Institute of Electrical and Electronic Engineers

IEEE y la Energía Renovable

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

IEEE y Energías Renovables, una relación simbiótica
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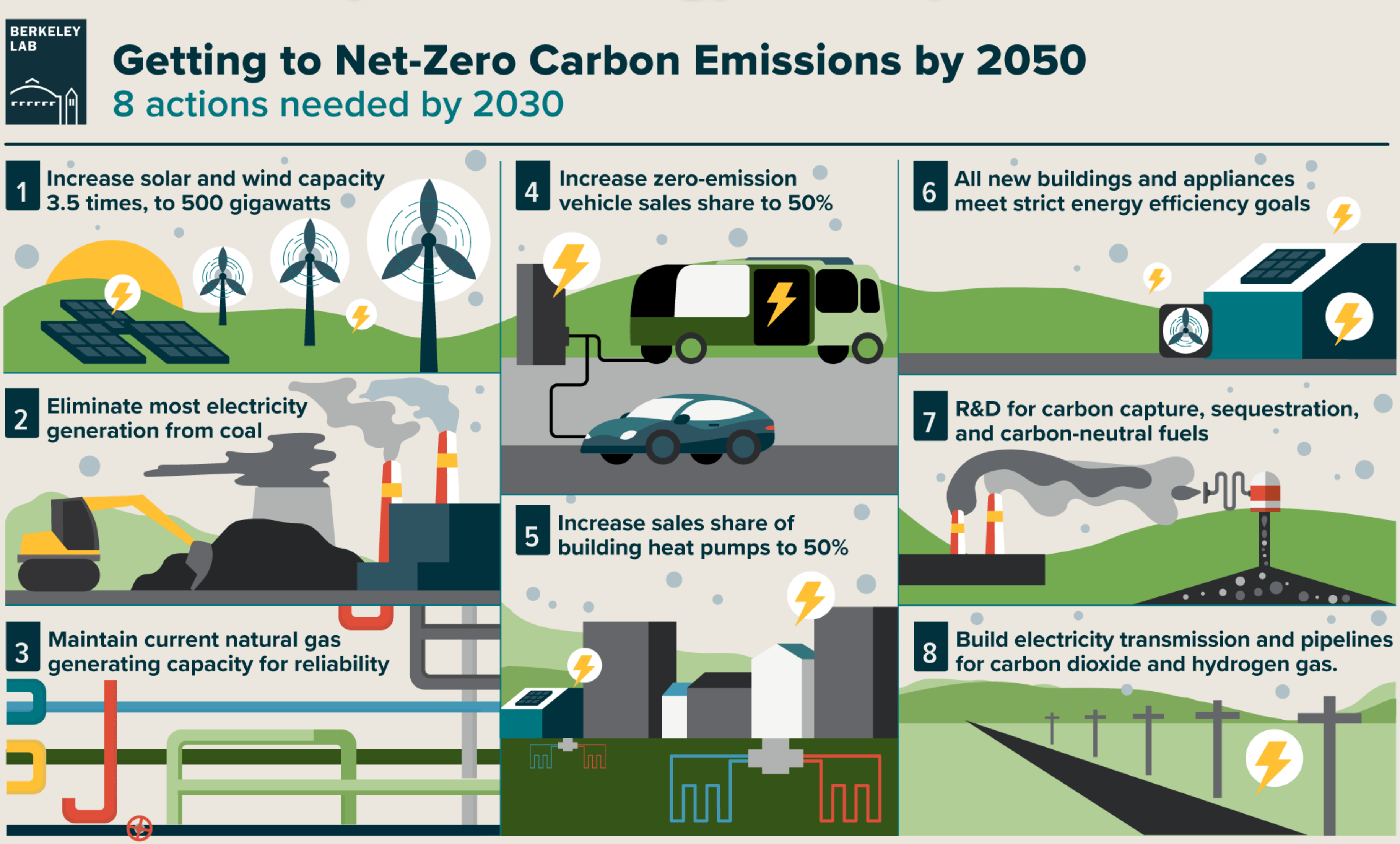
Introducción. Ventajas

Del pasado al futuro

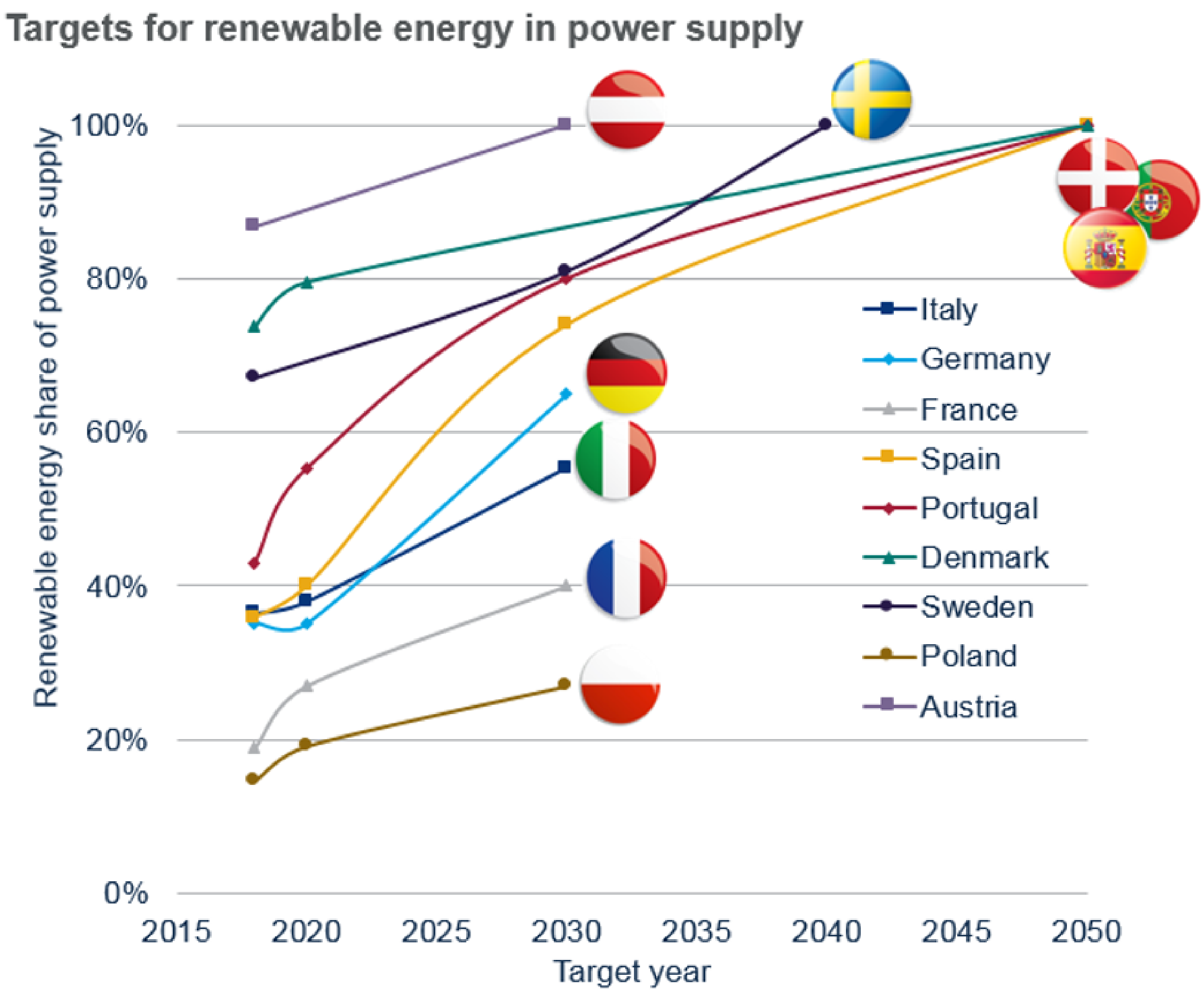
- Muy alta eficiencia comparando con los sistemas de potencia de décadas anteri…
- Convertidores de poten… prestacion… n…
- L… pe… po… muy alta eficiencia
- En … área de la distribución eléctrica, la electrónica de potencia permite mejorar la estabilidad de la red

