Smart Grids and Solar Energy

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Contents

Key concepts of Smart Grid

- Traditional power grids were constructed based on the predominance of bulk centralised generation.
- Their design involved the assumption of unidirectional power flows
- Because of the need to reduce environmental pollution a trend has emerged of generating power locally at distribution voltage level.
- This power generation may involve conventional generation and renewable energy sources, such as solar PV

Key concepts of Smart Grid

- These sources inject power into the utility distribution network. This type of power generation is known as ***distributed generation***.

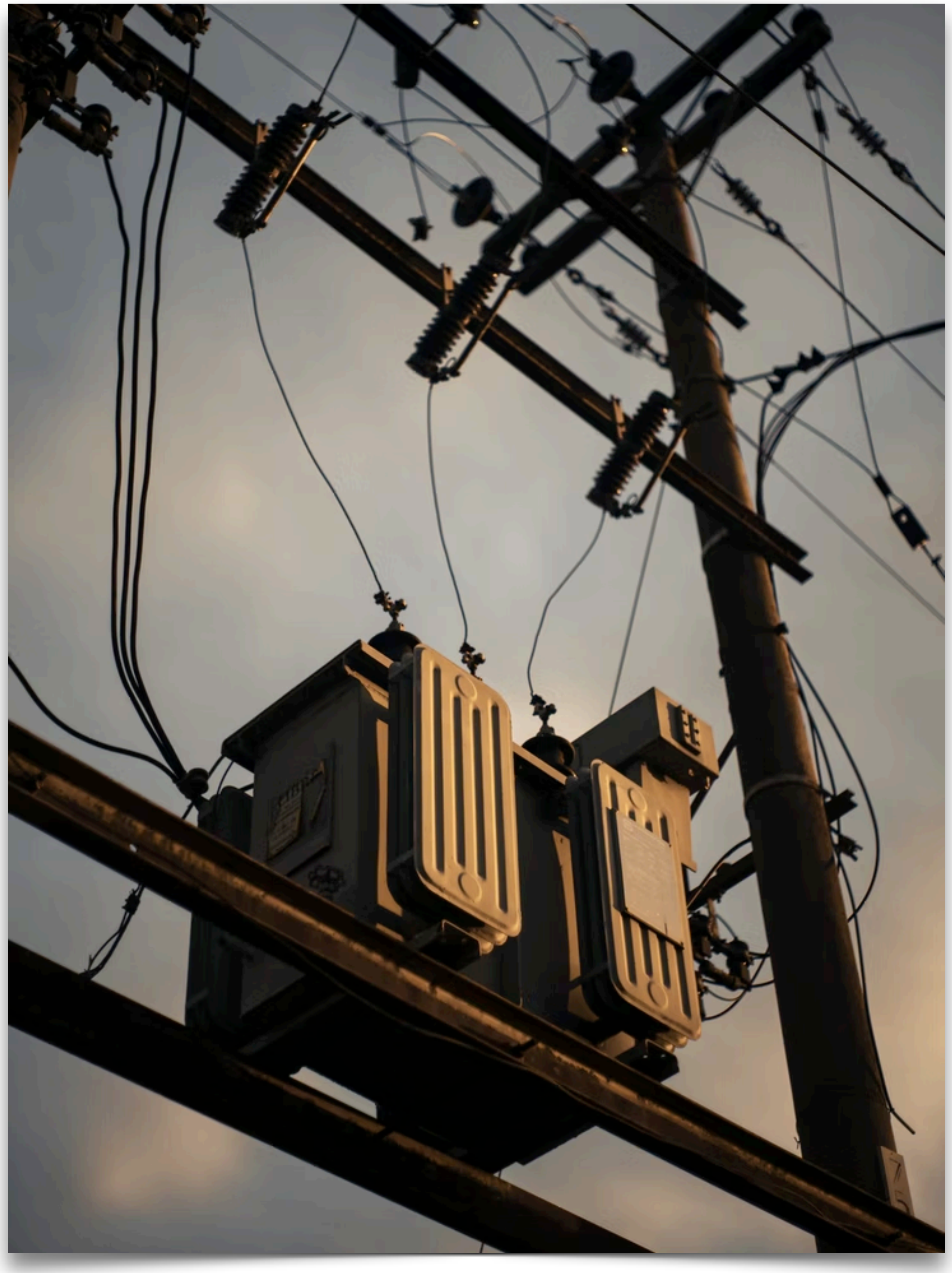
- These installations are not centrally planned but instead are funded and deployed by local entities,

- However, the penetration of distributed generation increases the complexity of power grids and presents significant stability, control and protection challenges.

Challenges faced by the traditional grid

The traditional power grid faces a number of other challenges, which include:

- Ageing infrastructures
- Integrating intermittent energy sources
- Security of supply and increase in energy needs
- Sustainability
- The need for lower energy prices



Challenges faced by the traditional grid

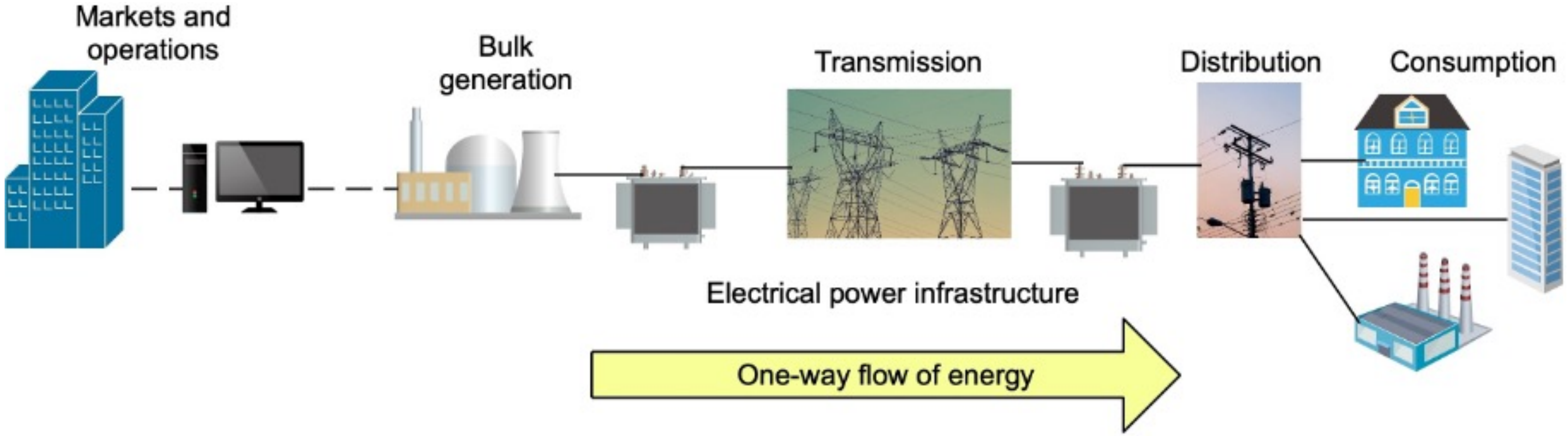
- The above challenges act as drivers for **modernisation**
- Modernisation can be achieved through the development and deployment of what is known as smart grid technologies.
- However, the need for modernisation of the power grid varies between countries and region.
- This need depends on on the state of the national or regional transmission and distribution grids, the level of penetration of variable renewable energy sources, and the trends in electricity demand.

