be seen in next sections,

IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 26, NO. 11, NOVEMBER 2011

3139

## Classification, Terminology, and Application of the Modular Multilevel Cascade Converter (MMCC)

Hirofumi Akagi, *Fellow, IEEE*

**Abstract**—This paper discusses the modular multilevel cascade converter (MMCC) family based on cascade connection of multiple bidirectional chopper cells or single-phase full-bridge cells. The MMCC family is classified from circuit configuration as follows: the single-star bridge cells (SSBC), the single-delta bridge cells (SDBC), the double-star chopper cells (DSCC), and the double-star bridge cells (DSBC). The term MMCC corresponds to a family name in a person while, for example, the term SSBC corresponds to a given name. Therefore, the term "MMCC-SSBC" can identify the circuit configuration without any confusion. Among the four MMCC family members, the SSBC and DSBC are more practical in cost, performance, and market than the others although a distinct difference exists in application between the SSBC and DSBC. This paper presents application examples of the SSBC to a battery energy storage system (BESS), the SDBC to a static synchronous compensator (STATCOM) for negative-sequence reactive-power control, and the DSBC to a motor drive for fans and blowers, along with their experimental results.

**Index Terms**—Battery energy storage, modular structure, motor drives, multilevel converters.

### I. INTRODUCTION

SINCE the middle of the 1990s, Robicon Corporation, presently a part of Siemens, has put a medium-voltage high-power motor drive with a multilevel pulsewidth modulation (PWM) inverter into practical use [1]. The emergence of this motor drive surprised and impressed research scientists and engineers who were engaged in research and development of medium-voltage motor drives. The per-phase circuit configuration of the multilevel inverter is based on cascade connection of the ac output terminals of modular single-phase full-bridge or "H-bridge" inverter cells. However, it requires a complicated multivinding phase-shifted line-frequency transformer for delivering electric power to all the floating H-bridge inverter cells. Before such a medium-voltage high-power motor drive was brought to the market, a few pioneering papers on the "modular multilevel structure" had been presented and published, taking the form of a single-phase circuit for plasma stabilization [2] and a three-phase circuit for motor drives [3].

Manuscript received February 9, 2011; accepted April 3, 2011. Date of current version November 18, 2011. Recommended for publication by Associate Editor A. Merten.

The author is with the Department of Electrical and Electronic Engineering, Tokyo Institute of Technology, Tokyo 152-8552, Japan (e-mail: akagi@ee.titech.ac.jp).

Color versions of one or more of the figures in this paper are available online at <http://ieeexplore.ieee.org>.

Digital Object Identifier 10.1109/TPEL.2011.2143431

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In the middle of the 1990s, Lai and Peng presented a static synchronous compensator (STATCOM) for reactive-power control, which is based on cascade connection of modular H-bridge converter cells with star-case modulation (SCM) [4], [5]. It was followed by a battery energy storage system (BESS) with SCM for motor drives [6]. These are characterized by eliminating the complicated multivinding phase-shifted line-frequency transformer from the power conversion systems.

Maquardt and coauthors presented another power conversion circuit referred to as a "modular multilevel converter" and its basic operating principle [7], [8]. Although the circuit configuration of each arm was described in [9], research has been conducted on the viability and effectiveness of the modular multilevel converter intended for applications to HVDC and back-to-back (B2B) systems [10], [11]. However, the sound of the modular multilevel converter makes it impossible for the beginners of power electronics to distinguish the circuit configuration from the others because the terms "modular" and "multilevel" do not have enough information to identify the circuit configuration. Moreover, it is reasonable to call the modular multilevel converter as a "cascade multilevel converter" because the converter is based on cascade connection of the lower dc voltage terminals of modular bidirectional choppers. Of course, it is allowable to use the term "modular multilevel converter" as a proper noun.

On the other hand, the multilevel inverter developed and commercialized by Robicon Corporation is referred to as a "cascade multilevel inverter," a "series-connected H-bridge multilevel inverter," or a "chain-link multilevel inverter" at present. That is, different manufacturers use different names, the trade names. However, the multilevel inverter can be considered as a "modular multilevel inverter" because it is one of the modular multilevel inverters based on modular H-bridge cells. This may lead to the following confusion: when a power electronics engineer uses either "modular multilevel converter" or "cascade multilevel converter" in his/her technical paper/article or presentation, the other engineers cannot identify the circuit configuration or may have a misunderstanding about it in the worst case.