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

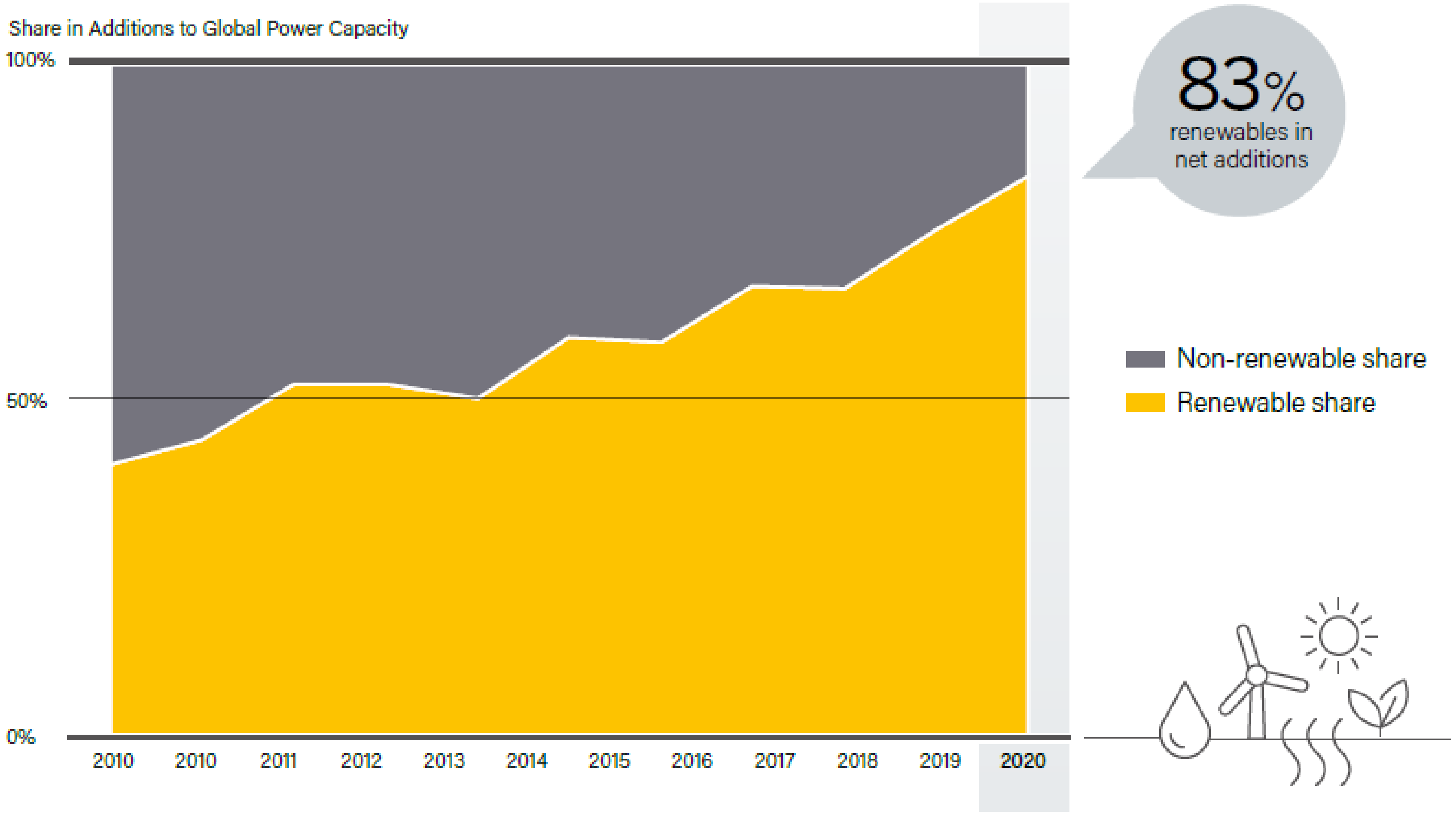
European Energy Policy. 2030-2050



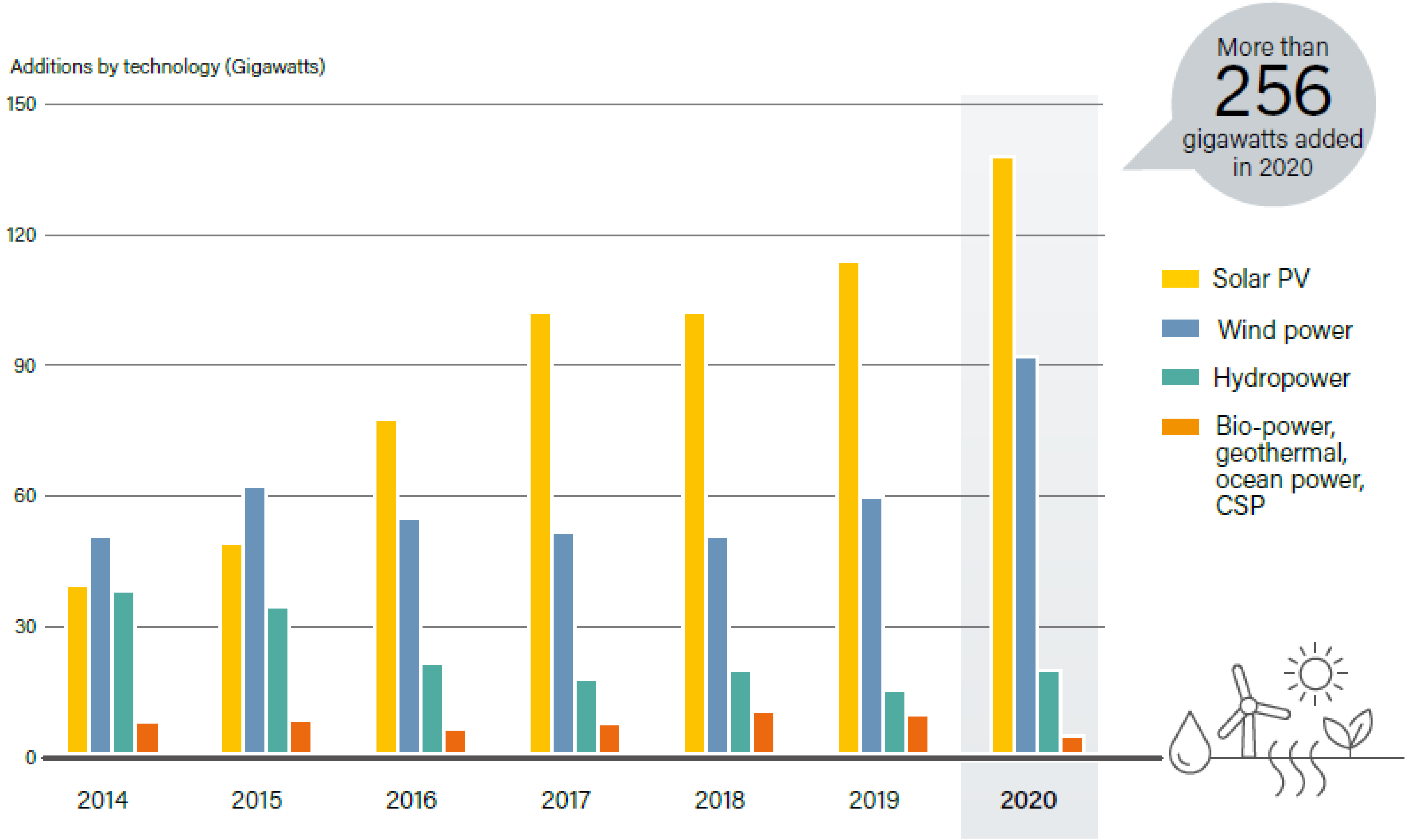
European Energy Policy. 2030-2050



Nuevas plantas de energía instaladas



Nuevas plantas de energía instaladas



REN21 Renewable Energy Policy Network for the 21st Century

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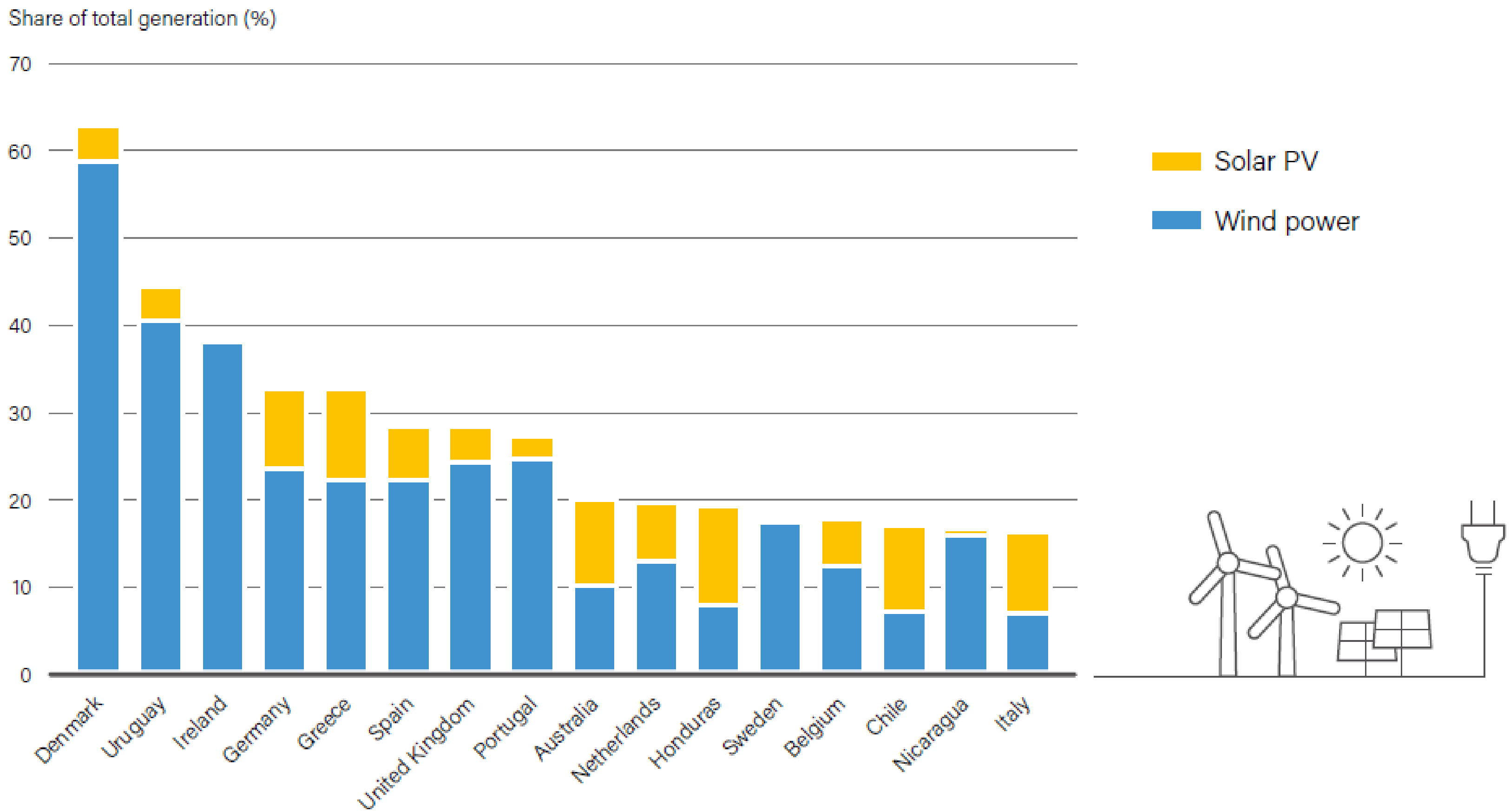
Penetración de energías renovables en 2020



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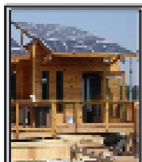
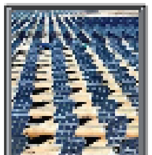
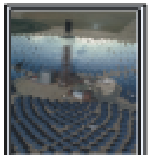
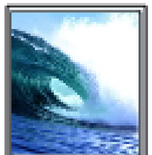
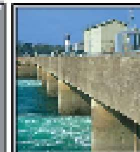
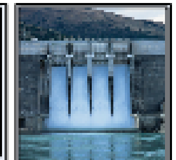
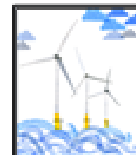
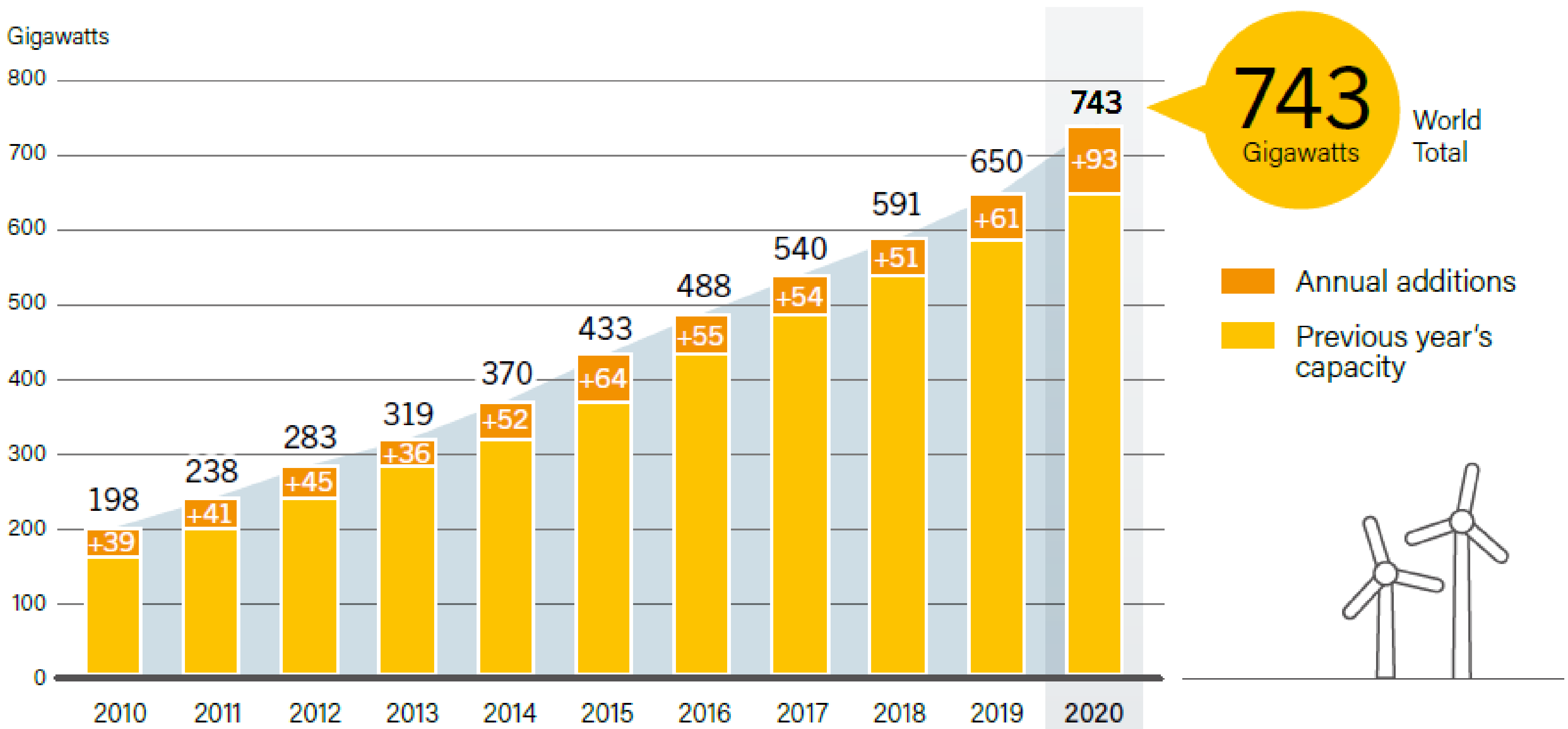
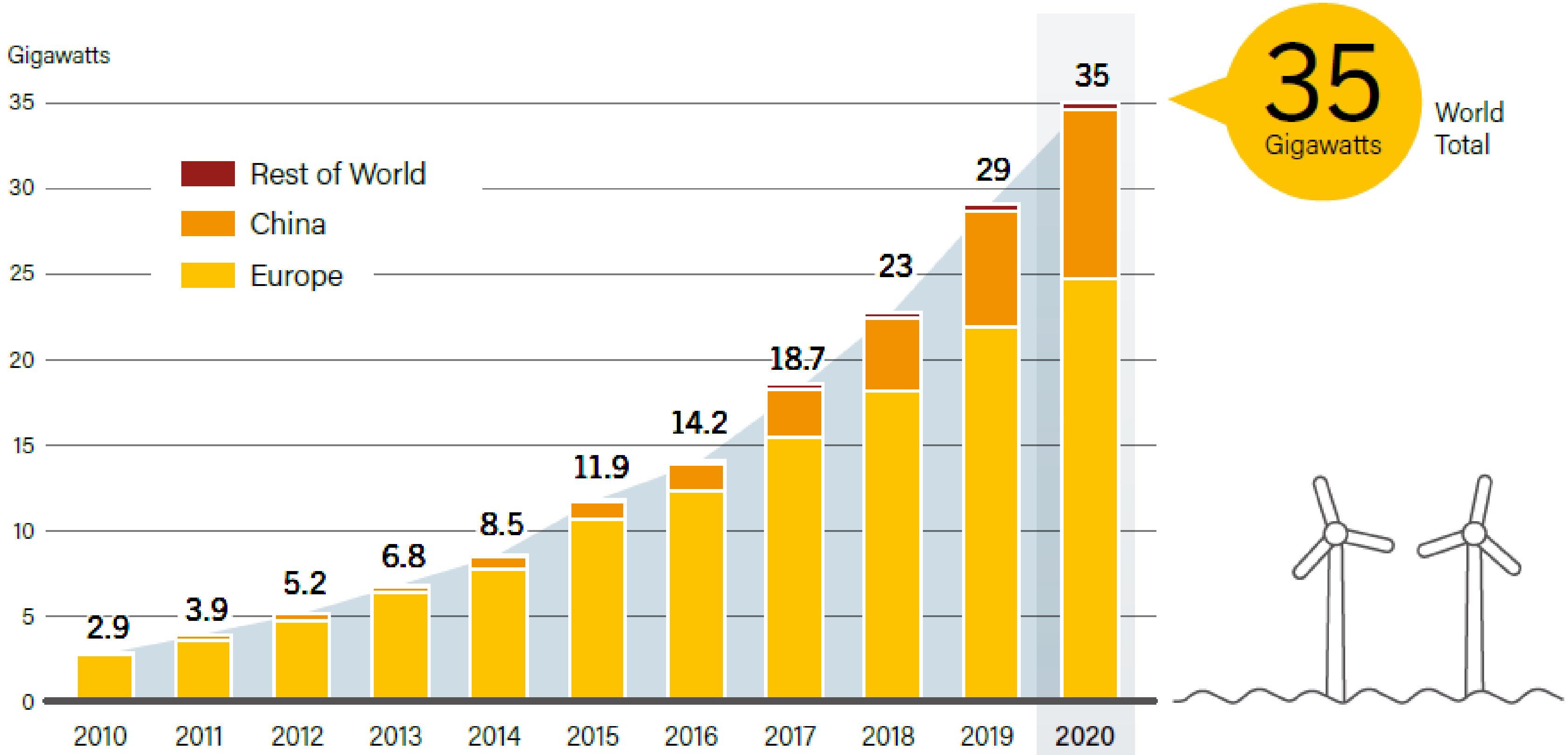
Tipos de Fuentes de Energía Renovable