Definition of Smart Grid

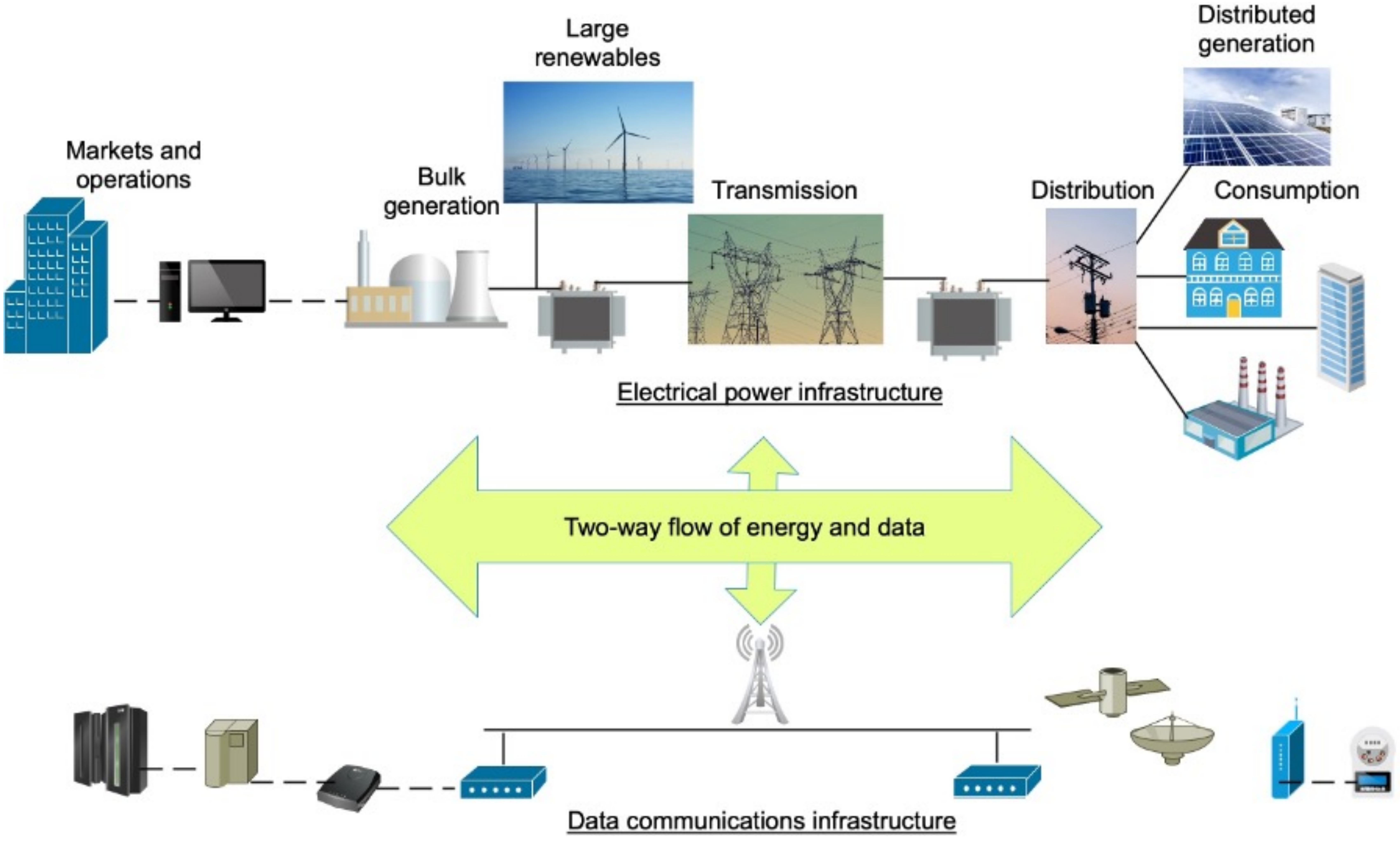
Although there is no universally accepted definition of smart grid, the following definition is useful:

A smart grid is an electricity network that uses comprehensive computing, sensing, power electronics, control and communication technologies to intelligently integrate the actions of all users connected to it to efficiently deliver sustainable, economic and secure electricity supplies.

Traditional vs Smart Grid



Traditional vs Smart Grid



Smart Grids and Solar Energy

- Solar photovoltaic plants produce cheap and clean electricity. Costs keep going down and installations are growing fast.
- There are aspects of smart grid that facilitate the integration of solar photovoltaic plants or may affect the operation of such plants in different ways.
- This talk focuses on critical aspects of the integration of solar photovoltaic plants of different sizes into the power grid.

Types of solar PV plants

Utility-scale solar farms.

- These plants occupy large areas and may have a capacity between a few to hundreds of MW.
- The power produced by these plants can be injected into the electric grid at transmission or distribution voltage levels.
- These plants are not dispatchable, but the power system operator may curtail their production occasionally

