UNIVERSITÀ DEGLI STUDI DI TRIESTE
Dipartimento di Ingegneria e Architettura

# An introduction to Smart Grid and Switching Converter

## Fundamentals of Modern Power Systems

## A.Y. 2025 - 2026

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# Smart grid (SG)

- The **hybrid centralized/distributed system** established in the 1890s faces challenges: increasing demand for electricity (50% by 2050), integration of intermittent renewables (90% by 2050), bidirectional flow, the need to respond to emerging loads such as  e-vehicles (opportunity too), varying demand patterns, energy saving policies make it **obsolete**
- These challenges force drivers to transform the current power system into a smarter grid

# Smart grid

- It is an **emerging area** of engineering and technology integrating electricity, communication and information infrastructures
- Ensure an efficient, clean, reliable and economic supply
- It is a complex field with different **engineering areas** such as the **SG architecture** (smart powers systems, communication systems, information technology, security and microgrid), **renewables**, **energy storages** and **power electronics**
- **Active participation** of customers**, new products, services, markets and industries**

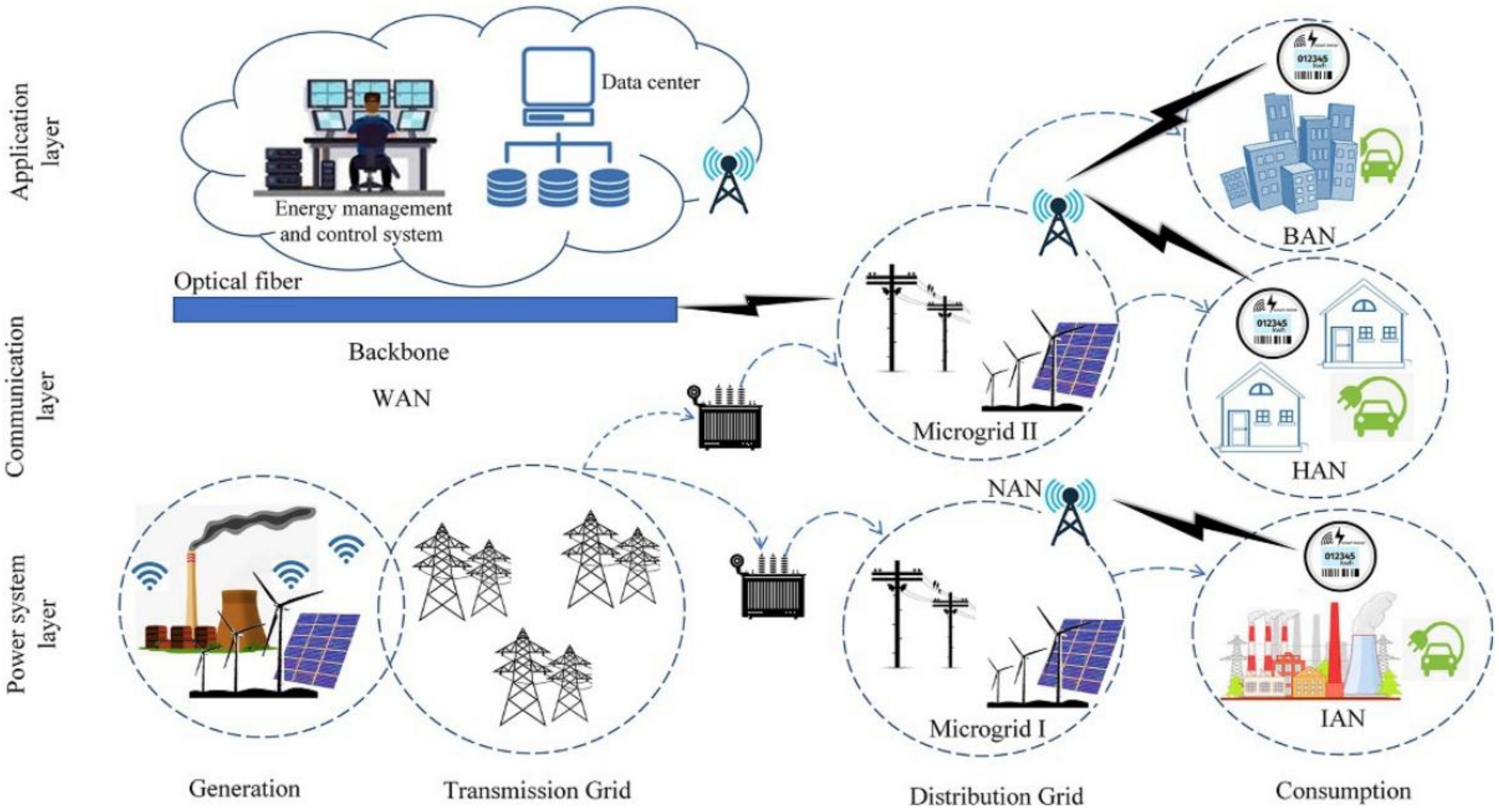
# Smart grid

- **Fundamentals applications**: energy management strategies, reliability models, security, privacy and the promotion of demand-side management
- **Emerging applications**: the deployment of electric vehicles
- **Crucial tools**: Big Data management and analytics, cloud management and monitoring, consumer engagement, artificial intelligence and business models

# Smart grid

A smart grid is the **electric power grid** which establishes
a **communication network** between power suppliers
and power consumers **with the help** of smart sensors,
smart meters, electric vehicles, and power-generating utilities
Smart grid includes an **energy management system** that helps
in balancing the energy demand and supply to produce
and consume electricity **efficiently** at a **lower cost**