	Housing applications		Solar Energy		Marine/Fluvial Energy			Wind Energy	Geothermal Energy
Renewable Energy Systems	 RoofPV	 Solar Thermal Roof	 PV Plants	 Solar Thermal	 Wave Energy	 Tidal Energy	 Hydroelectric	 Wind Energy	 Geothermal
Maximum nominal power	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
Usual converter topologies	DC/AC DC/DC	- -	DC/DC DC/AC	- -	AC/DC, DC/DC, DC/AC		-	Back-to-back	-
Typical power semiconductors	MOSFET	- -	IGBT IGCT	- -	IGBT, IGCT		-	IGBT IGCT	-
Availability	Solar irradiance dependance				Random	Intermittent	Seasonal	Intermittent	Constant
Technology trend	↑ Power Density ↑ Efficiency		↑ Nominal Power ↑ Efficiency		↑ Robustness Under Storms		-	Gearless, Offshore, ↑ Power	↓ Development cost

Instalaciones de Energía Eólica



Energía eólica offshore



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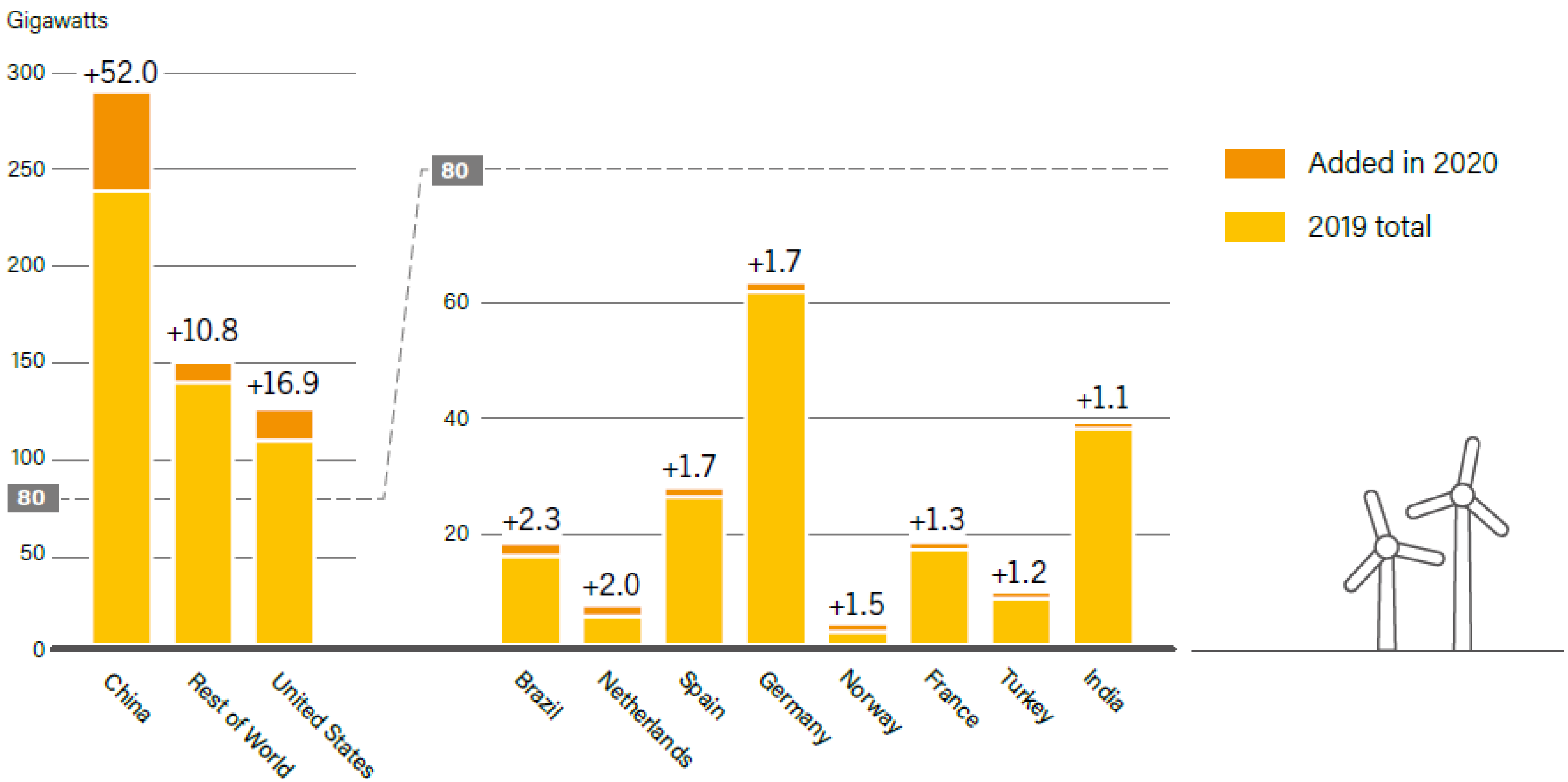
Nuevas instalaciones de energía eólica



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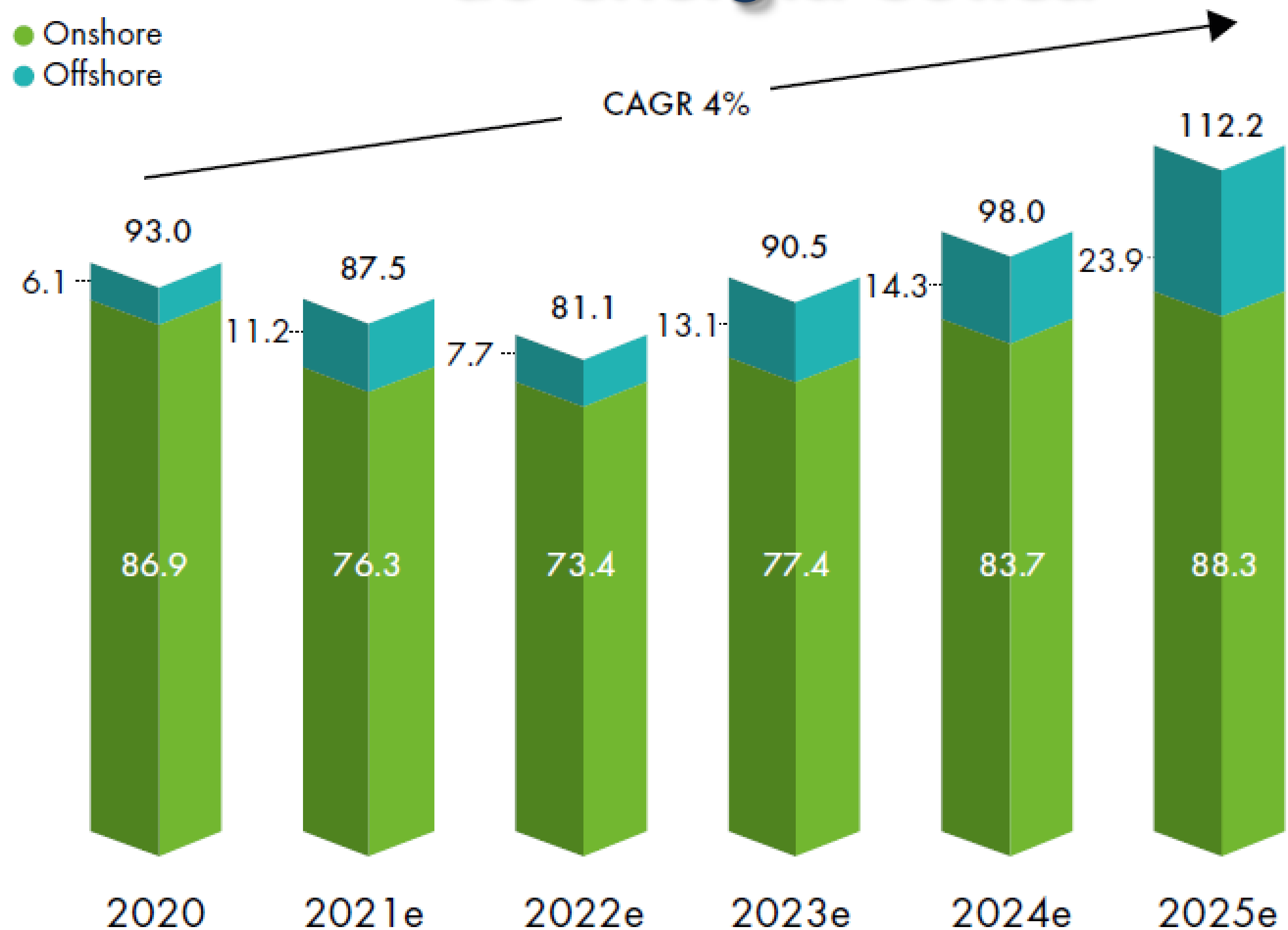
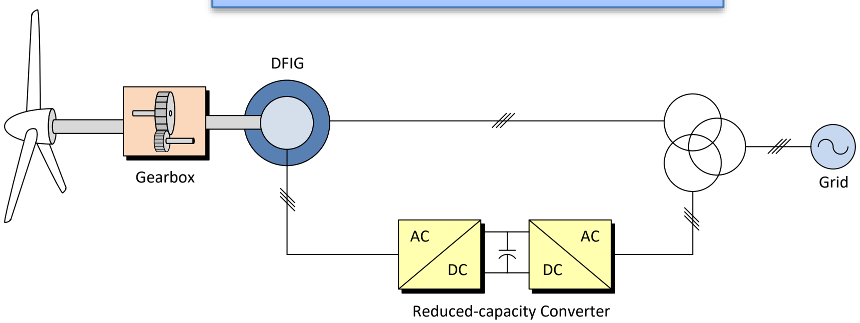
Predicción de nuevas instalaciones de energía eólica