Types of solar PV plants

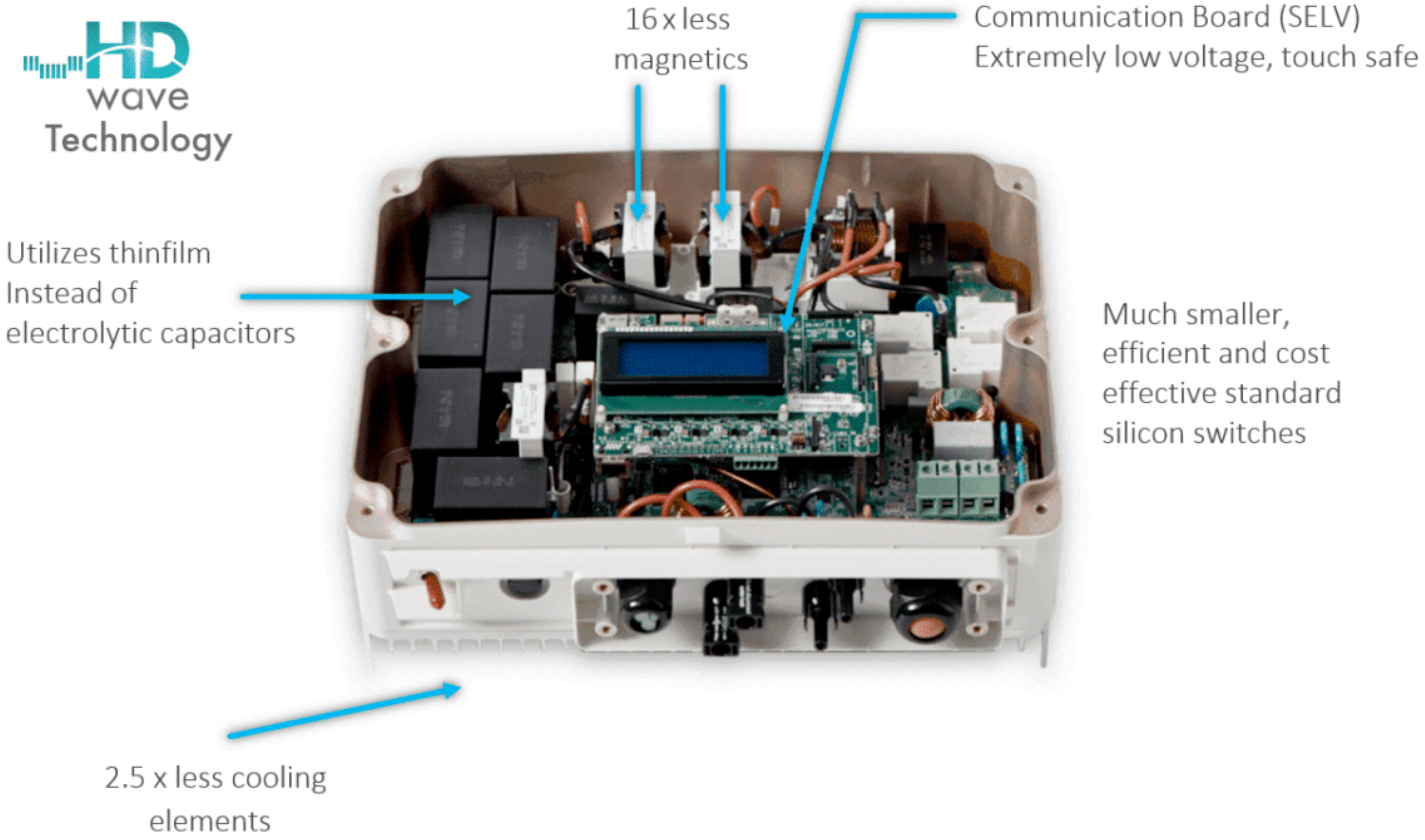
Distributed PV generation

- Small residential and commercial plants range between a few to hundreds of kW.
- They are located on rooftops or land at homes, commercial, municipal or industrial property.
- These resources are interfaced to the grid at distribution voltage levels.
- They can be deployed for self-consumption, for export to the grid, or both

Inverters

- The integration of PV systems to the electricity grid requires grid-connected inverters.
- This type of inverter takes the DC input from the PV array and produces the AC output required by the utility grid.
- A grid-connected inverter will only function when the grid is operating within particular voltage and frequency ranges. Many, but not all, grid-connected inverters are designed to allow exporting AC power to the grid.

Typical 5 kW string inverter



https://www.zerohomebills.com/product/solaredge-se3500h-hd-wave-3-5kw-solar-inverter/

Inverters

Central solar inverters at Westhampnett solar farm in West Sussex, England. These inverters interface the 7.4 MWp solar photovoltaic array with the three-phase electricity grid.

Requirements of PV integration

The integration of a significant share of variable renewables into power grids requires a substantial transformation of the existing networks in order to:

- Allow for a bi-directional flow of energy;
- Establish an efficient electricity demand and grid management mechanisms
- Improve the interconnection of grids at the regional, national and international level
- Introduce technologies and procedures to ensure grid operation stability and control
- Introduce energy storage capacity aimed at increasing system flexibility

Requirements of PV integration

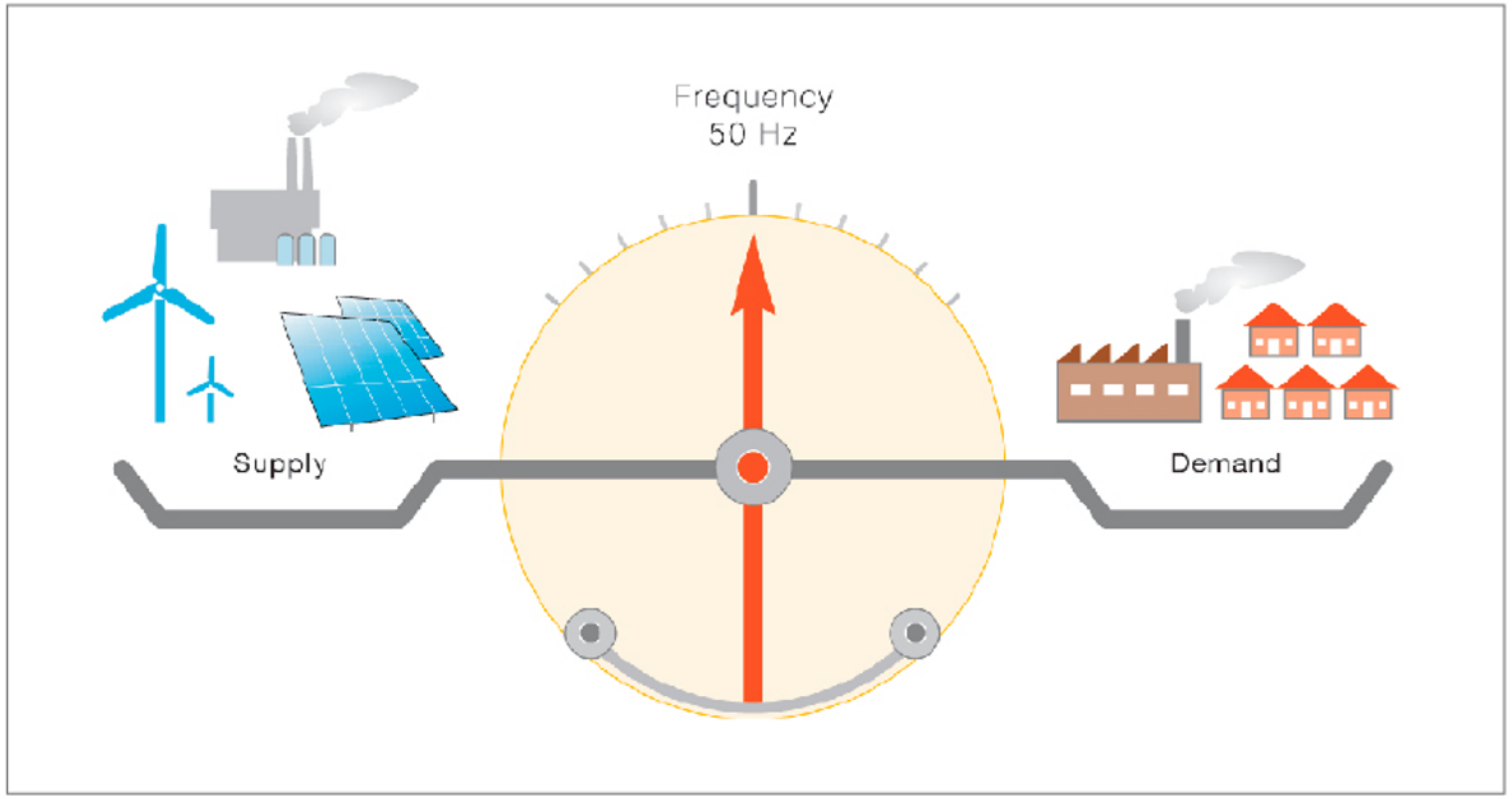
By adding aspects of smart functionality to the grid to balance supply and demand and employing information and communication technologies to boost flexibility and improve reliability and efficiency, smart grid technologies can act as an enabler for these developments.