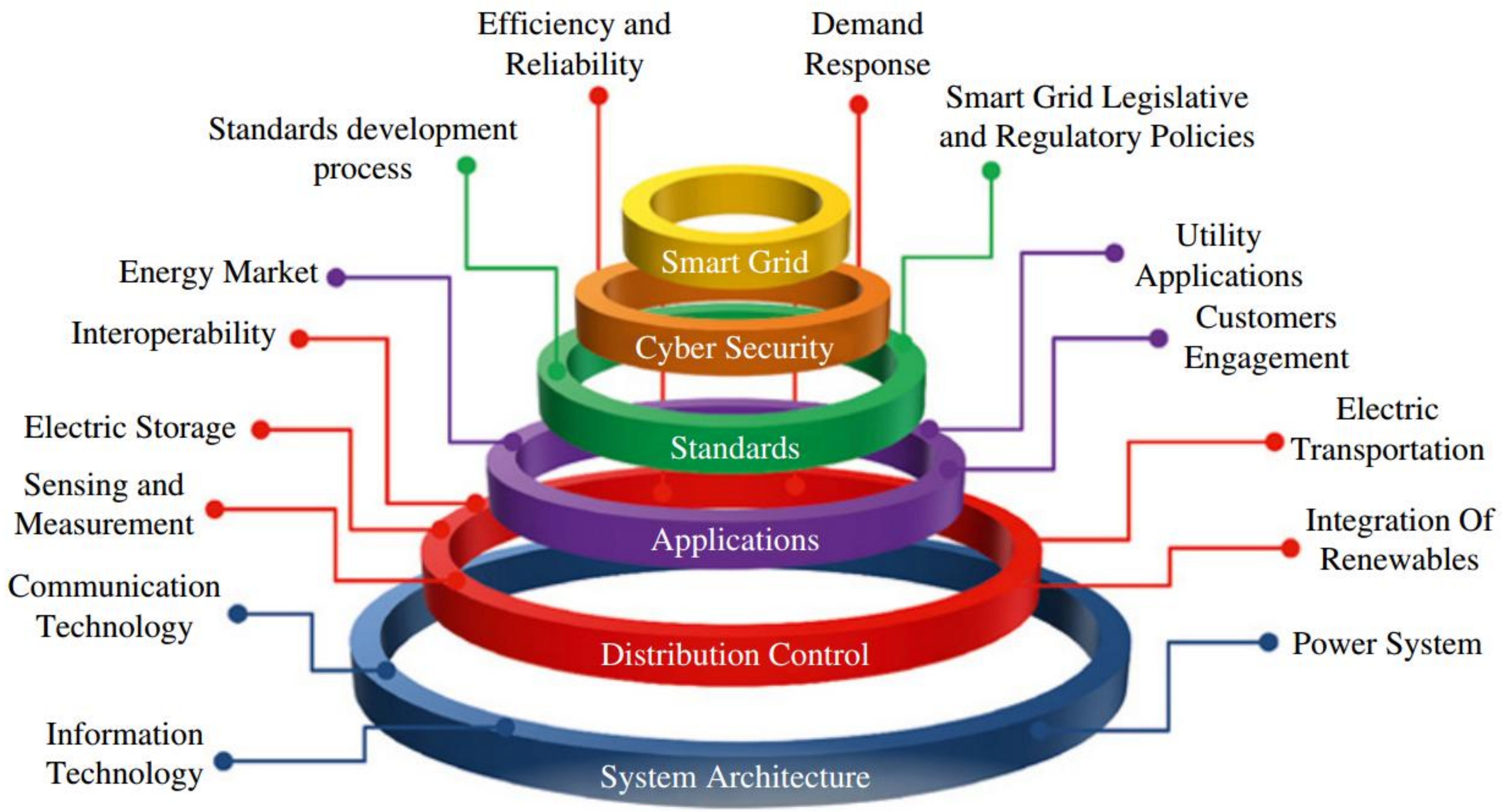
# Smart grid design



# Traditional versus Smart grid

| Characteristic | Traditional grid | Smart grid |
|---|---|---|
| **Technology** | ▪ Electromechanical metering<br>▪ No communication between devices<br>▪ Little internal regulation | ▪ Digital metering<br>▪ Increased communication between devices<br>▪ Remote control and self-regulation |
| **Flow of power and communication** | ▪ One way<br>▪ Power flow starts from centralized power plants | ▪ Two ways<br>▪ Power flow from and to various grid users |
| **Generation** | Centralized | Distributed |
| **Fault location** | Hard to determine | Can be detected remotely as well as predicted |
| **Monitoring** | Manual | Self-monitoring |
| **Control** | Limited | Pervasive control |
| **Operation and maintenance** | Manual checks | Remotely monitor equipment |

# Smart grid architecture

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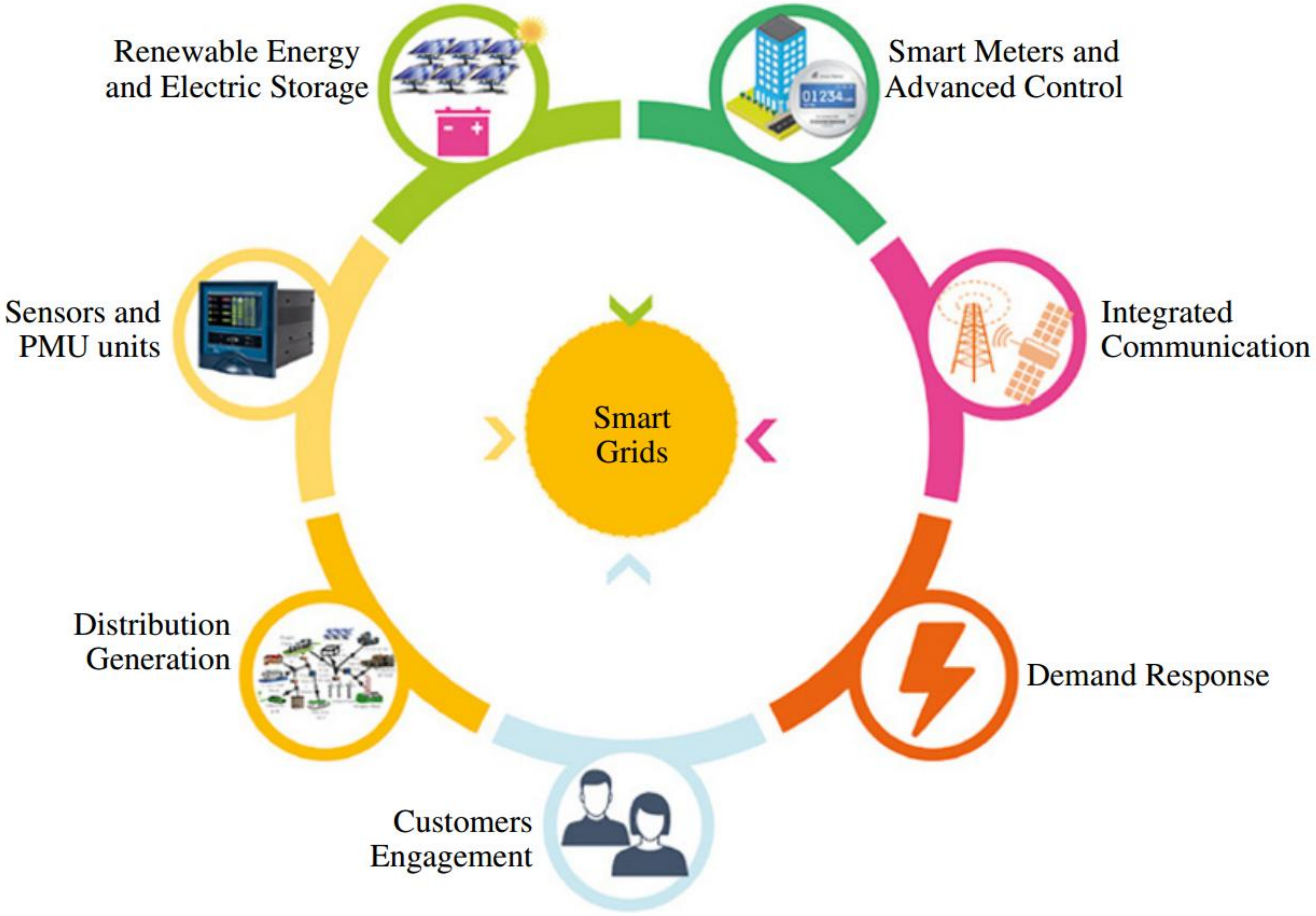
- Five main layers
- Multiple stakeholders
- Different vendors need interoperability requirements
- Real-time dynamic control and management systems
- Intelligent appliances