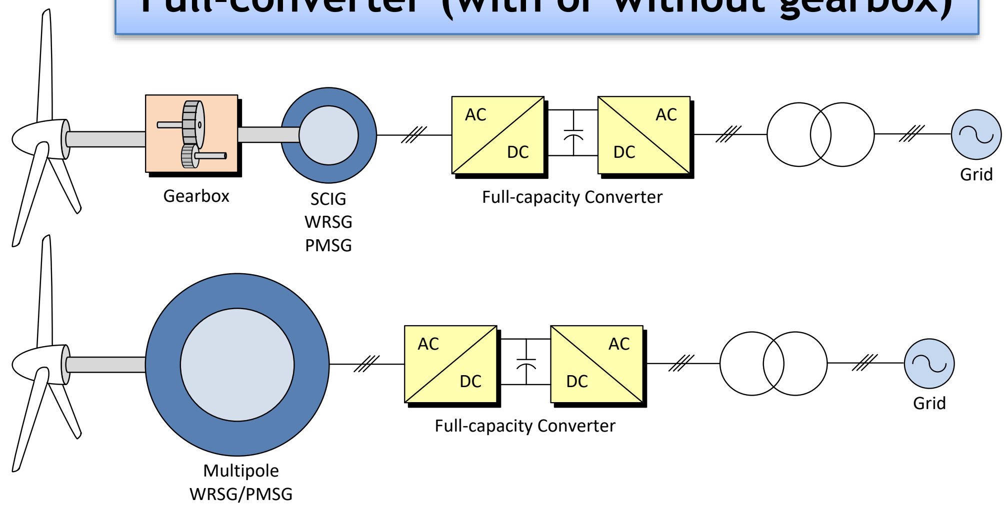
Fuente: GWEC Global Wind Report 2020

Sistemas de conversión de energía eólica

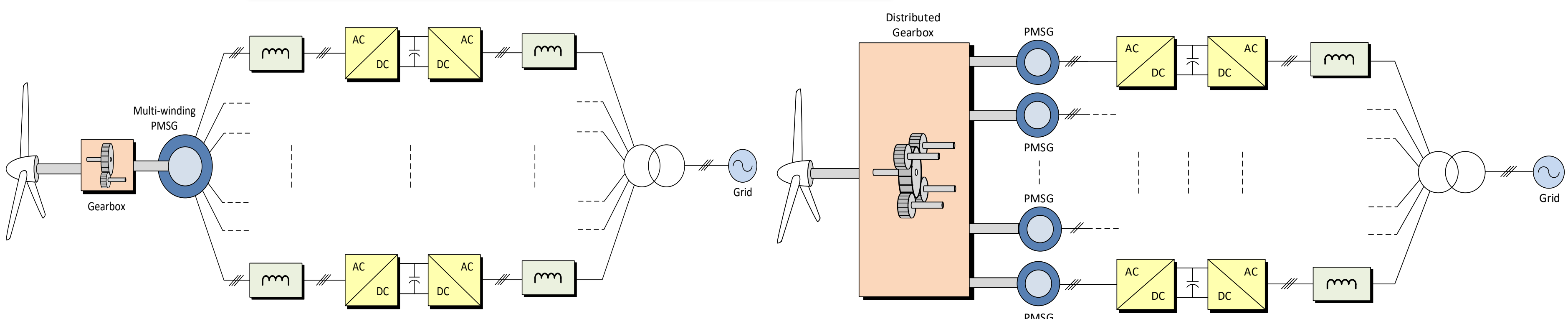
Doubly-fed converter



Full-converter (with or without gearbox)



Distributed back-to-back converters



Fuentes de Energía Renovable

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INVITED PAPER

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 wind 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 farm; 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].

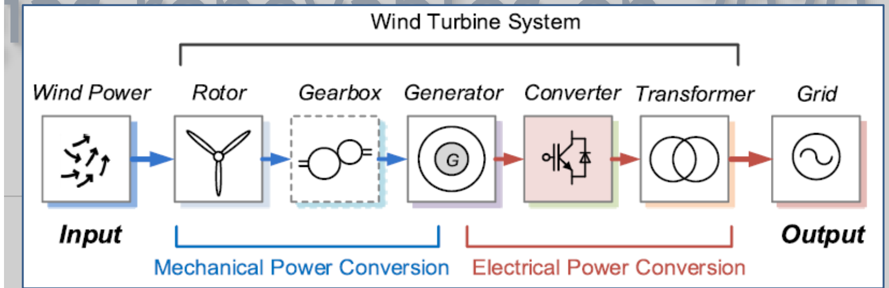
In the 1980s, the power electronics in wind turbines was simply a soft-starter, which is used to initially interconnect a squirrel-cage induction generator (SCIG) with the power grid when the wind turbine starts to produce power. Because power electronics did not need to carry power continuously, simple 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.

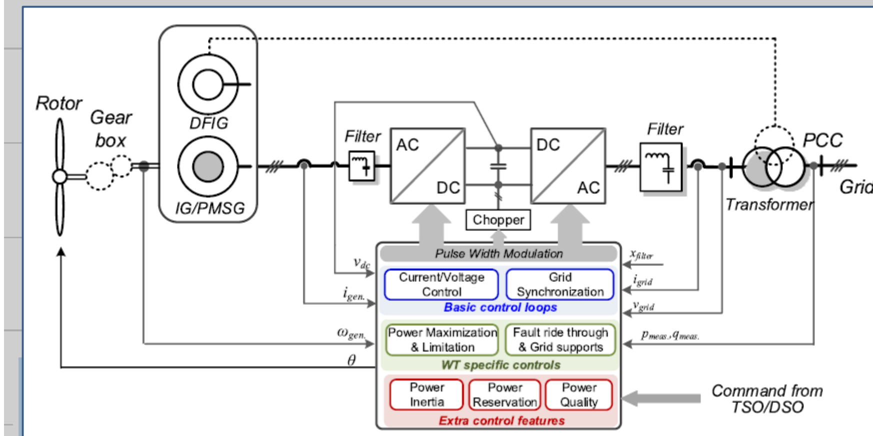
In the 1990s, power electronics technology was mainly used for rotor resistance control of wound-rotor induction generators (WRIGs), in which more advanced power electronics devices such as diode bridges and choppers were used to control the rotor resistance for the generator. In this solution, the rotational 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 turbines 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 (A/SGs) [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.

Manuscript received February 15, 2017; revised March 27, 2017; accepted March 28, 2017. Date of publication May 16, 2017; date of current version October 18, 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 Jiao Tong University, Shanghai, China (e-mail: kema@sjtu.edu.cn).

Digital Object Identifier 10.1109/JPROC.2017.2695485





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.

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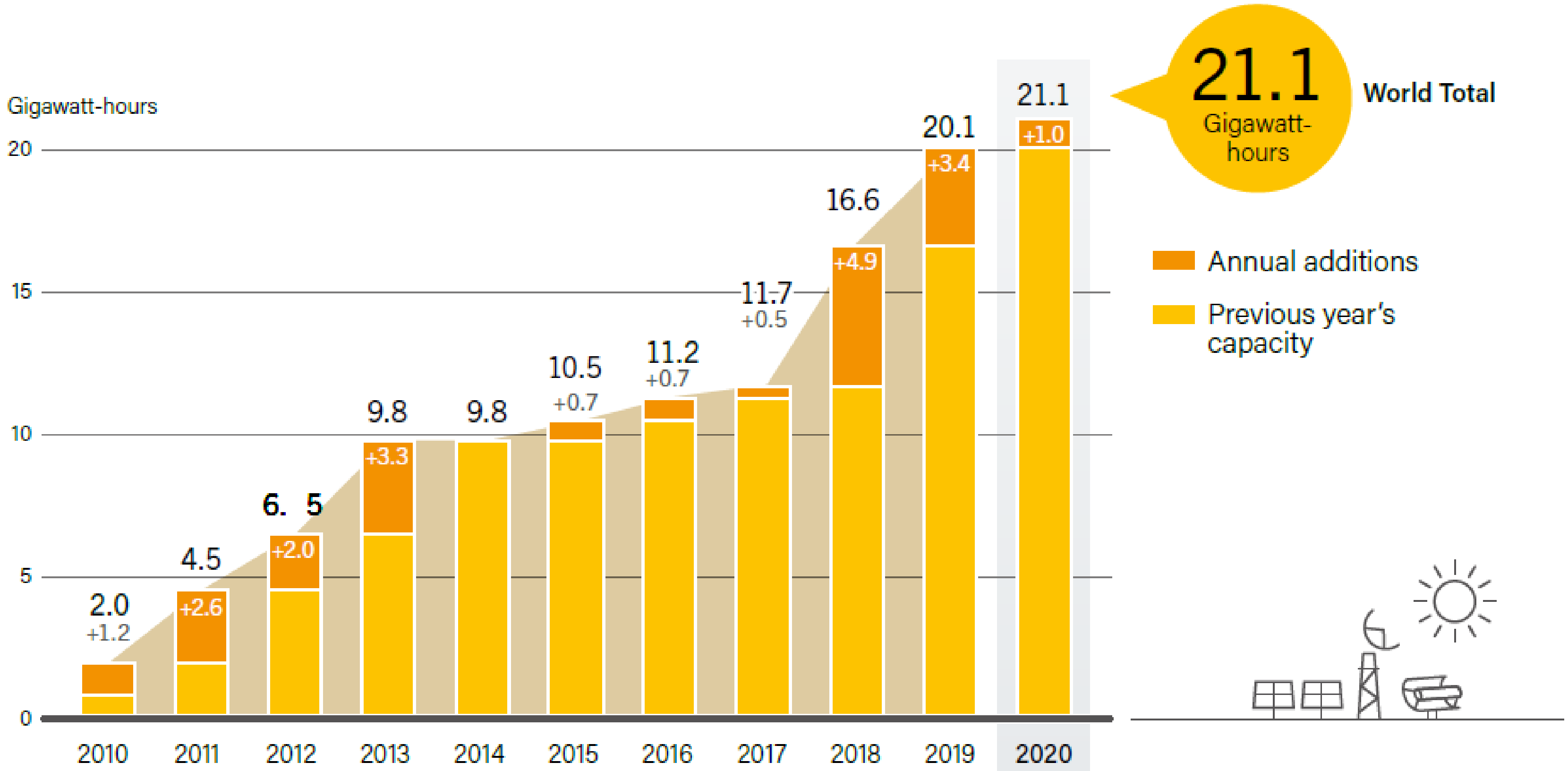
Concentrated solar power (CSP)
Potencia instalada



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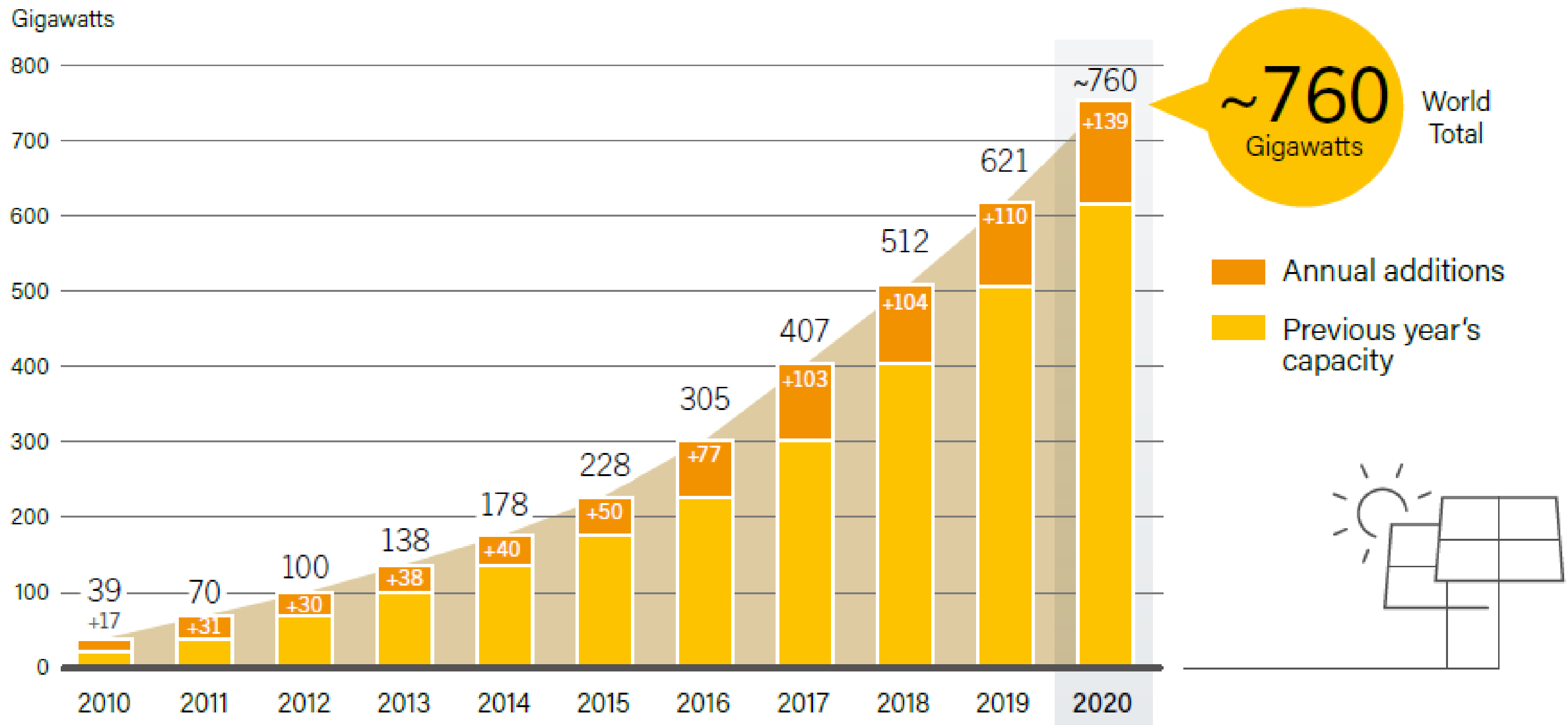
Solar Fotovoltaica
Potencia instalada