Challenges of PV integration

- Balancing demand and generation
- Estimating the PV hosting capacity of distribution feeders
- Coordination of protection systems
- Voltage regulation

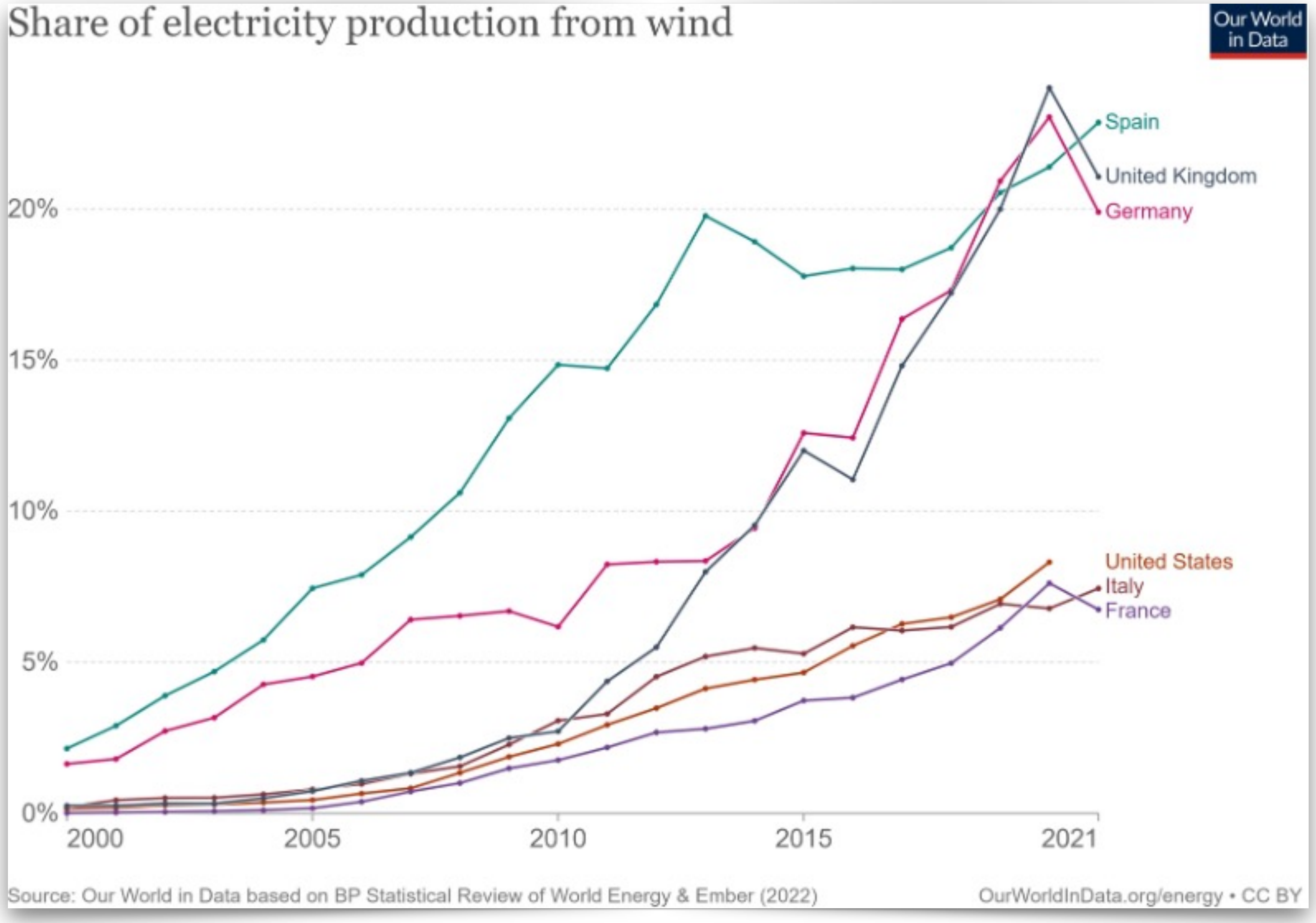
Supply and demand balancing

- In order to balance supply and demand, power system operators need to make important decisions:
  - *Unit commitment (once per day)*
  - *Economic dispatch (every 30 min)*
- The power system needs to employ **automatic generation control** (AGC), which performs more frequent adjustments to generation

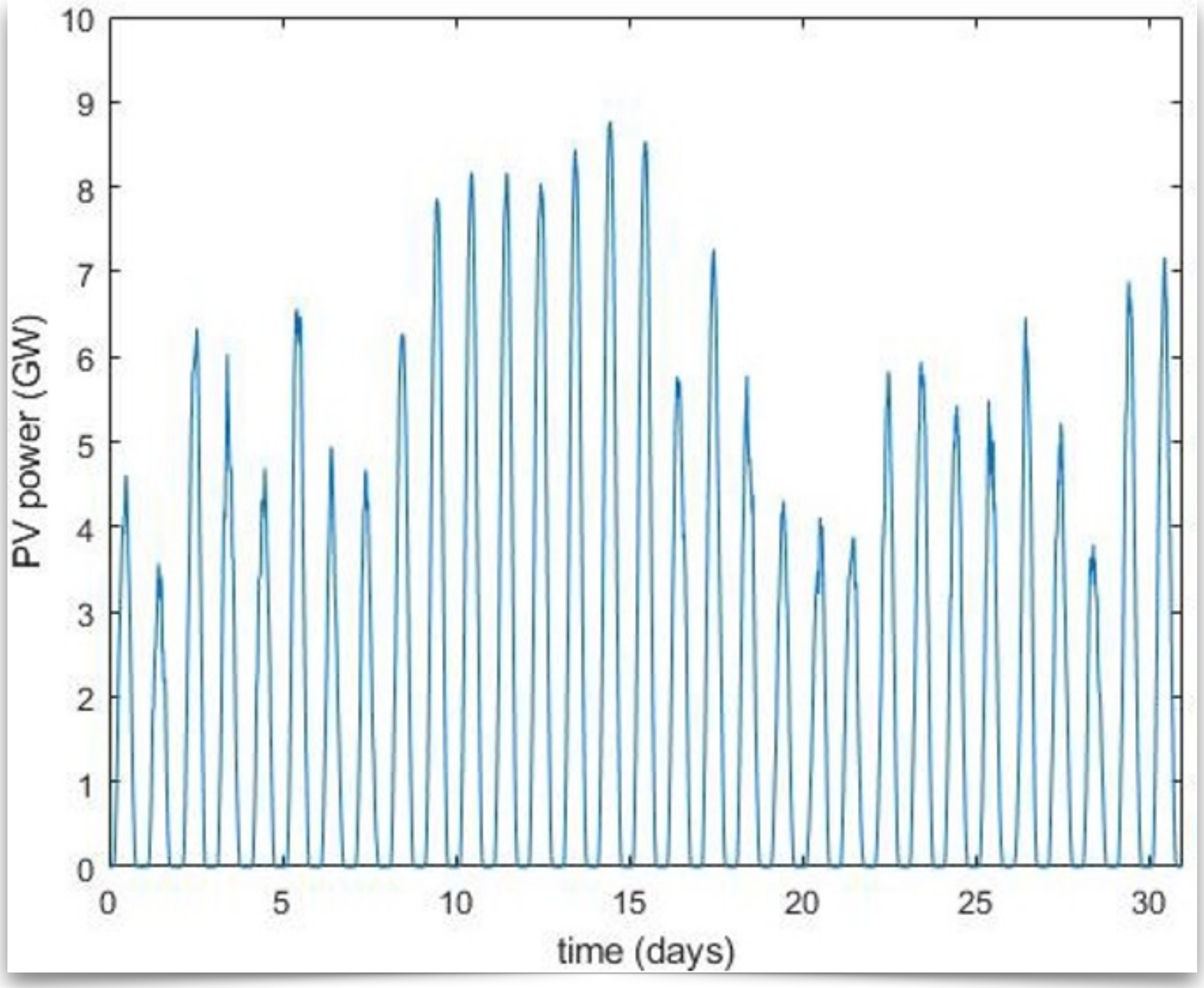


Requirements and challenges of PV integration

The share of variable renewables in overall power generation is rapidly increasing in many countries.