# Smart grid elements

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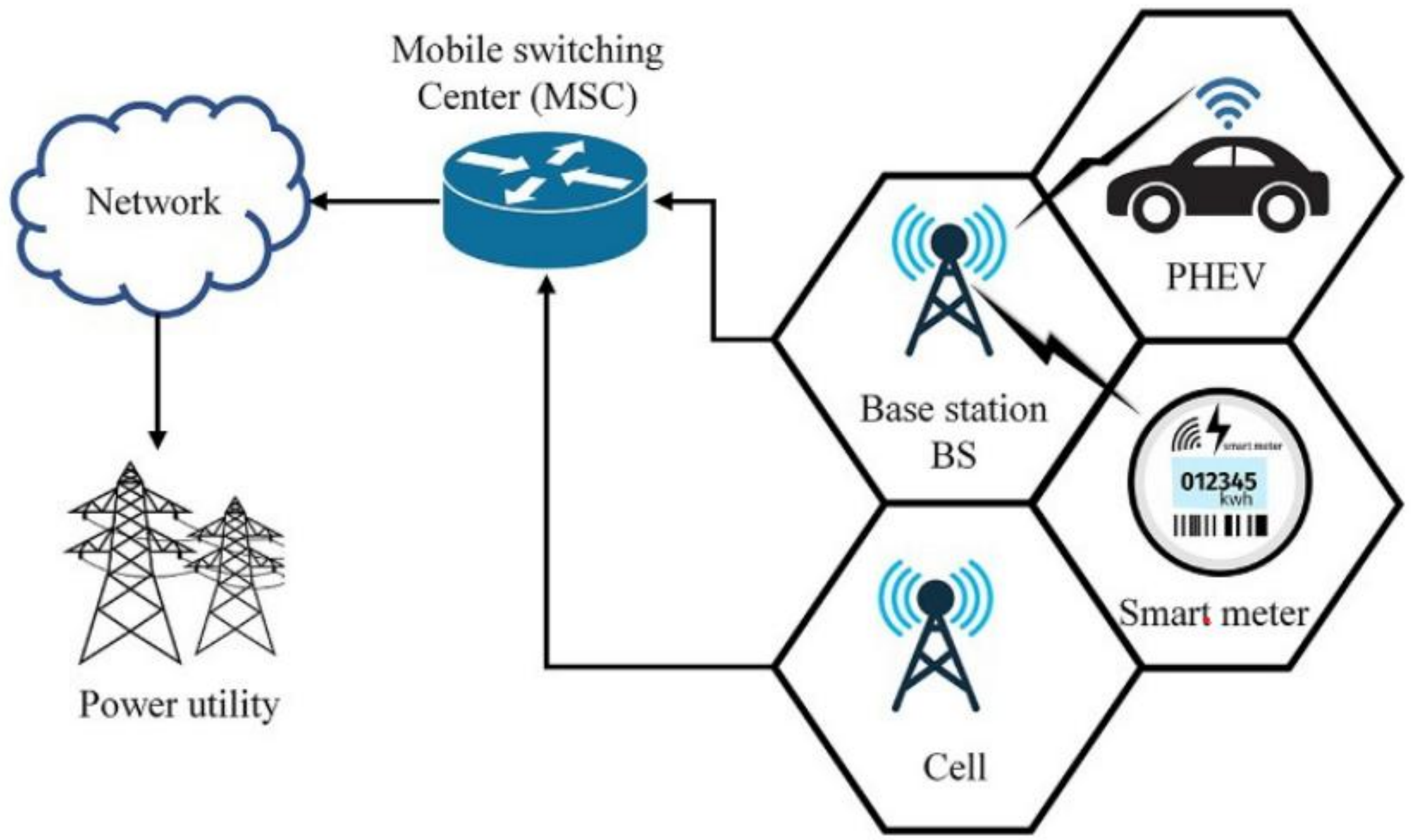
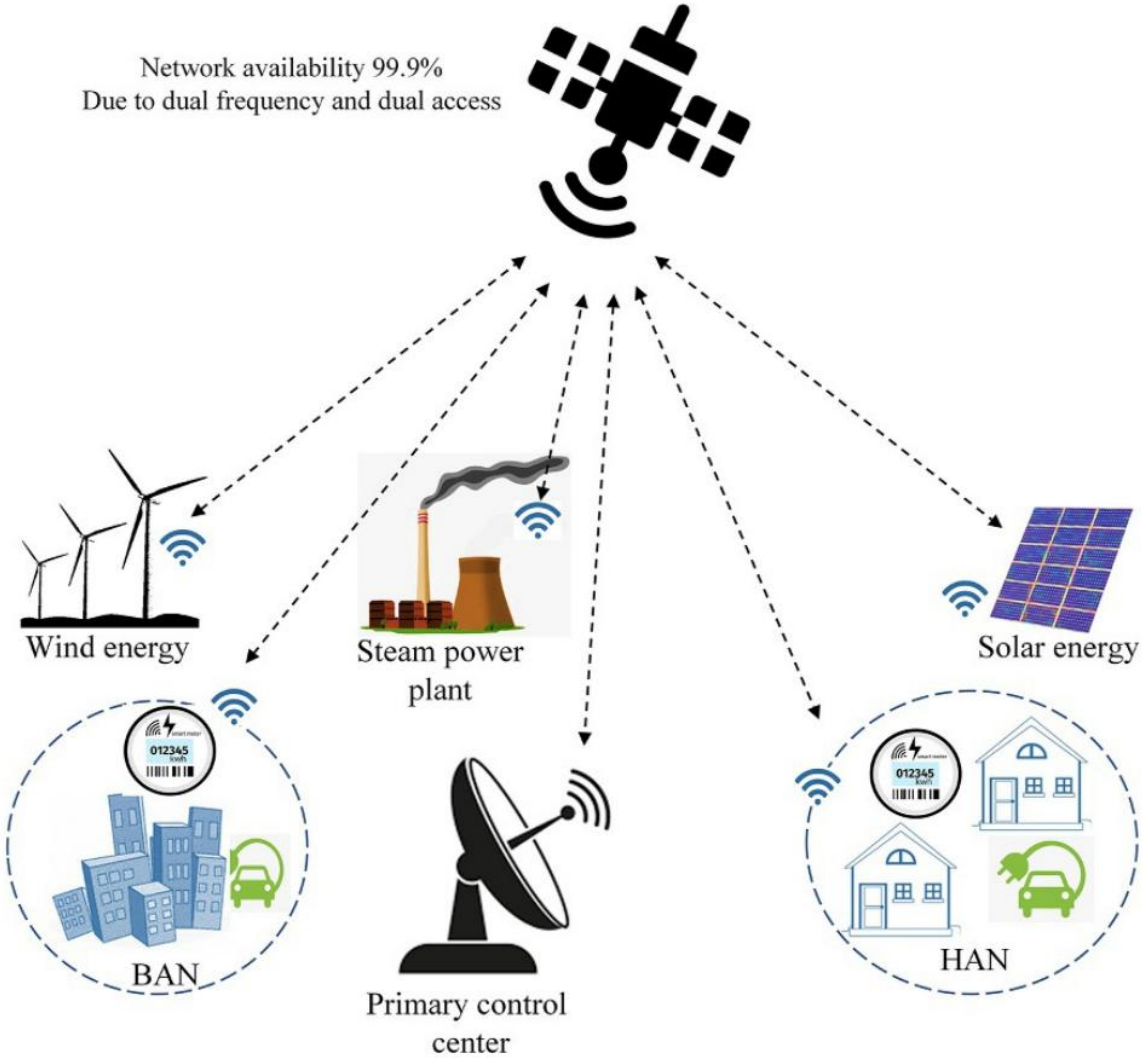
- **Customer engagement**: active role in sharing energy patterns, local RES production, strong and energy sharing
- **Sensors and PMU**: collecting data, monitoring states and health status, customer awareness
- **Demand response**: capability of changing the load profile from normal patterns (changes in electricity price or incentive payments)