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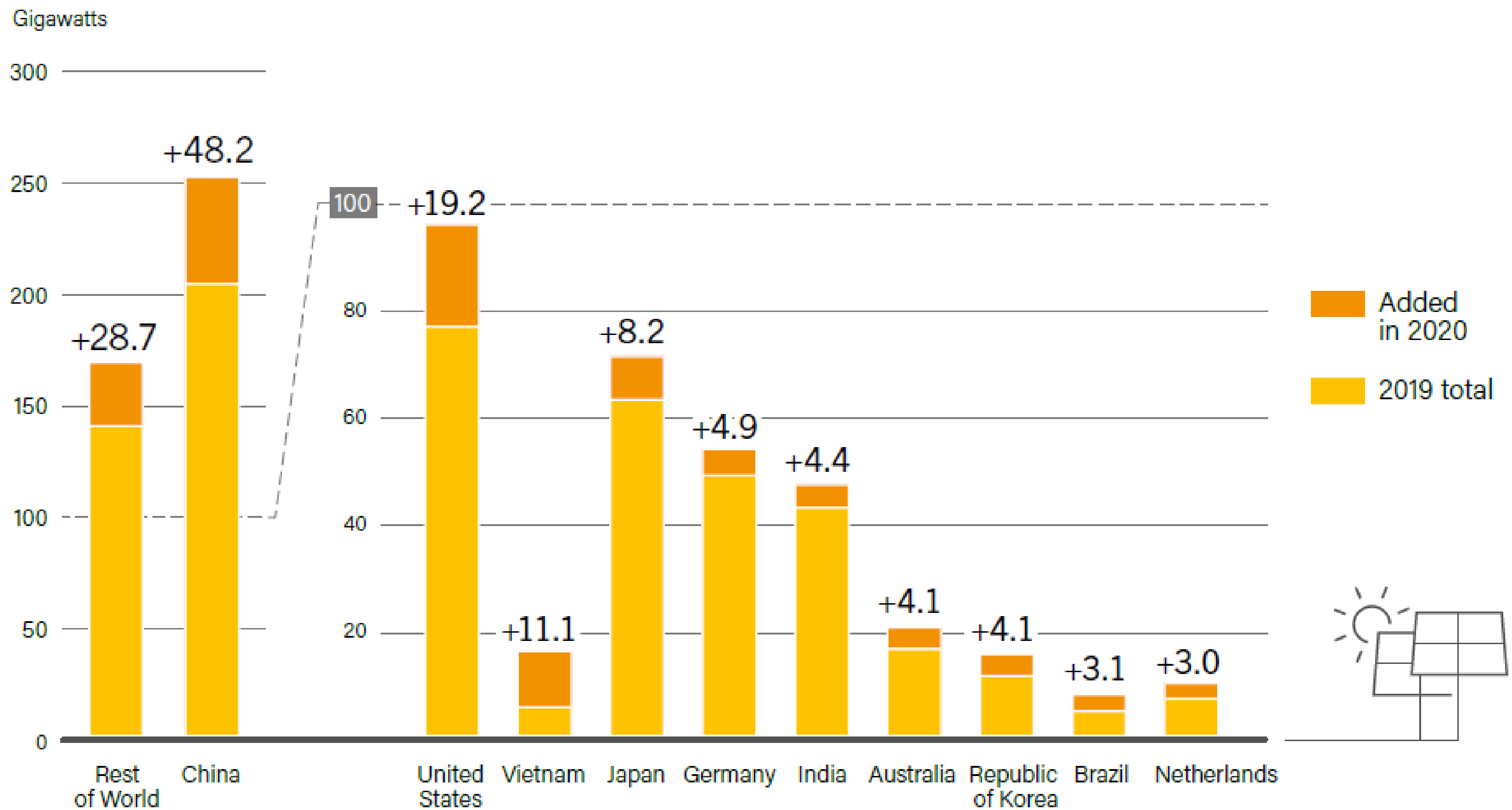
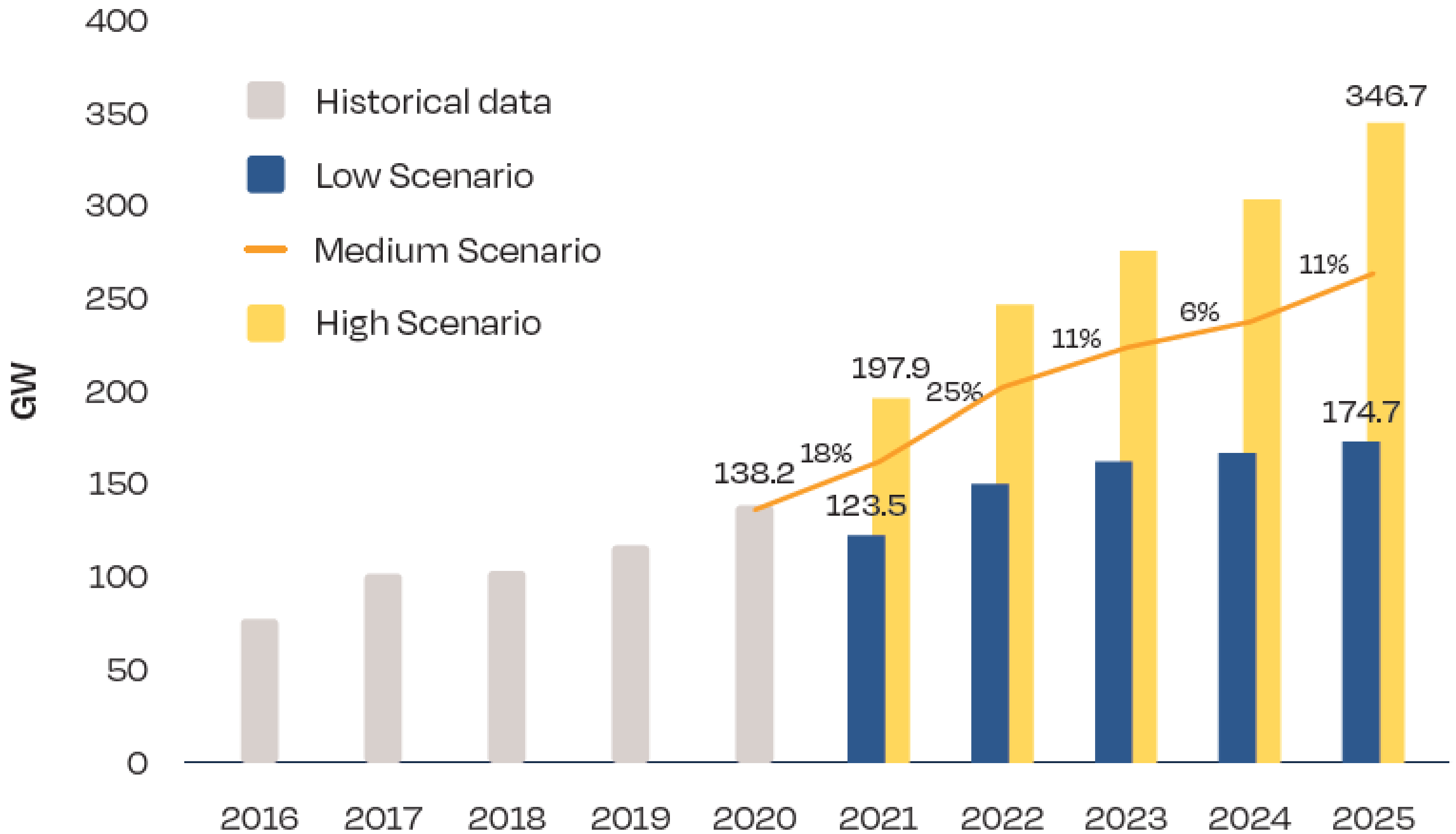
Nuevas instalaciones de solar fotovoltaica

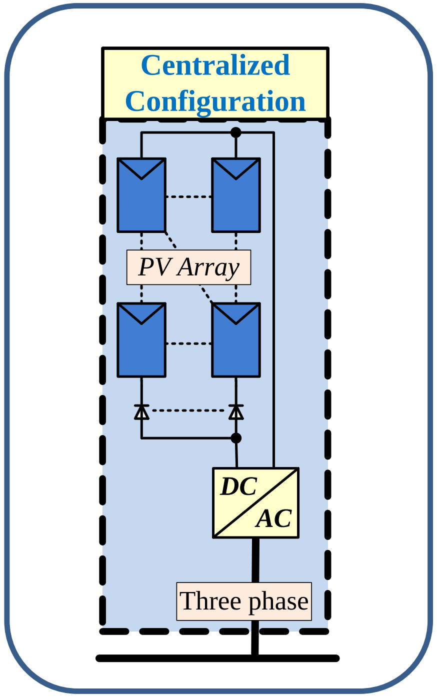


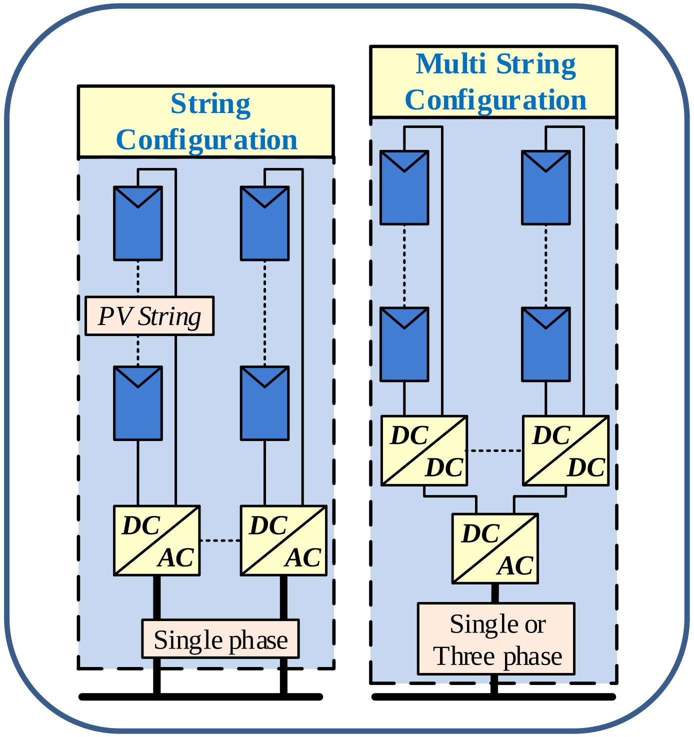
Predicción de nuevas instalaciones de solar fotovoltaica

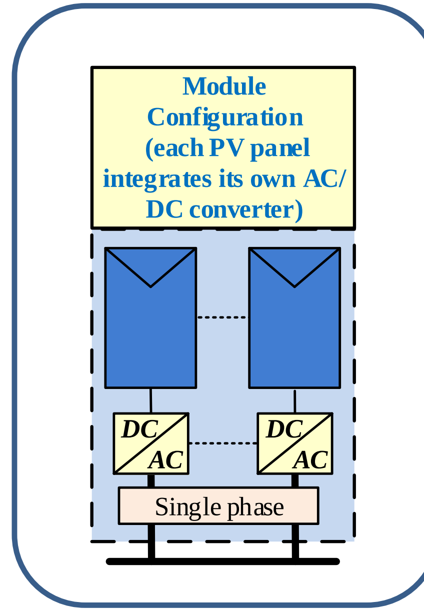


Fuente: Global Market Outlook for Solar Power 2020

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

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IEEE y Energías Renovables, una relación simbiótica

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INVITED PAPER

Solar Photovoltaic and Thermal Energy Systems: Current Technology and Future Trends

This paper reviews solar photovoltaic systems with solar cells and different topologies of power conversion systems.

By Mariusz Malinowski, *Fellow IEEE*, Jose I. Leon, *Fellow IEEE*, and Haitham Abu-Rub, *Senior Member IEEE*

ABSTRACT | Solar systems have become very competitive solutions for residential, commercial, and industrial applications for both standalone and grid connected operations. This paper presents an overview of the current status and future perspectives of solar energy (mainly photovoltaic) technology and the required conversion systems. The focus in the paper is put on the current technology, installations challenges, and future expectations. Various aspects related to the global solar market, the photovoltaic (PV) modules cost and technology, and the power electronics converter systems are addressed. Research trends and recommendations for each of the PV system sectors are also discussed.

KEYWORDS | Photovoltaic (PV) systems; renewable energy sources; solar power generation

I. INTRODUCTION

Currently, the reliable and resilient energy systems are based on fossil fuels burning which are still dominating worldwide. However, fossil fuels are nonrenewable and directly emit greenhouse gases to the environment. This has been leading to serious environmental and health impacts. Furthermore, the fluctuating price of the fossil fuels has serious impact on the energy security.

There are several alternative resources that can provide clean, continuous, and renewable energies such as hydropower, solar, wind, biomass, and geothermal. Nuclear energy is potential, however its use brings huge safety risks, therefore as this, it cannot be deemed as a clean or safe source.