Requirements of PV integration



Total grid-connected solar PV power generated in Great Britain during the month of July, 2021. The installed grid-connected PV capacity is estimated at 13.08 GWp. To have an idea on the relative contribution of solar, consider that the total power demand was, on average, 30.8 GW in 2021.

Criteria for solar power integration

- The connection to the power grid of variable renewable electricity generation, such as solar plants, requires the analysis of several factors which may impact the grid's operation.
- Note that the main criteria for integrating solar plants is dictated by the locally applicable **standards and regulations**
- A major criterion for plant connection is the **impact on the grid voltage** during normal operations, such as slow voltage variations.
- The plant to be connected is required to keep the voltage increase in an acceptable range of typically 2%–3%.

Criteria for solar power integration

- Modern inverters can provide grid-supporting functions, such as **frequency droop** and **reactive power support** to help maintain local grid parameters within their required limits.
- Moreover, three important technical parameters affecting the quality of the power injected into the grid by inverters are **harmonic distortion**, **flicker** and **DC injection**.
- The applicable standards regulate these criteria, and thus inverter manufacturers need to ensure that their products comply with the appropriate limits in the markets where they are sold.

Image by David Hawgood, licensed under CC BY-SA 2.0 https://www.geograph.org.uk/photo/2624304

Criteria for solar power integration

- A further criterion for connecting a renewable electricity generation plant to the distribution grid is the **thermal limit of the grid components**
- These thermal limits are related to the short circuit levels, which are increased by the presence of generation in the vicinity of the components.

Criteria for solar power integration

- The scenario in which a grid-connected PV facility continues to energise the circuit even when utility grid power is unavailable is known as **islanding**.
- Utility personnel may not recognise that a circuit is still powered while working on repairs or maintenance, which might compromise their safety.
- As a result, most countries mandate anti-islanding capability, which requires the PV system to stop energising the grid when grid power is unavailable.

Criteria for solar power integration

- However, in power grids with a high share of distributed renewable generation, the simultaneous loss of many generation plants can threaten the grid's overall stability.

- The ability of generation plants to remain connected to the network during faults of short duration — also referred to as **Fault Ride-Through (FRT) capability** — is crucial for the integration of large-scale renewables into the power grid.

- As a result, modern inverters are provided with functionality that allows them to stay connected to the grid during short grid faults

Source: https://i.ytimg.com/vi/jnnJp-XAZdU/hqdefault.jpg

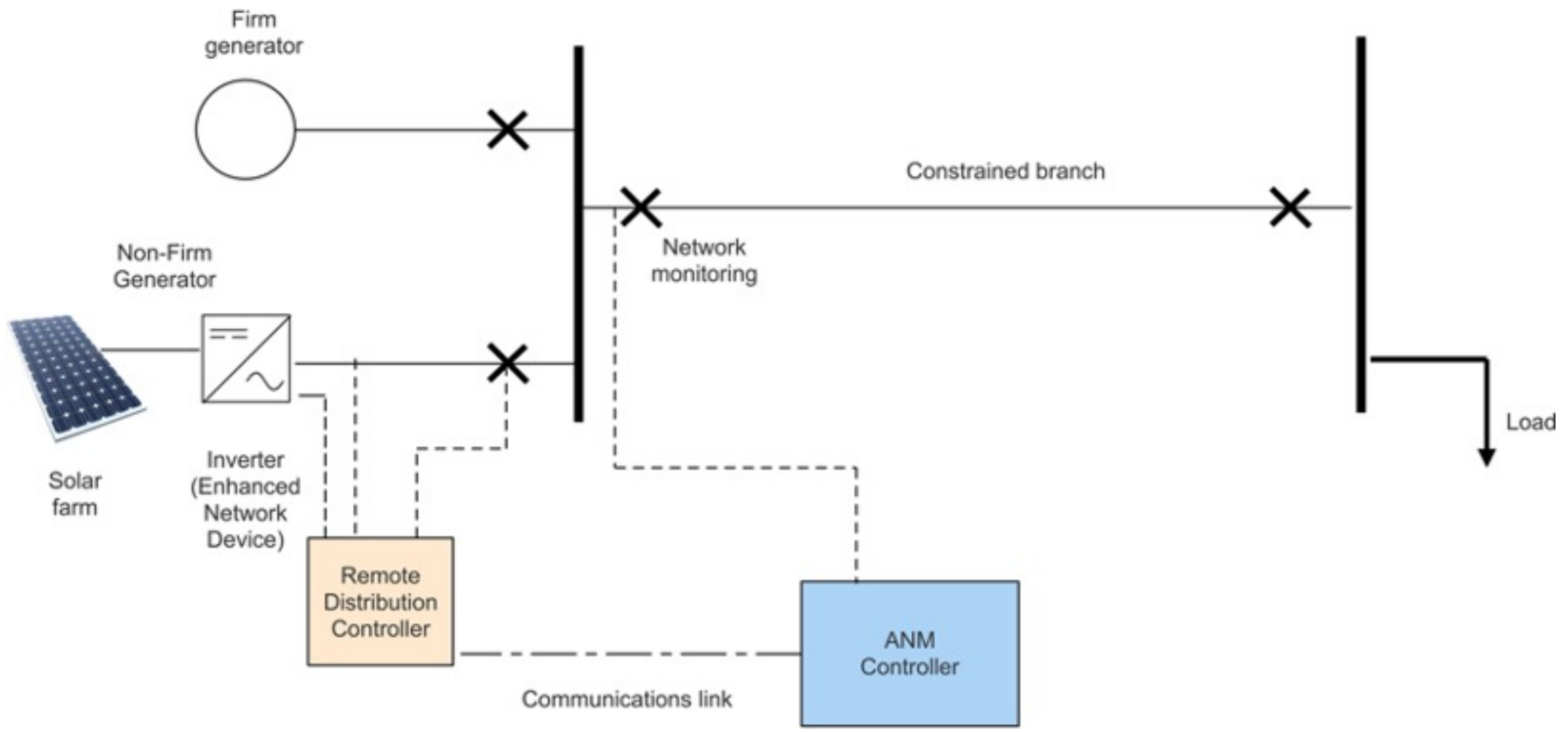
Mechanisms to facilitate PV integration

- Using fast responding generators (usually gas or hydro powered)
- Energy storage
- Demand response schemes
- Enabling the use of curtailment
- Active Network Management
- Other mechanisms for providing flexibility (e.g. time-based connections, intertrips, export limitation, etc).