# Cellular and satellite communication

**Integrated communication**: fiber optics, WLAN, cellular, WiMAX, PLC



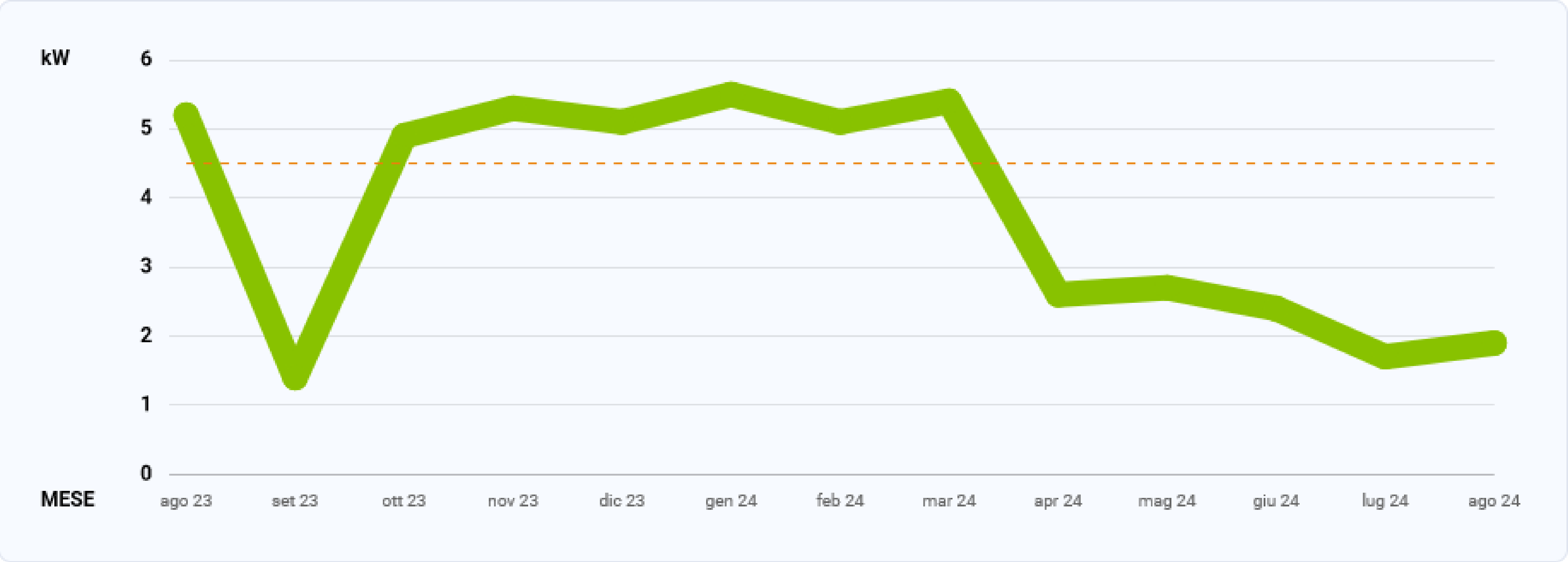




**M. Kamran**
**Fundamentals of smart grid systems**

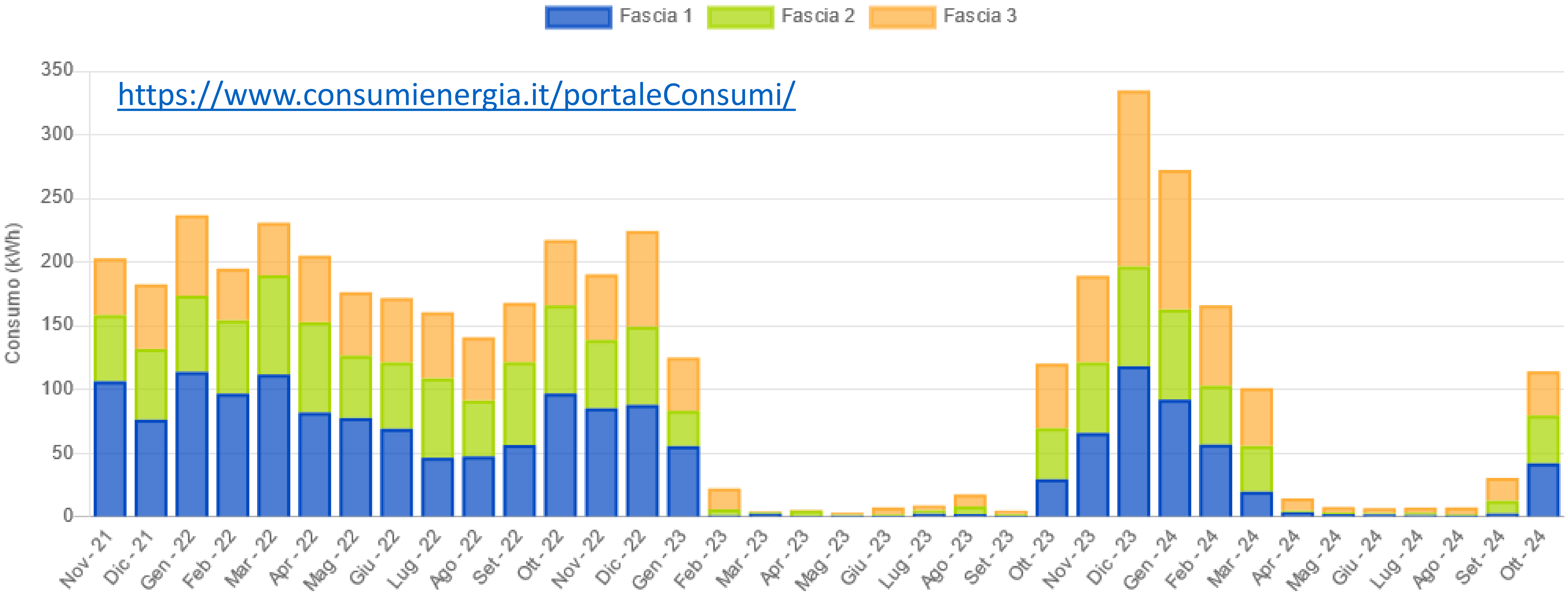
# SG elements: Smart meters and control

- Two-way communicators, real-time sensors, power outage notification, power quality monitoring
- Remote consumer price signals
- Enhance energy diagnostic and profiling
- Collect, store and report users’ consumption
- Obtain location and degree outages remotely
- Possibility for remote connection/disconnection
- Control systems provide timely response and enables detection, prediction, disconnection and self-healing