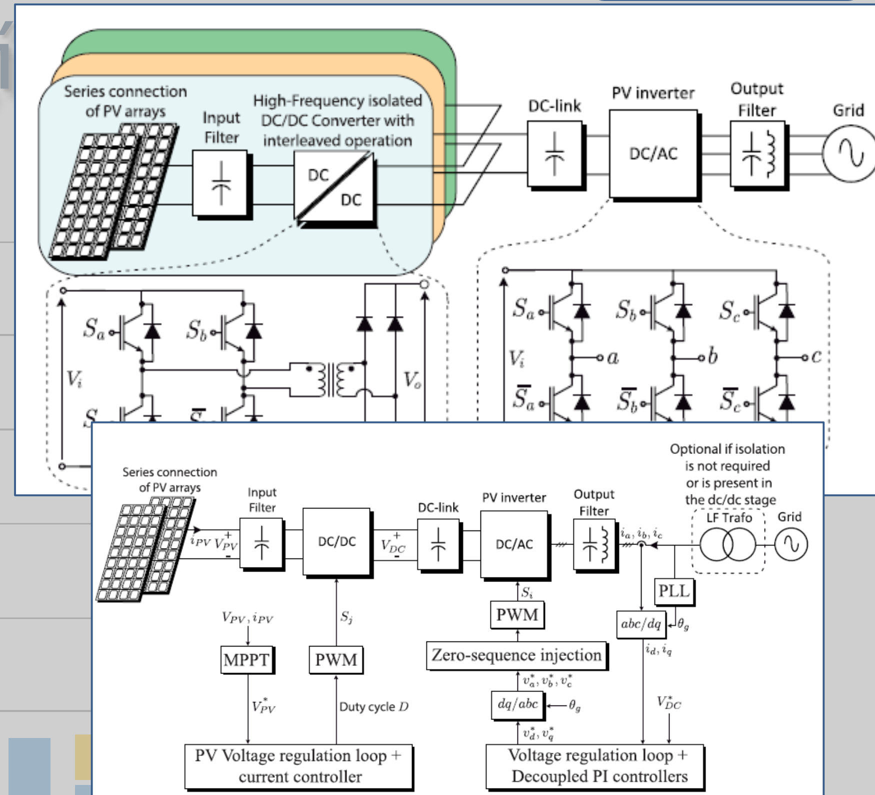
Renewable energy sources (RESs) are receiving significant attention worldwide as a sustainable alternative type of energy supply being an important sector of the global energy generation [1]. Renewable energies are expected to overtake coal around 2030 to become the largest power source and achieving 34% of total energy generation on 2040 as shown in Fig. 1 [2]. The renewable energy growth rate in different areas is increasing sharply with promising target as shown in Fig. 2.

RESs are clean and environmental friendly resources, hence they play an important role in reducing greenhouse gas emissions. Investing in RESs could help in reaching little to no global warming effects and gas emissions, which would help in improving public health and in protecting our environment [3]. This improves human life quality by providing enormous and inexhaustible energy supply, with more jobs, and other economic benefits such as stable energy prices. Wide spread of RESs has more benefits than aforementioned economic, health, and environmental aspects [4]. There are many political, social, and technical advantages of adopting renewable energies. Among those are: energy security and self-sufficiency, industry development, local ownership and public decision making, community building, and empowerment. Energy security is priceless; it justifies all efforts and expenditures being put for

Manuscript received January 30, 2017; revised March 26, 2017; accepted March 27, 2017. Date of publication April 28, 2017; date of current version October 18, 2017. This work was supported by the Qatar National Research Fund (a member of Qatar Foundation) under the NPRP-EP Grant [illegible], by the TEAM-TECH/2016-1/6 Project carried out within the TEAM-TECH program of the Foundation for Polish Science cofinanced by the European Union under the European Regional Development Fund, by the Andalusian Science and Innovation Project [illegible], and by the Spanish Science and Innovation Ministry under Project [illegible]. (Corresponding author: Mariusz Malinowski, e-mail: [illegible].)

M. Malinowski is with the Institute of Control and Industrial Electronics, Warsaw University of Technology, Warsaw, Poland.
J. I. Leon is with the Electronic Engineering Department, Universidad de Sevilla, Spain (e-mail: jileon@us.es).
H. Abu-Rub is with the Electrical & Computer Engineering Program, Texas A&M University at Qatar, Qatar (e-mail: [illegible]).

Digital Object Identifier 10.1109/JPROC.2017.2690343



M. Malinowski, J. I. LEON and H. Abu-Rub, "Solar Photovoltaic and Thermal Energy Systems: Current Technology and Future Trends," in ***Proceedings of the IEEE***, vol. 105, no. 11, pp. 2132-2146, Nov. 2017, doi: 10.1109/JPROC.2017.2690343.

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Fuentes de Energía Renovable

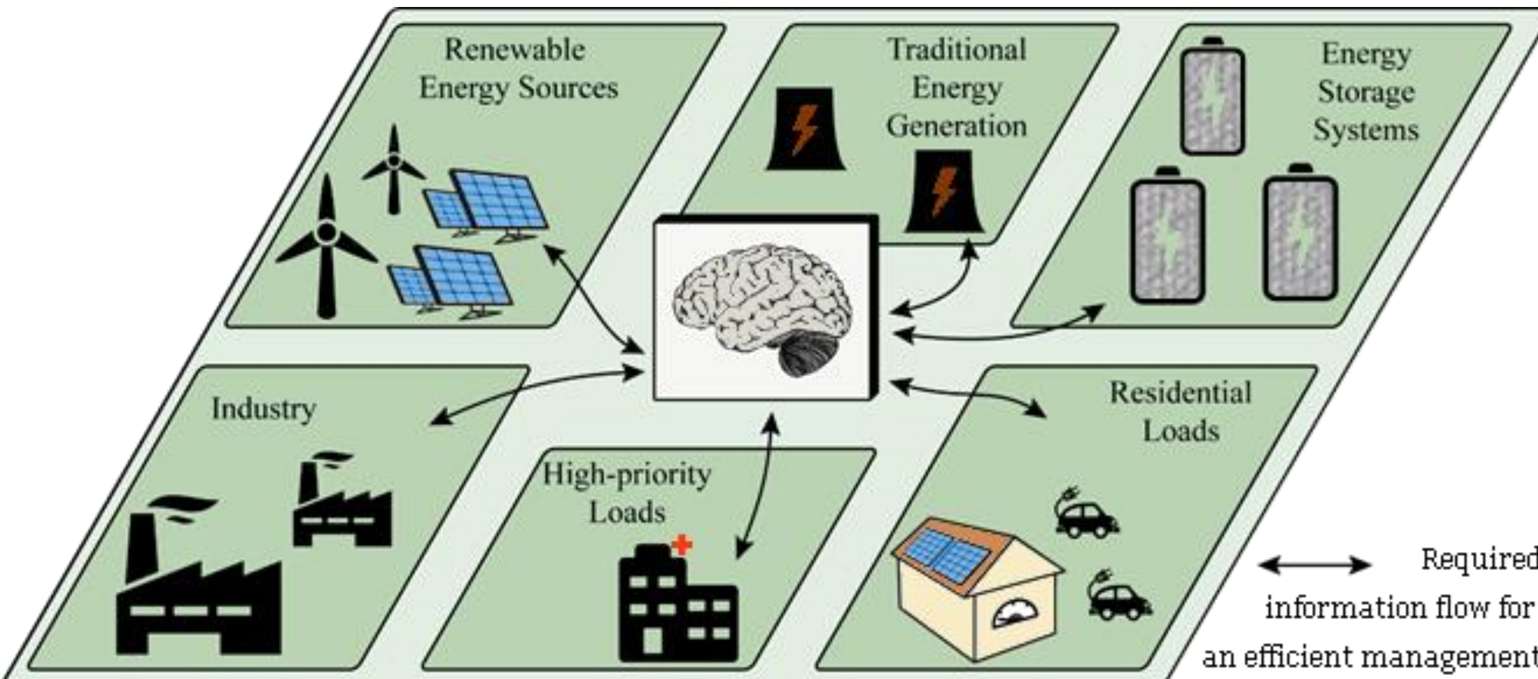
visión

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

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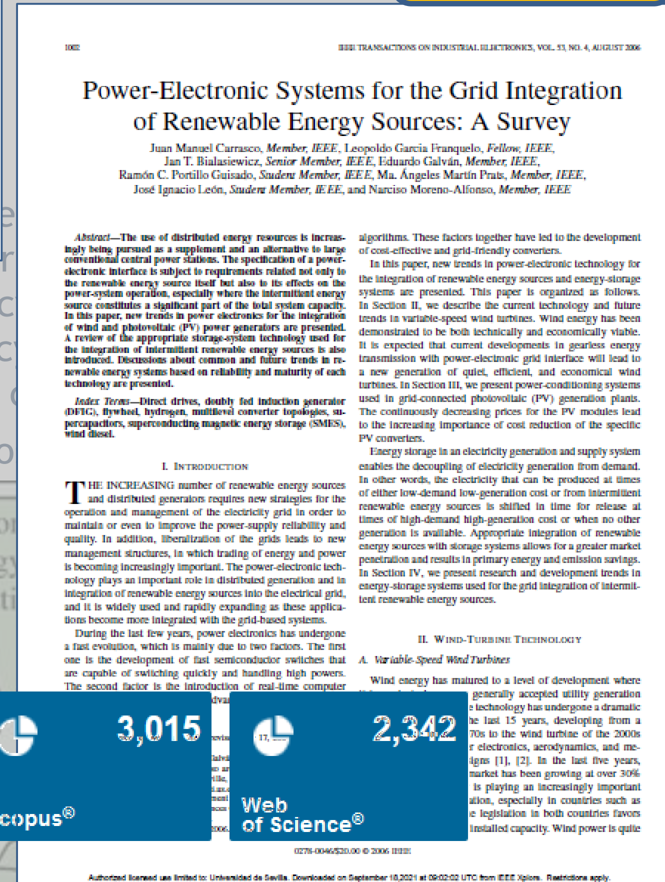
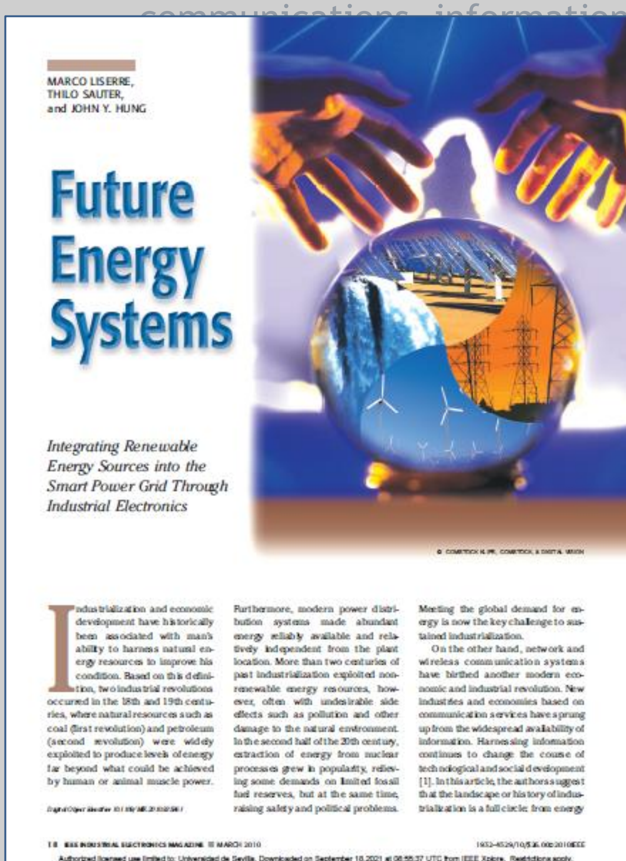
J. M. Carrasco et al., "Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey," in **IEEE Transactions on Industrial Electronics**, vol. 53, no. 4, pp. 1002-1016, June 2006, doi: 10.1109/TIE.2006.878356.





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.