Active Network Management

Active network management (ANM) is a control system that enables utility companies to

- manage distributed generation, storage and flexible demand in real-time
- increase the utilisation of network assets without breaching operational limits,
- Reduces the need for network reinforcement, facilitates connections, and reduces costs



Energy storage and PV integration

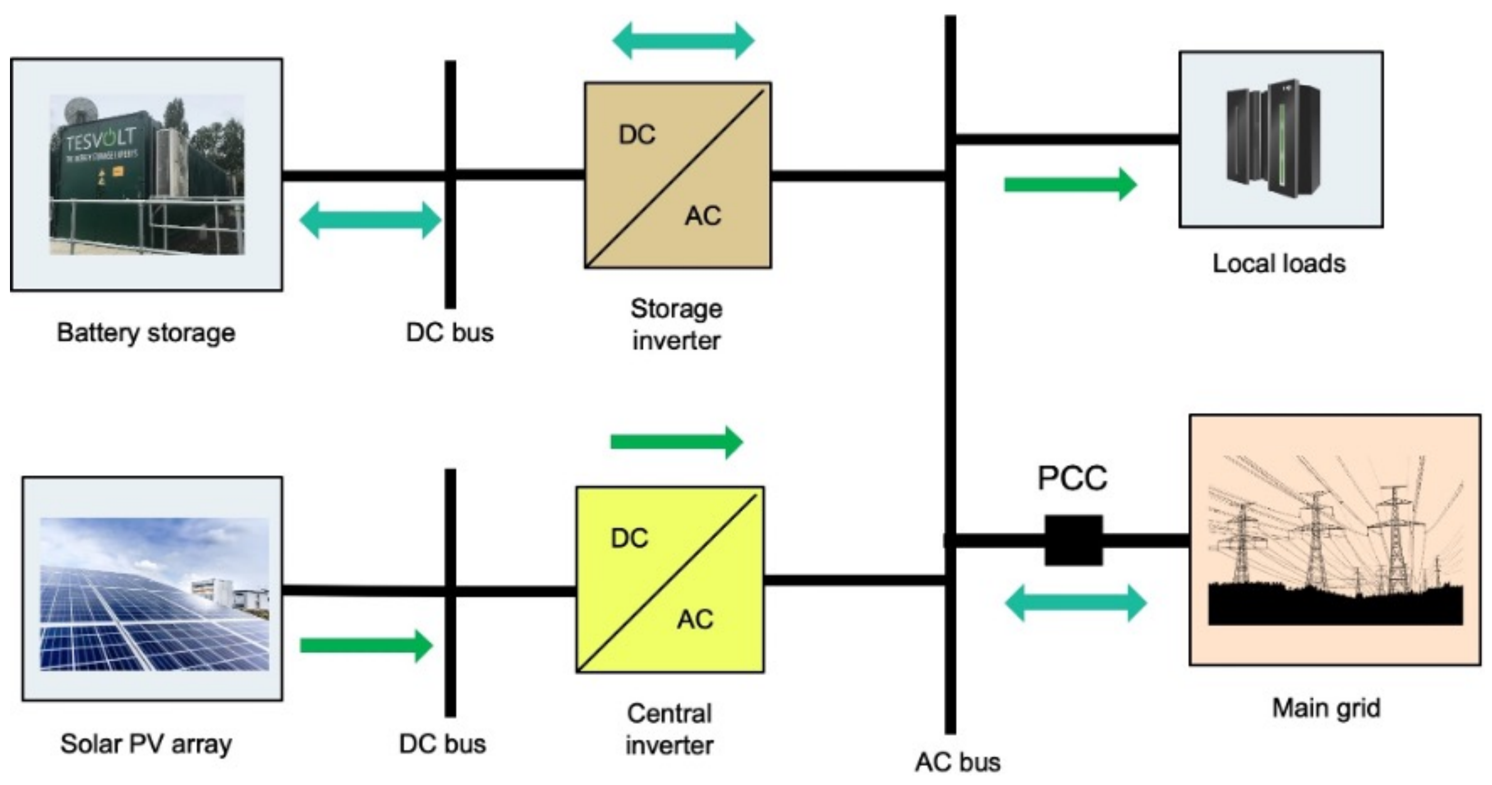
- Energy storage can assist PV integration by increasing power system flexibility.
- Different types of storage. Pumped hydro storage facilities are significant in terms of capacity in some countries
- The cost of battery-based energy storage has gone down significantly in recent years, which has stimulated interest in deploying battery technology in power systems

Grid-scale 2 MWh Lithium-Ion battery storage container at Westhampnett solar farm in West Sussex, England.

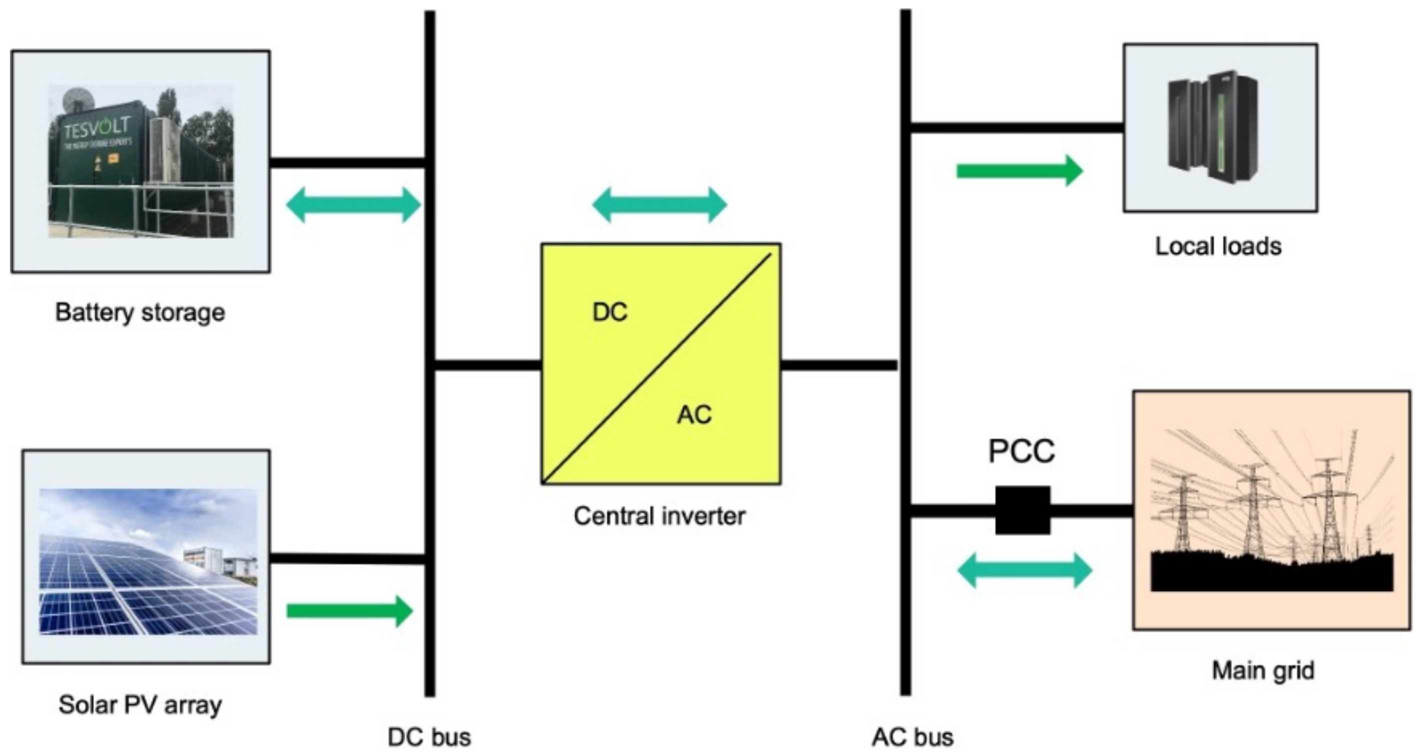
Energy storage and PV integration

There are different categories of association between battery storage and photovoltaic plants.