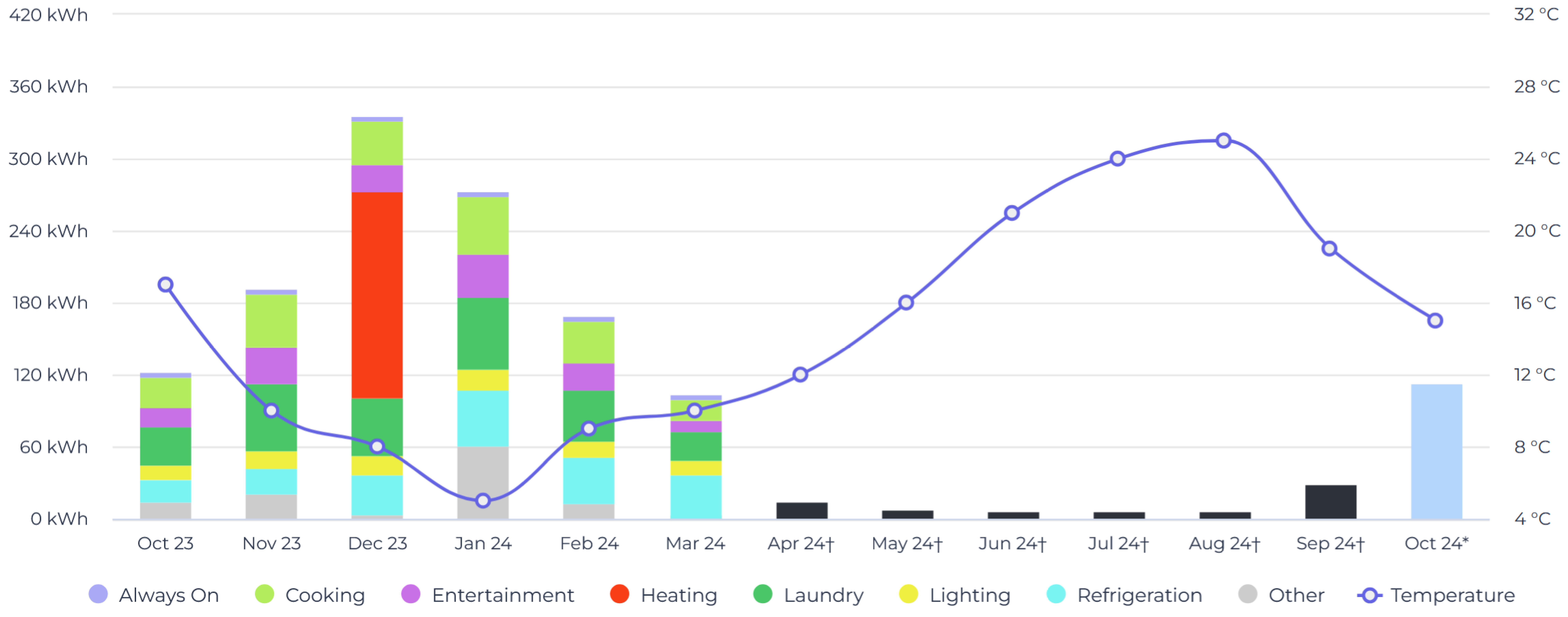
# Users’ consumption


https://www.consumienergia.it/portaleConsumi/



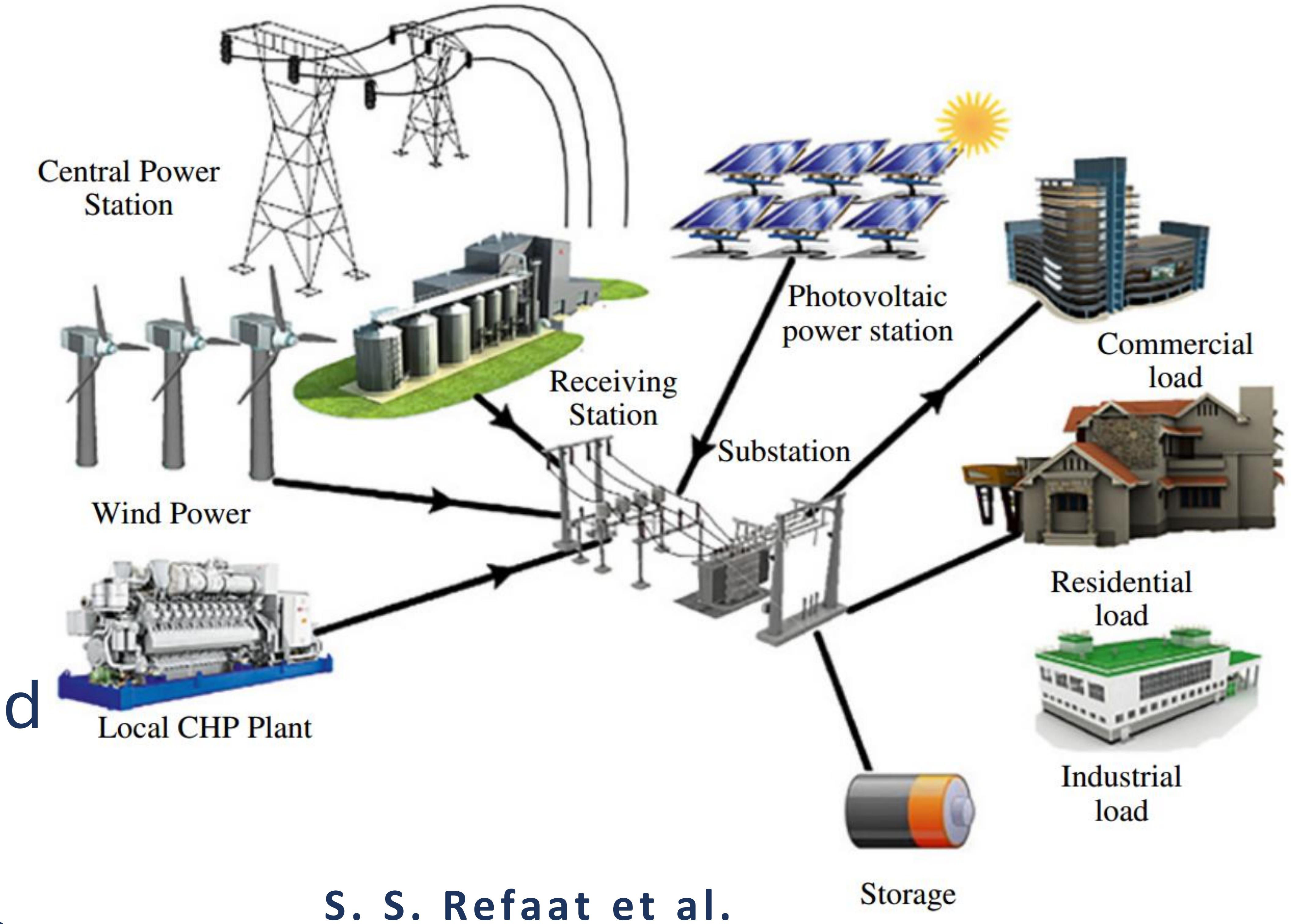
# Users’ profiling



# SG elements: Distributed generators

## Small-scale decentralized power generators

- Modular, flexible, usually closed to the load
- Mostly RES-based
- Can be controlled and coordinated within a smart grid
- Make the grid bidirectional
- Offer benefits to the grid
- May be part of an isolated grid, of a microgrid or grid-connected
- Support in reducing losses and delivering RS
- Increase the complexity