This paper classifies the modular multilevel cascade converter (MMCC) family, the name of which merges both terms "cascade multilevel converter" and "modular multilevel converter" together [12]. The author gives appropriate names to the four family members with focus on circuit configuration, thus resulting in identifying the individual circuit configurations. Then, this paper makes a detailed description of comparisons among the four members in terms of circuit configuration, circulating current, and application. Finally, this paper has an intensive discussion on applications of these promising family members, the

of data signals  
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waveforms  
elements

phase  $k$  ( $k=a,b,c$ )  
power cell  $j$   
( $j=1,\dots,M$ )

Negative DC ca

$V_{j,}(V_{Ck,j} - V_{Ck,j}^*)$   
per arm

M. A. Perez, S. Bernet, J. Rodriguez, S. Kouro and R. Lizana, "Circuit Topologies, Modeling, Control Schemes, and Applications of Modular Multilevel Converters," in **IEEE Transactions on Power Electronics**, vol. 30, no. 1, pp. 4-17, Jan. 2015, doi: 10.1109/TPEL.2014.2310127.

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M. A. Perez, S. Bernet, S. Kouro, and R. Lizana are with the Departamento de Electrónica, Universidad Técnica Federico Santa María, Casilla 170-V, Chile (e-mail: marcelo.perez@ufsm.cl; jose.rodriguez@ufsm.cl; samir.kouro@ufsm.cl; ricardo.lizana@ufsm.cl).

S. Bernet is with the Professor-Lehrstuhl für Elektrische Maschinen, Technische Universität Dresden, Dresden 01062, Germany (e-mail: stefan.bernet@tu-dresden.de).

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Digital Object Identifier 10.1109/TPEL.2014.2310127

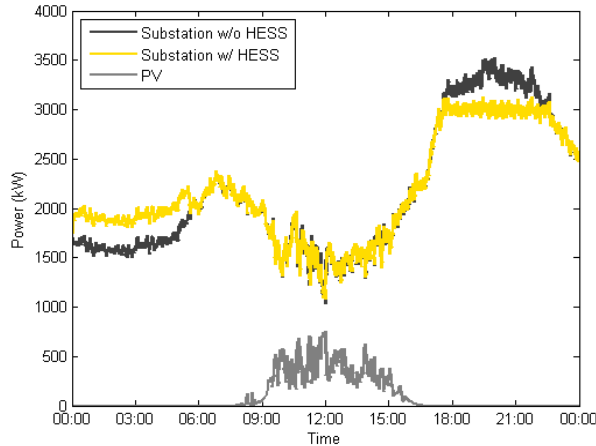
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## Necesidad de Almacenamiento de Energía

IEEE y Energías Renovables, una relación simbiótica  
Jose I. Leon - Univ. de Sevilla & Harbin Inst. Of Technology

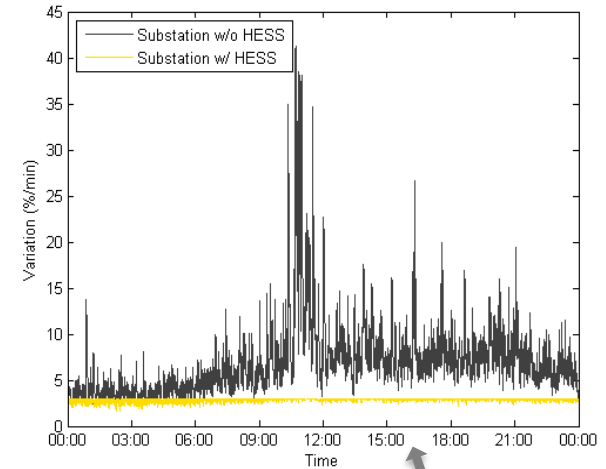
### Output power profile (kW)