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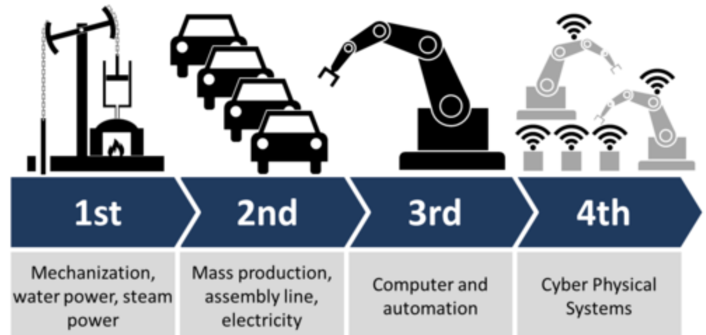
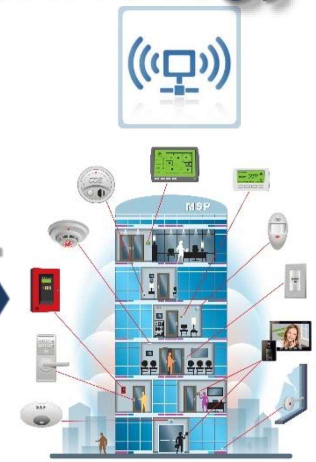
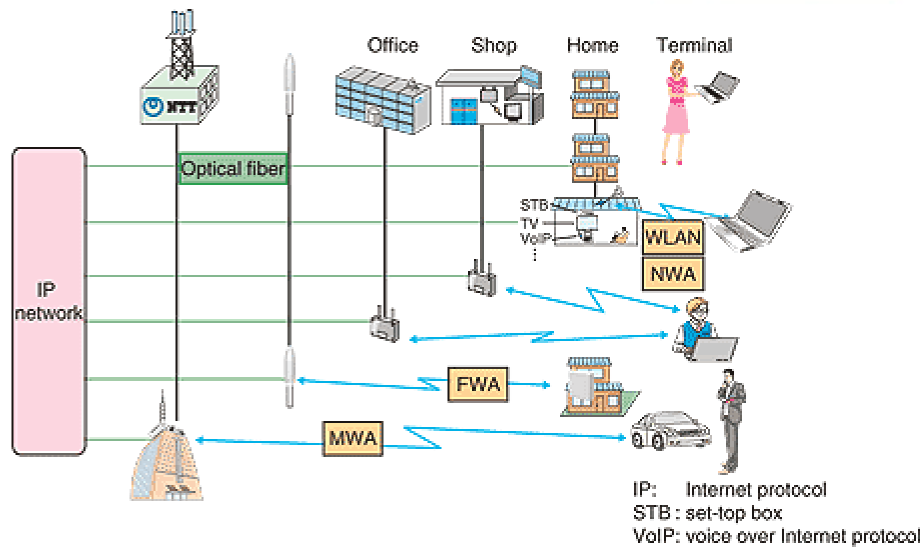
Information & Communications Technology





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



Retos de la Energía Renovable

IEEE

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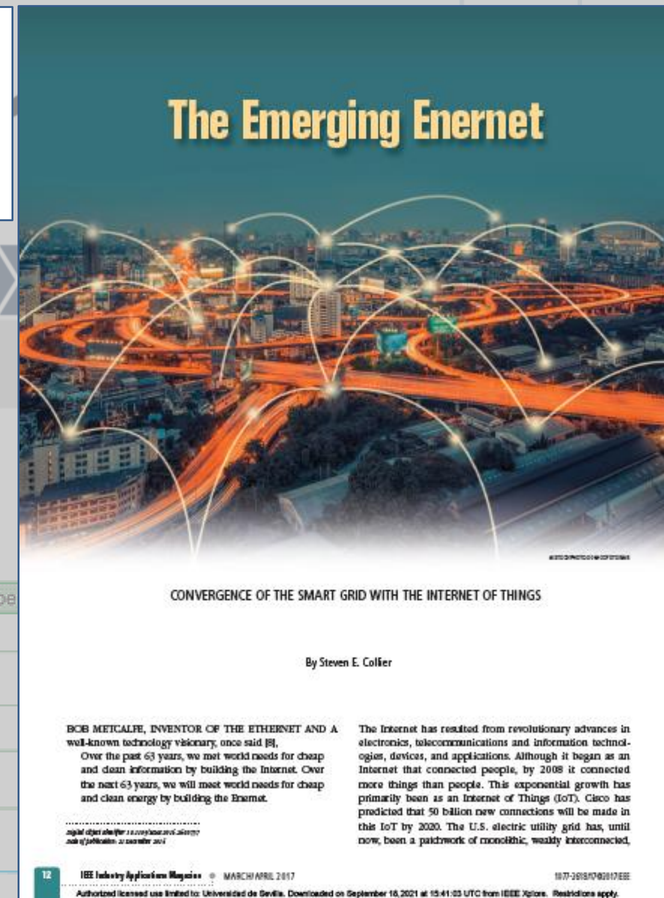
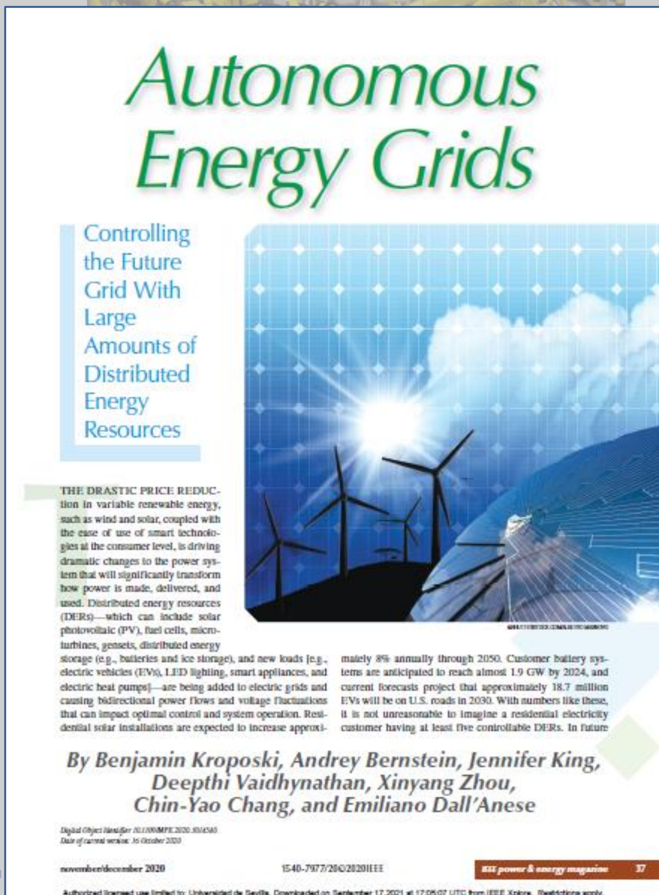
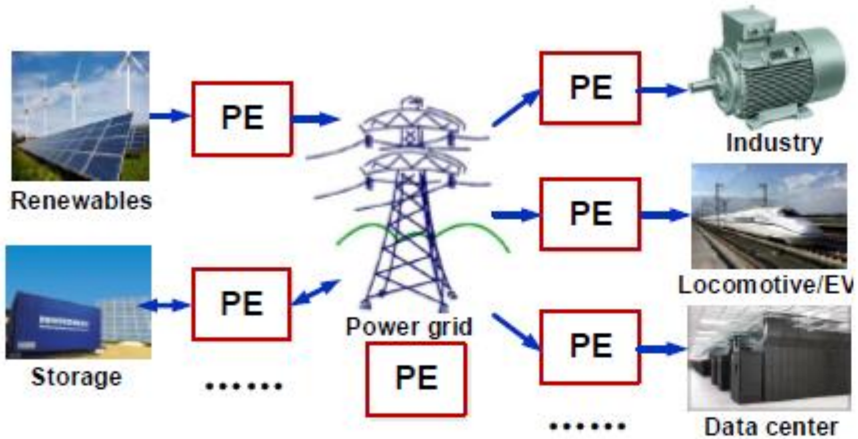




B. Kroposki et al., "Autonomous Energy Grids: Controlling the Future Grid With Large Amounts of Distributed Energy Resources," in **IEEE Power and Energy Magazine**, vol. 18, no. 6, pp. 37-46, Nov.-Dec. 2020, doi: 10.1109/MPE.2020.3014540.

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

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OPEX


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

Currently, 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

... grid paradigm with distributed energy storage systems [2]–[5]

- efficient and low-cost freight transportation based on electric vehicles, low-fuel-consumption cargo ships, and More Electric Aircraft [6]

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.

BEST PAPER AWARD 2020

+ O&M)/Tiempo en operación

ucción del coste de energía

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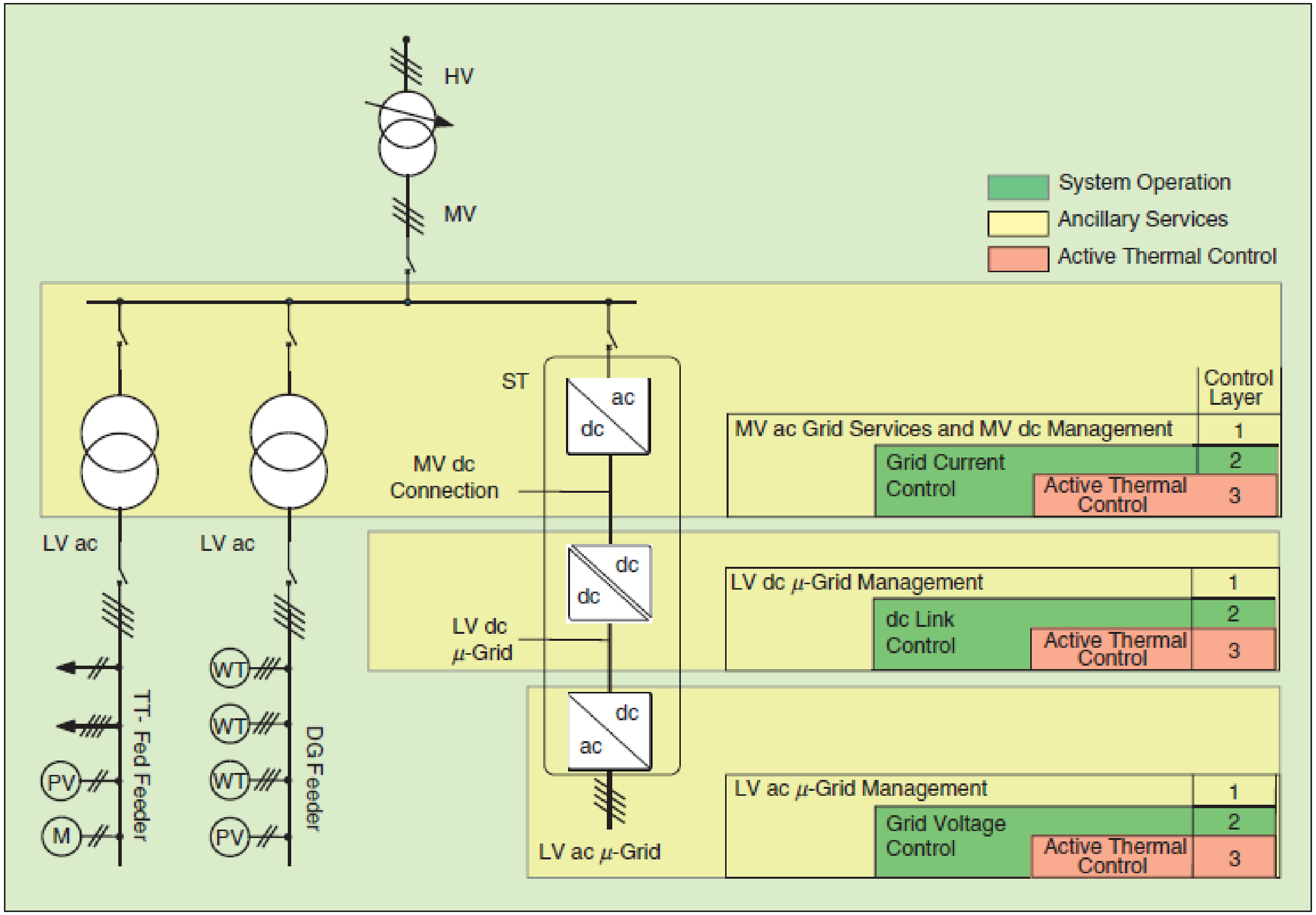
Smart Transformer como nodo de una Smart Grid



IEEE y Energías Renovables, una relación simbiótica
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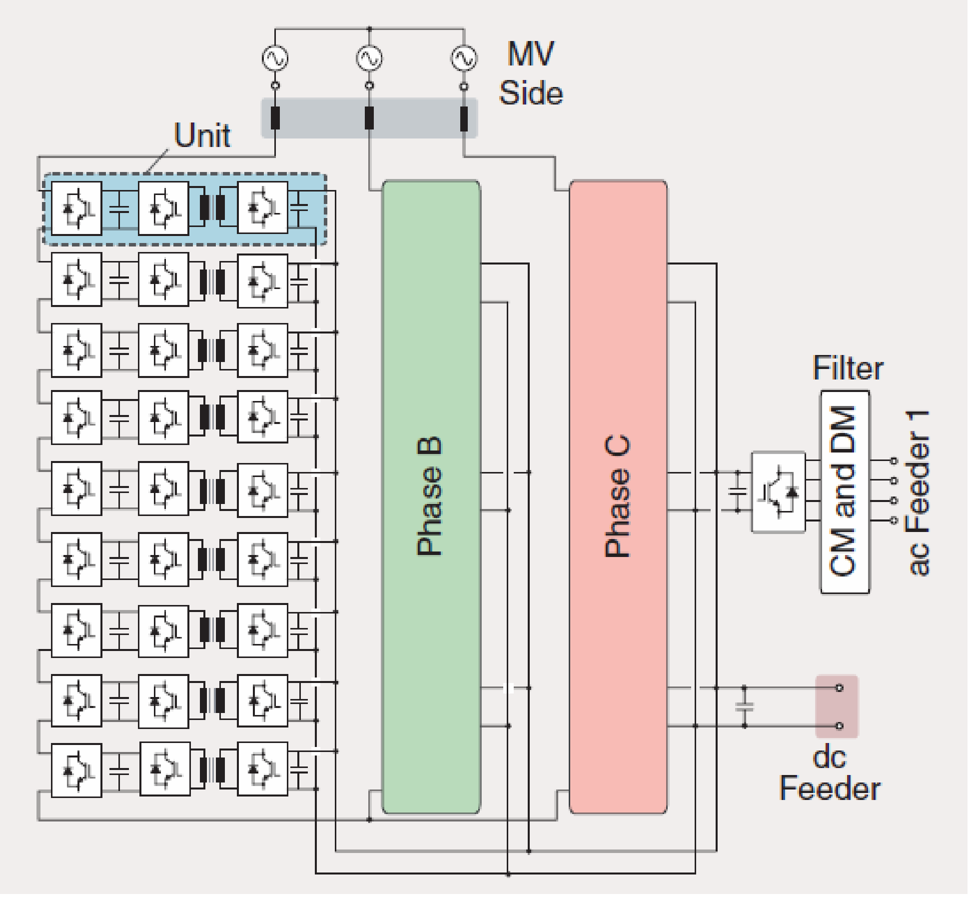
Smart Transformer como nodo de una Smart Grid