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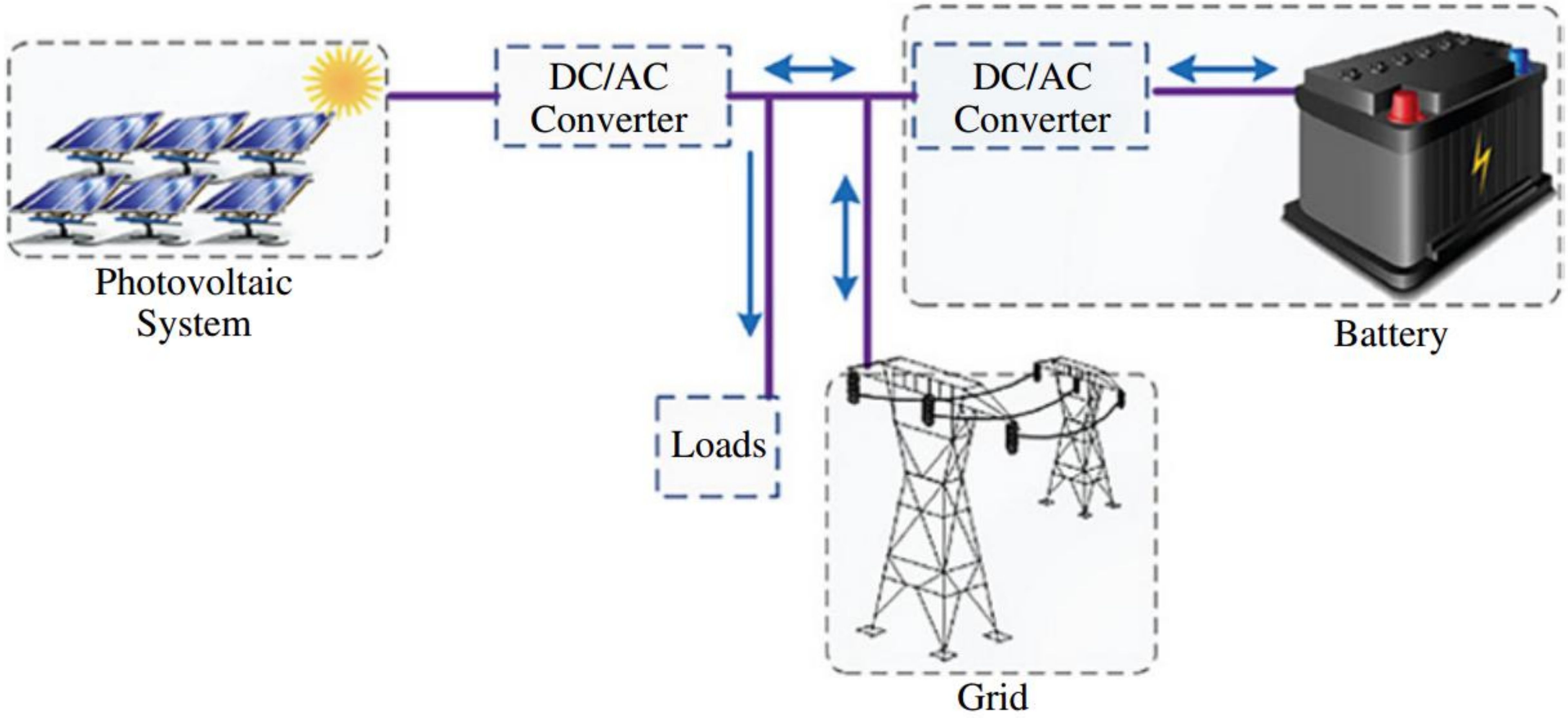
# SG elements: Energy storage

More in “Materials and Systems for the Energy Transition” and “Electrical Energy Storage”

- To settle peaks and valleys of supply
- Combined with power electronics
- Grid support: grid’s voltage and frequency, spinning reserve, resilience …
- Financial benefits (automatic pricing signals
- Power congestion avoiding upgrades in the grid
- Challenges: policies, business models, financing mechanisms

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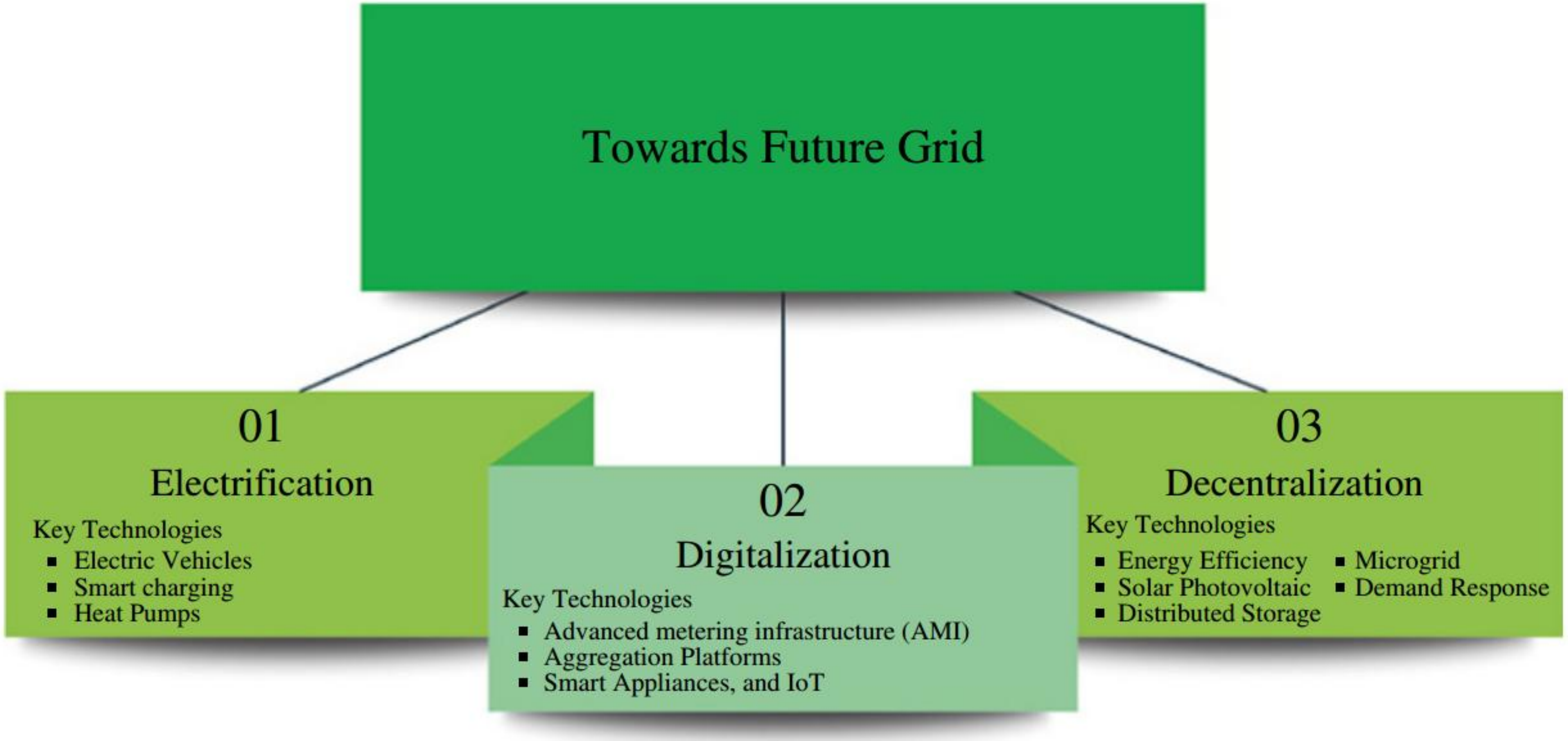
# Smart grid characteristics