### Peak shaving

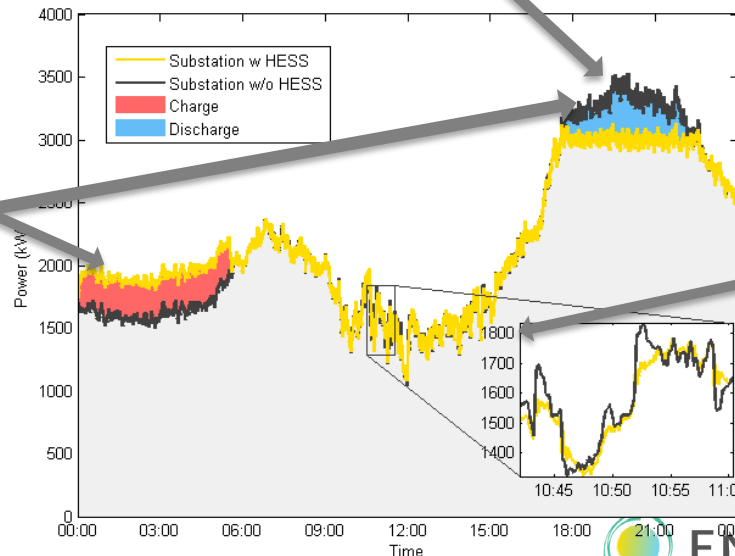
El almacenamiento de energía (ESS) permite suavizar los picos de demanda energética aliviando el estrés de las subestaciones eléctricas y ahorrar en las instalaciones necesarias

### Output power variation (%/min)



### Price arbitrage & Load following

El ESS se carga cuando la energía es más barata o cuando la demanda es baja, mientras que se descarga cuando es más cara o existe una demanda de energía



### Solar smoothing

El ESS es capaz de reducir la rampa de caída de la potencia de salida cuando existen eventos de sombreado en la instalación fotovoltaica

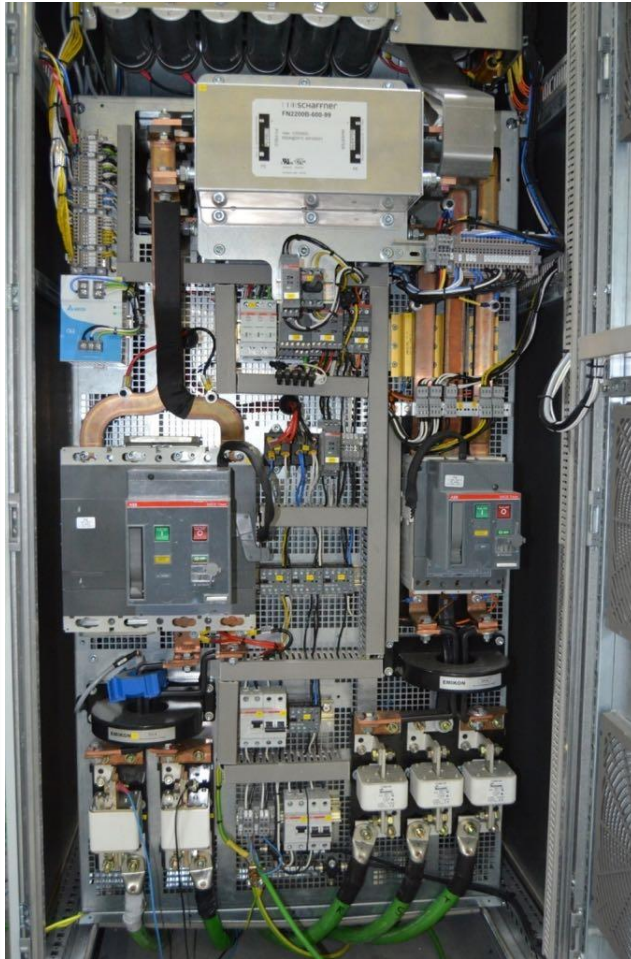




# Necesidad de Almacenamiento de Energía

IEEE y Energías Renovables, una relación simbiótica

Jose I. Leon - Univ. de Sevilla & Harbin Inst. Of Technology



**Location:** Gaston County, N.C. (USA)

**Site:** Rankin Substation

**Technology:** Ultracapacitor-Battery HESS

**Grid layer:** Distribution grid

**Services:** PV Intermittency Smoothing, Load Shifting

**Commissioned:** 02/15/16



W. Luo, S. Stynski, A. Chub, L. G. Franquelo, M. Malinowski and D. Vinnikov, "Utility-Scale Energy Storage Systems: A Comprehensive Review of Their Applications, Challenges, and Future Directions," in **IEEE Industrial Electronics Magazine**, doi: 10.1109/MIE.2020.3026169.