- Independent
- AC coupled
- DC coupled



AC coupled



DC coupled

Energy storage and PV integration

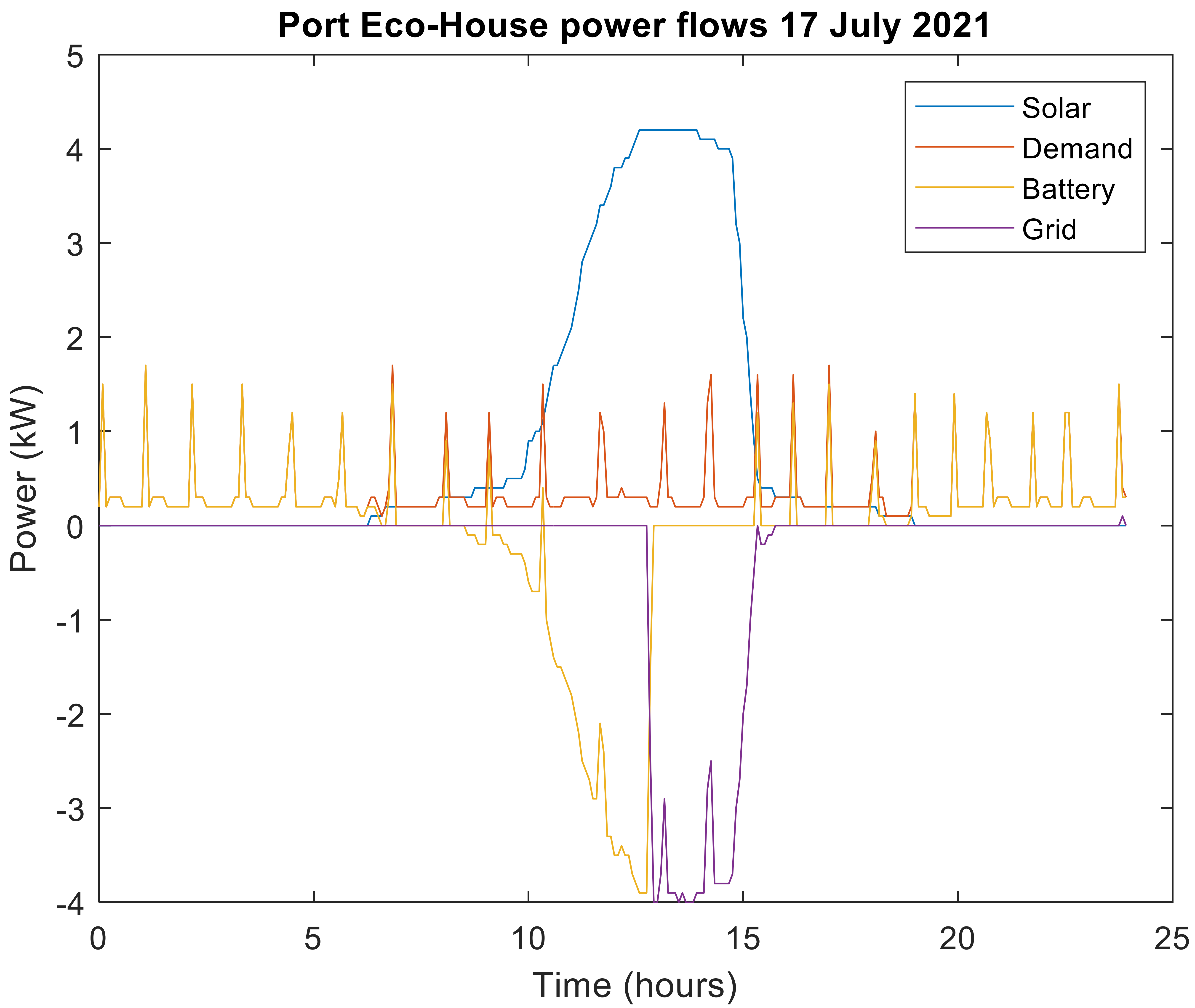
- AC and DC-coupled PV and storage are often used to **maximise self-consumption of solar energy** at sites where there is also a local electricity demand behind the point of common coupling.
- This application is attractive when exporting electricity to the power grid brings little benefit due to low export prices.
- Another benefit of co-located systems is that the storage can often provide a backup service in case of power outages affecting the grid.

Energy storage and PV integration

At the University of Portsmouth, we have an experimental house equipped with a 5 kW PV and a 13.5 kWh Tesla Powerall battery

Energy storage and PV integration

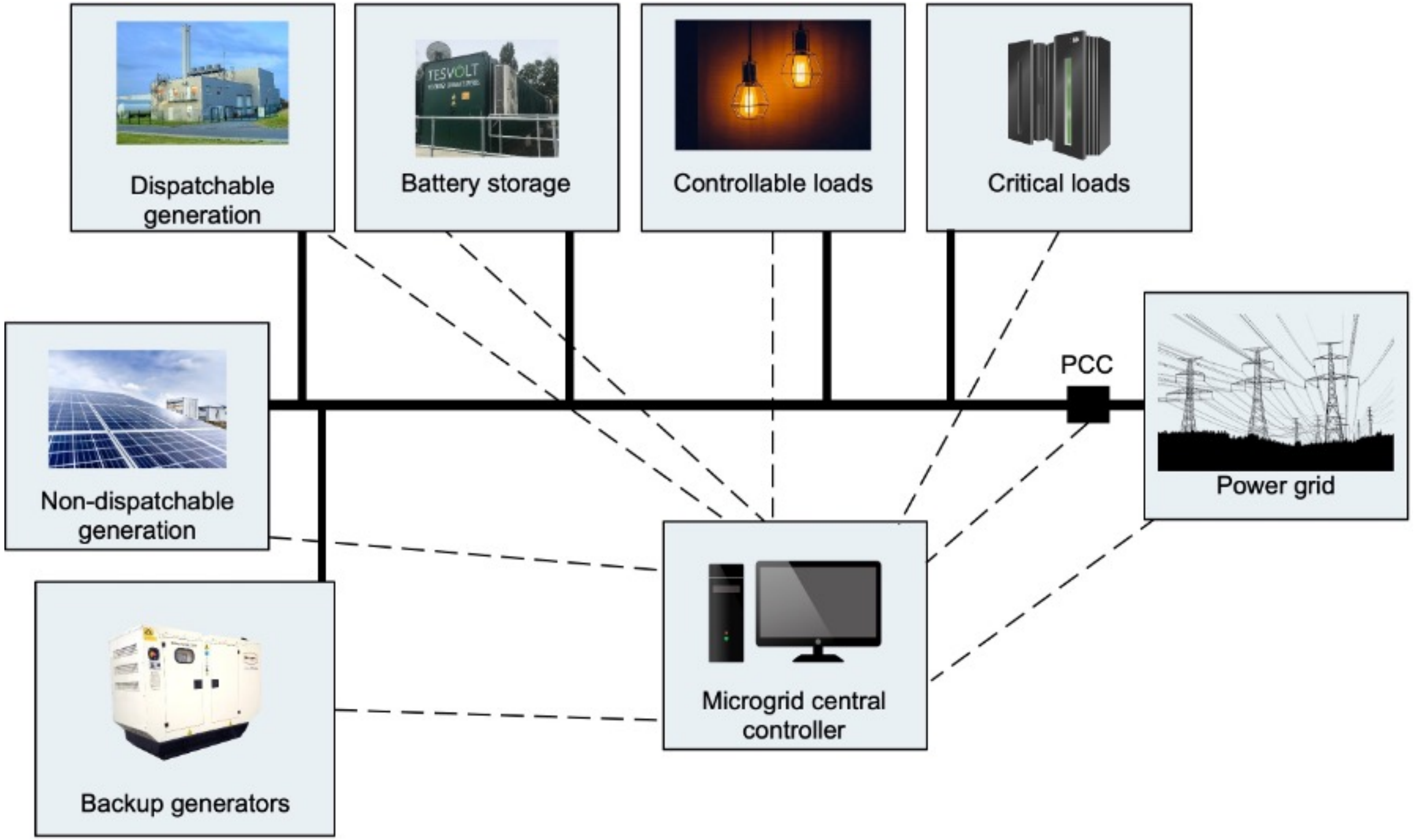
- The figure shows the power flows at the Eco-House on 17 July 2021
- Notice how the excess solar power is stored in the battery between approximately 08:00 and 13:00.
- At around 13:00 the battery becomes fully charged and the excess solar power is exported into the local grid until about 15:20.
- Also notice that during this day the house was electrically self-sufficient, with no electrical energy being imported from the grid.