- **Flexibility**: various types of generation, storage, loads, EV, …
- **Efficiency**: energy efficiency, product innovation, distributed energy allows for smaller transmission and distribution losses
- **Smart transportation**: smart EVs compensate the infrastructure expansion – V2G, V2B, V2X
- **Reliability and power quality**: reliable supply of electricity and minimized vulnerability to attacks or natural disasters
- **Market enabling**: aggregated supply, ancillary services
- (**Customers' acceptance** and **engagement - prosumers**)

# Smart grid enabling technologies

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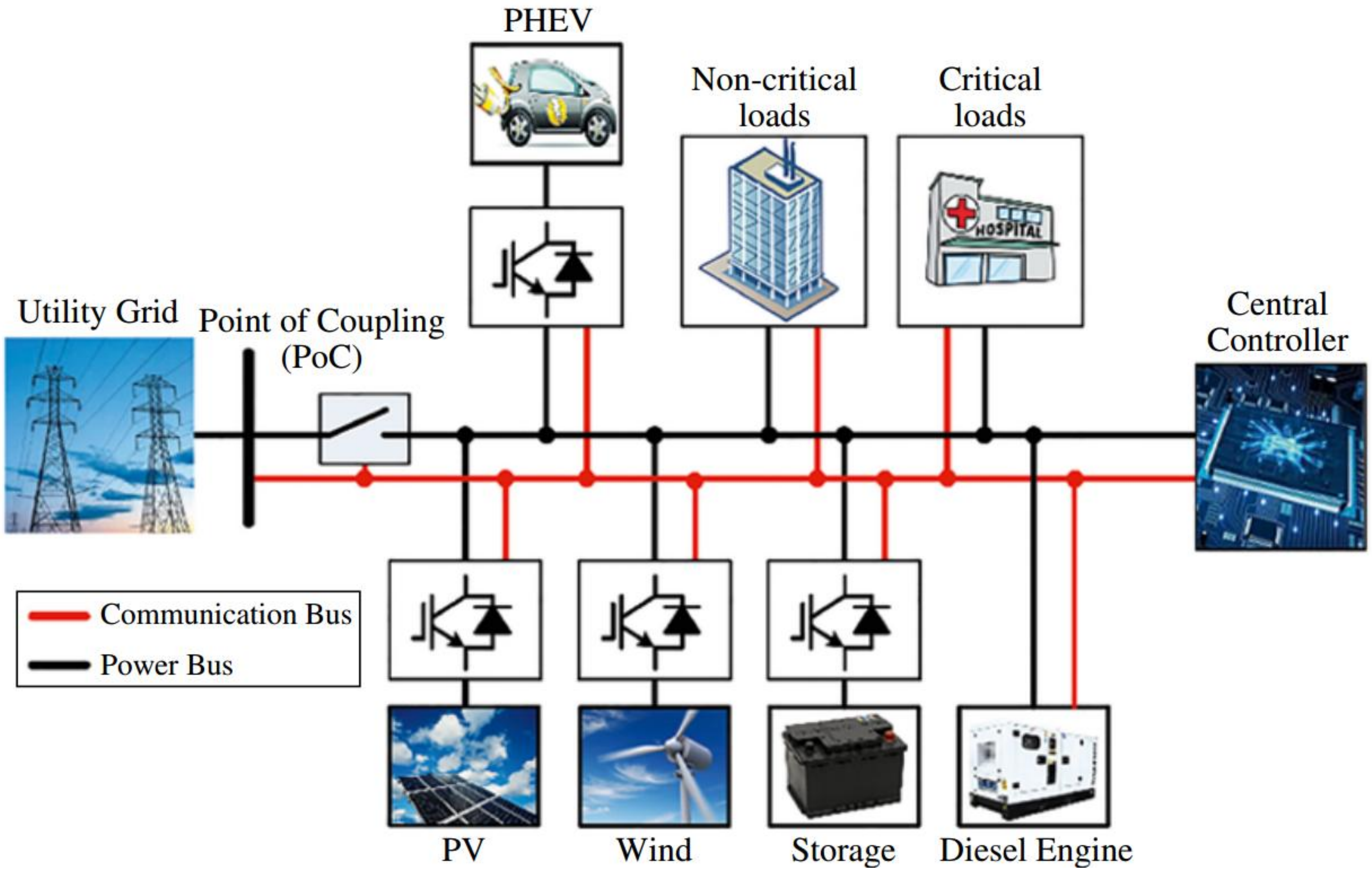
- **Electrification**: more RES, more loads (heating and transportation) away from fossil fuels, more efficiency
- **Digitalization**: enhancing the grid's utilization, optimization and management

# Decentralization: microgrid

- **(Smart) Microgrid** are the building blocks of Smart Grid
- Perceived by the main grid as a **single element** responding to appropriate controlling signals. Can operate in both **grid-connected** or **island** mode and have clearly defined electrical **boundaries**
- Usually contain at least a **distributed generator**, an electrical **storage** system, some (controllable) **loads**, an Energy Management System (**EMS**)
- **DC microgrid** are traditionally used in marine, automotive and avionics for power distribution. Today, data centers, manufacturing industries, …
- Computers, LED lights, variable speed drives, house appliances, industrial equipment need DC power for their operation and … most distributed generators produce DC power >> **DC microgrids**