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

IEEE

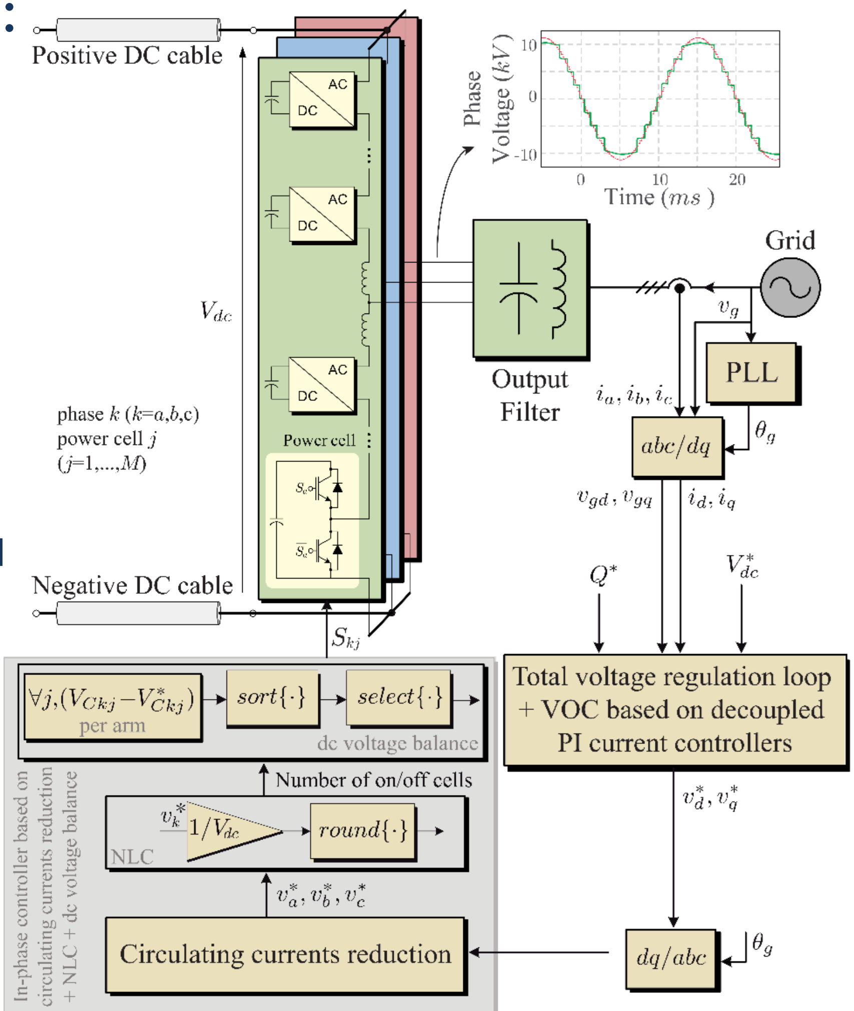
M. Liserre, G. Buticchi, M. Andresen, G. De Carne, L. F. Costa and Z. Zou, "The Smart Transformer: Impact on the Electric Grid and Technology Challenges," in **IEEE Industrial Electronics Magazine**, vol. 10, no. 2, pp. 46-58, June 2016, doi: 10.1109/MIE.2016.2551418.

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.

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



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Retos de la Energía Renovable

IEEE

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.

IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 26, NO. 11, NOVEMBER 2011 3119

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

Hirofumi Akagi, *Fellow, IEEE*

4 IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 30, NO. 1, JANUARY 2015

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*

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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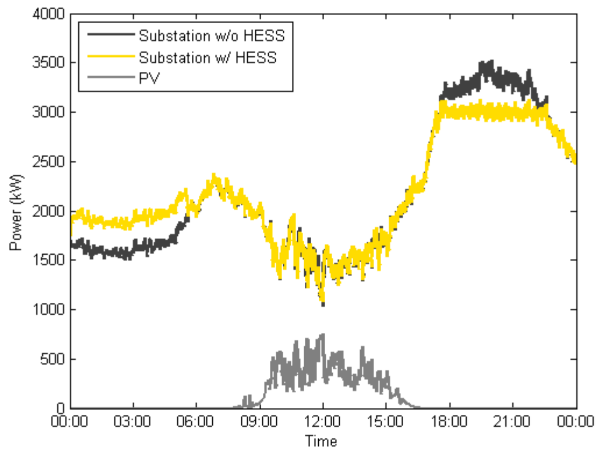
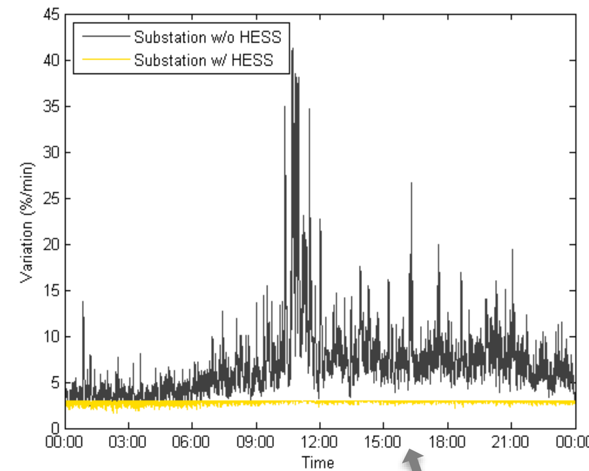
Necesidad de Almacenamiento de Energía

Output power profile (kW)



Output power variation (%/min)

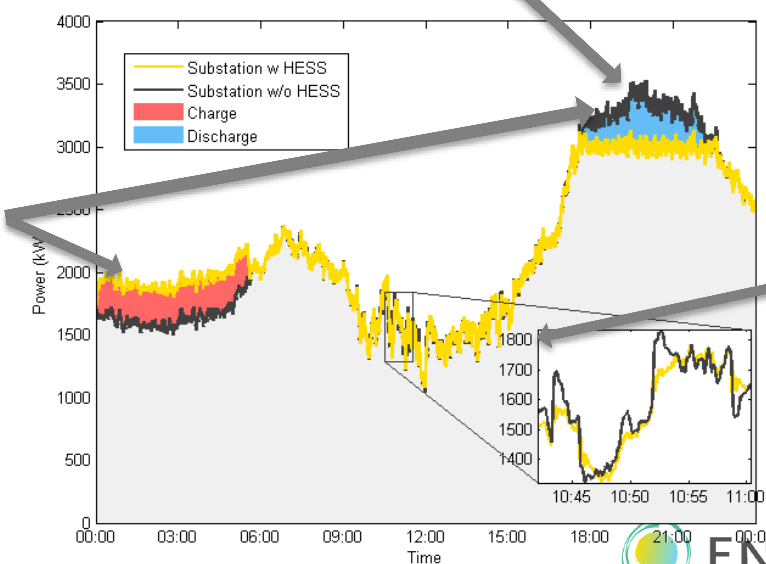


Peak shaving

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

Price arbitrage & Load following

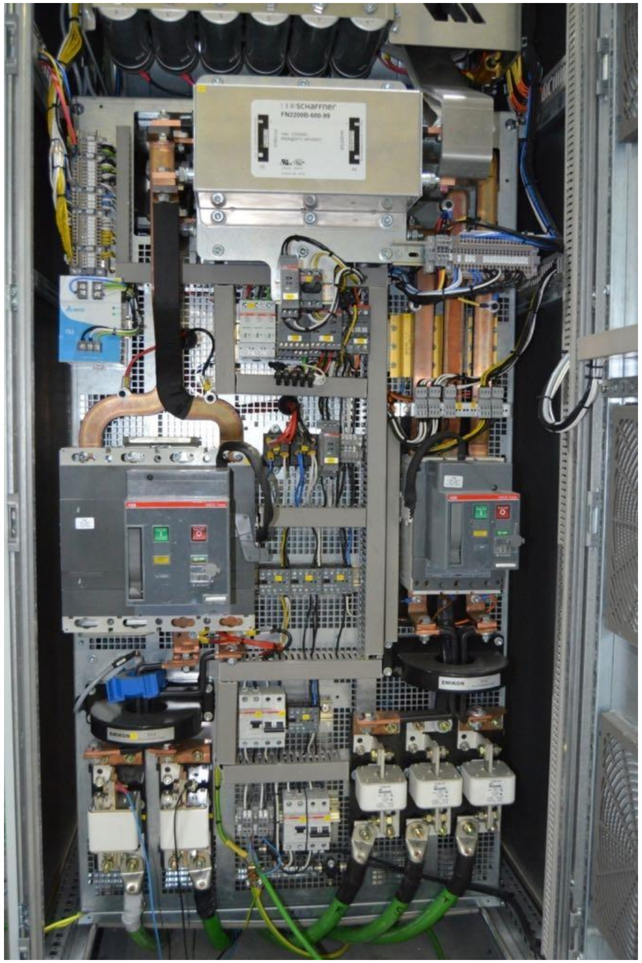
El ESS se carga cuando la energía es más barata o cuando la demanda es baja, mientras que se descarga cuando es más cara o existe una demanda de energía



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



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

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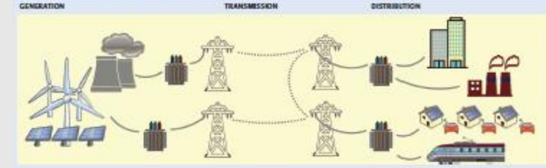
W. Luo, S. Stynski, A. Chub, L. G. Franquelo, M. Malinowski and D. Vinnikov, "Utility-Scale Energy Storage Systems: A Comprehensive Review of Their Applications, Challenges, and Future Directions," in **IEEE Industrial Electronics Magazine**, doi: 10.1109/MIE.2020.3026169.

Utility-Scale Energy Storage Systems

TABLE 1 – 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 DMITRI VINNIKOV

Conventional 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 banked 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.

Digital Object Identifier 10.1109/MIE.2020.3026169
Date of current version: 6 January 2021

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Hybrid Energy Storage Systems

Concepts, Advantages, and Applications

JOSE I. LEON, EUGENIO DOMINGUEZ, LEIJANG WU, ABRAHAM MARQUEZ, MANUEL REYES, and JIANXING LIU

Energy 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

Digital Object Identifier 10.1109/MIE.2020.3016914
Date of current version: 21 December 2020

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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

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.

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El siglo XXI: La revolución energética

IoE
Internet of Energy

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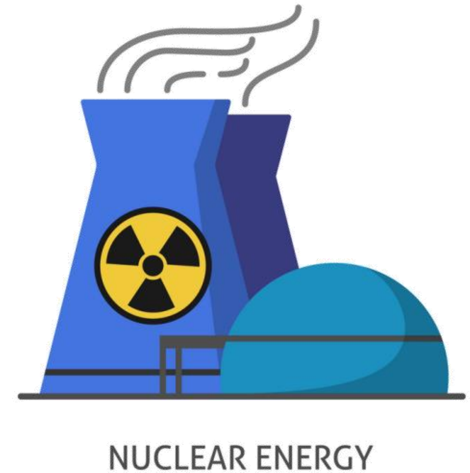
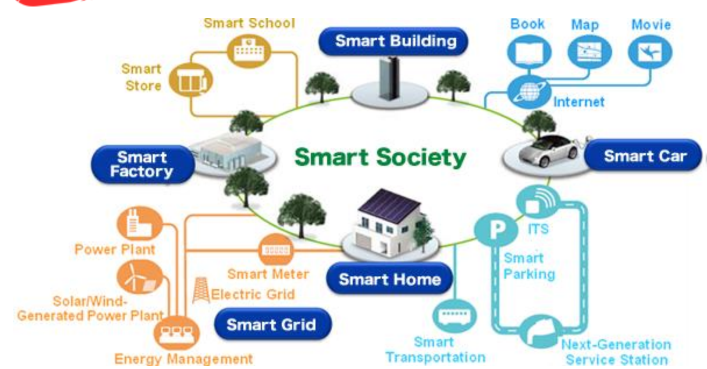
En 25 años...



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



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IEEE & Energías Renovables, una relación simbiótica

Dr. Jose I. Leon
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Gracias por su atención

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