Microgrids and solar energy

A microgrid is a local energy system consisting of a grouping of small scale generating units, loads and possibly energy storage, all within a bounded and controlled network, and which may or may not be connected to the grid

Microgrids and solar energy



Components of a microgrid

Microgrids and solar energy

The microgrid model offers numerous advantages to those who adopt it.

- Microgrids **enable grid modernisation** by facilitating the integration of multiple smart grid technologies.
- Microgrids are known to **enhance the integration of distributed and renewable energy sources**, including solar energy, into the main power grid.
- They **promote energy efficiency** and reduce losses by locating generation near the location of the demand. Fourth, they help improve reliability and power quality
- Microgrids also **promote participation in new markets**, including demand-side management, load levelling and ancillary services.

Selling solar electricity

- The conjunction of **smart grid technologies** and modern **deregulated electricity markets** open a range of opportunities for owners of solar generation facilities of different sizes to participate in, and profit from, various electricity markets.

- **Power purchase agreements (PPAs)** are long-term renewable energy contracts. In PPAs both parties agree on various aspects, such as the price of energy, amount of energy delivery, and duration of the contract.

Selling solar electricity

- A simple way for owners of photovoltaic assets to participate in the market may be to sell excess electricity back to the grid.
- The possibility of doing so depends on the local regulations, but where this is possible an export tariff per kWh of electricity is typically paid to the customer.
- **Smart meters** usually support different schemes for selling solar energy

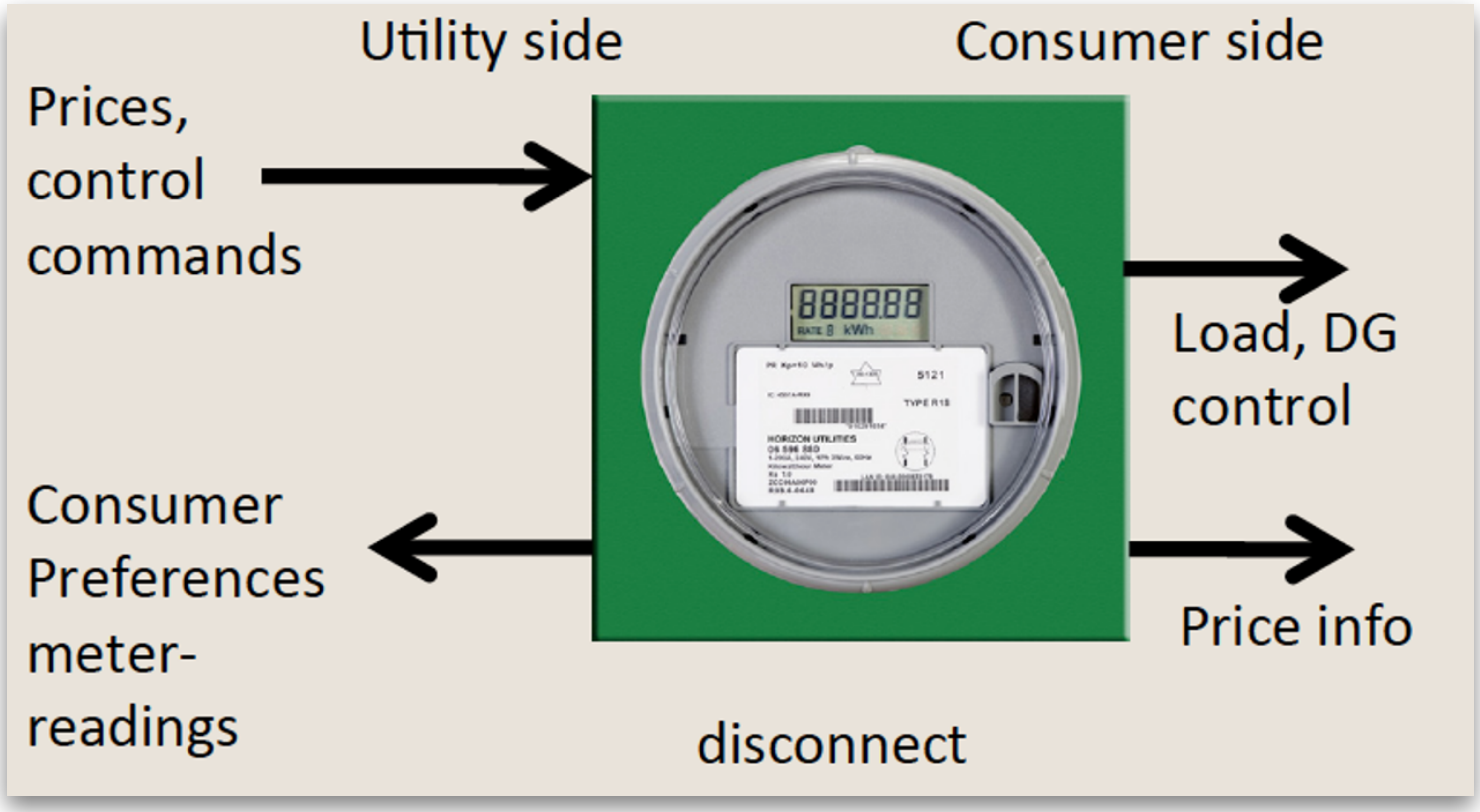
Smart Meters

- A **smart meter** is a new kind of energy meter that can send readings to the utility company via wireless or wired communications.
- This can ensure more accurate energy bills.
- Smart meters also come with monitors, so consumers can better understand their energy usage.

Smart meter by Asurnipal (Creative Commons Attribution-Share Alike 4.0 International)

Smart meters

- Smart meters automatically inform the utility company about the amount of exported energy by PV installations.
- They also have advanced functionality that enable services such as variable tariffs, control of distributed generation, and demand response.



Virtual Power Plants and Energy Markets

- The term **virtual power plant (VPP)** is used to describe a collection of power generation sources, energy storage devices and demand response participants which are spread within a distribution grid.
- Distributed energy resources can be attractive for investors. Nonetheless, their intermittency makes it difficult to dispatch these resources.
- Combining them into a larger VPP that can be dispatched and controlled efficiently addresses this issue.
- Virtual power plants are a viable option for aggregating and operating distributed energy resources in order to participate in wholesale energy markets while also providing the flexibility and grid services

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Thank you