## Hybrid Energy Storage Systems

Concepts, Advantages, and Applications

JOSE I. LEON, EUGENIO DOMINGUEZ, LIGANG WU, ABRAHAM MARQUEZ, MANUEL REYES, and JIANQING LIU

Digital Object Identifier 10.1109/MIE.2020.3026169  
Date of current version: 17 December 2020

**E**nergy storage systems (ESSs) are the key to overcoming challenges to achieve the distributed smart energy paradigm and zero-emissions transportation systems. However, the strict requirements are difficult to meet, and in many cases, the best solution is to use a hybrid ESS (HESS), which involves two

or more ESS technologies. In this article, a brief overview of the HESS, highlighting its advantages for a wide range of applications, is addressed.

**Energy Storage is the Key**  
During the 20th and 21st centuries, economic and environmental issues have forced governments and industry to develop policies and R&D

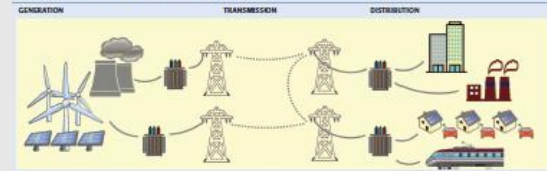


HESS enables peak shaving after reaching a predefined output power limit in order to relieve stress on the substation and allow a deferral of investment

- Substation w/ HESS
- Substation w/o HESS
- Charge
- Discharge

## Utility-Scale Energy Storage Systems

TABLE 3—ESS APPLICATIONS IN DIFFERENT UTILITY SUBSYSTEMS



A Comprehensive Review of Their Applications, Challenges, and Future Directions

WENSHENG LUO, SEBASTIAN STYNSKI, ANDRII CHUB, LEOPOLDO G. FRANQUELO, MARIUSZ MALINOWSKI, and DIMITRI VINNIKOV

Digital Object Identifier 10.1109/MIE.2020.3026169  
Date of current version: 4 January 2021

**C**onventional utility grids with power stations generate electricity only when needed, and the power is to be consumed instantly. This paradigm has drawbacks, including delayed demand response, massive energy waste, and weak system controllability and resilience. Energy storage systems (ESSs) are effective tools to solve these problems, and they play an essential role in the development of the smart and green grid. This article discusses ESSs applied in utility grids.

### The Modern Grid

Existing utility grids were built many decades ago and without facilities for convenient and efficient power storage. This implies that electricity is produced when it is needed and must be immediately consumed. The consequences of this paradigm include

1) delayed demand response due to the large grid inertia and 2) massive energy waste caused by the mismatch between the power that is supplied and the power that is consumed. Moreover, the conventional utility grid is liable to instability in the face of large and sudden variations in the supply and the load, and the situation can become more challenging with the increasing penetration of renewable resources (RESs) [1]–[4].

Along with the development and application of ESSs, the utility grid is moving toward a new generation—the smart and green grid. Acting as an energy buffer, ESSs store extra electricity in the grid when production is higher than consumption, and the stored energy is fed back to the grid when production falls to meet demand. On the one hand, ESSs provide extra freedom for grid control, thus improving feasibility and smartness.

J. I. LEON, E. Dominguez, L. Wu, A. Marquez Alcaide, M. Reyes and J. Liu, "Hybrid Energy Storage Systems: Concepts, Advantages, and Applications," in **IEEE Industrial Electronics Magazine**, vol. 15, no. 1, pp. 74–88, March 2021, doi: 10.1109/MIE.2020.3016914.



# El siglo XXI: La revolución energética

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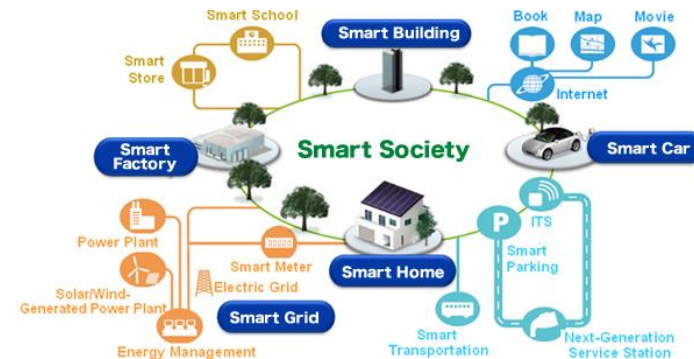


# En 25 años...

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- Vehículo eléctrico
- Uso intensivo de ESS
- Energía ¿GRATIS?
- Internet of Energy



NUCLEAR ENERGY



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