# Simplified structure of a microgrid

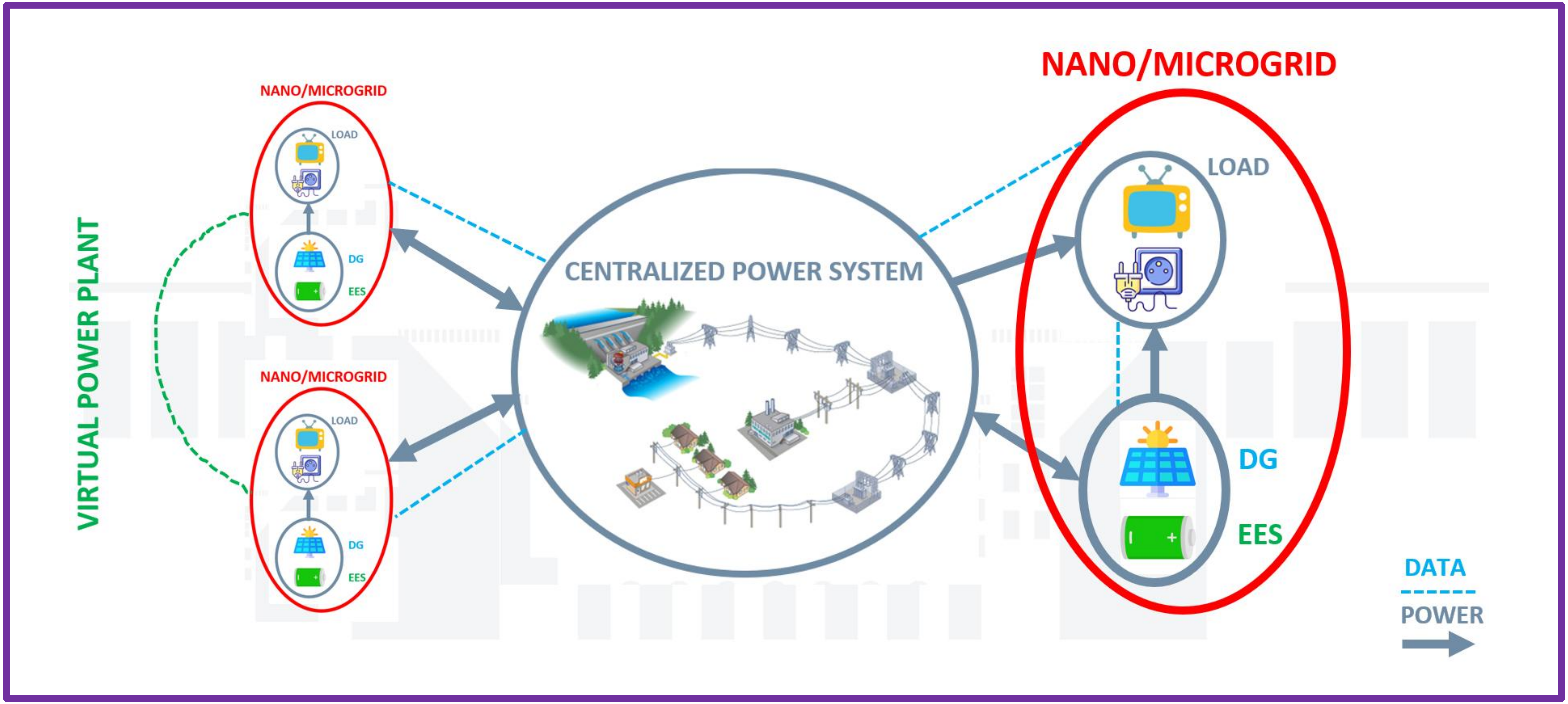



- **Critical loads** need to be supplied constantly
- **The selection of DGs** depends on local conditions
- EES (and EV) can be used for **energy arbitrage**
- The **switch at PCC** performs the grid-connection

# Evolution of the power sector

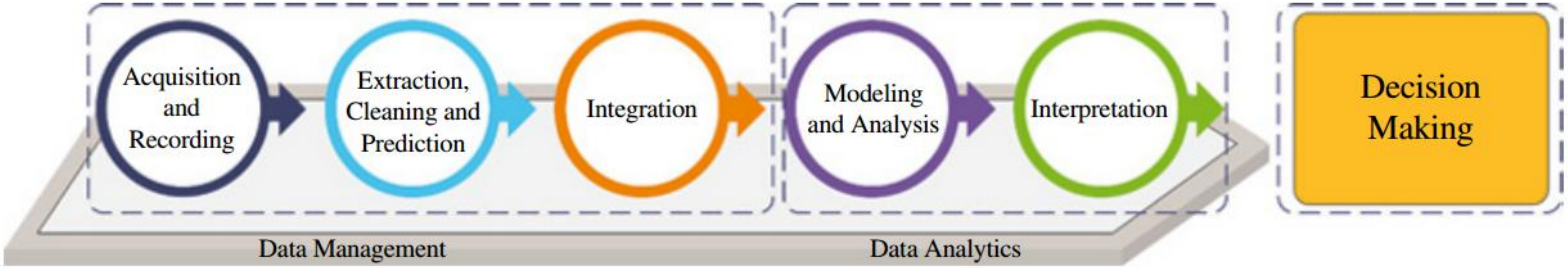
# Evolution of the power sector

SMART GRID



# Data management in smart grid

- **Massive and various amount of data** (electricity and information) new types of consumers (EVs, smart households, producers, …) and new communication equipment
- Assisting utilities **avoiding peak loads**, understanding **customers' behavior** and achieve grid **stability** and better **reliability**
- Big data processing: **data management and analytics**
- The role of artificial intelligence is pivotal, for **forecasting** too
- Security challenges and privacy

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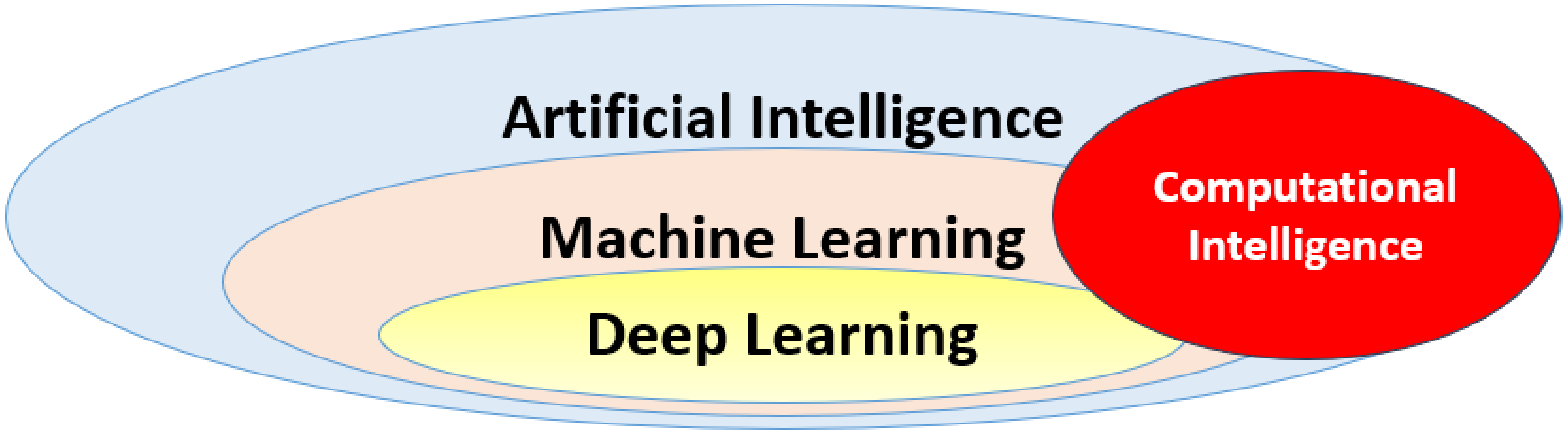
# Energy forecasting

- **Forecasting:** "a statement of what is judged likely to happen, based on information you have now" – Cambridge Dictionary
- **Three types of forecasting:** energy demand, energy production and price forecasting
- Various methods: persistence, linear regression, artificial intelligence



# Time horizon

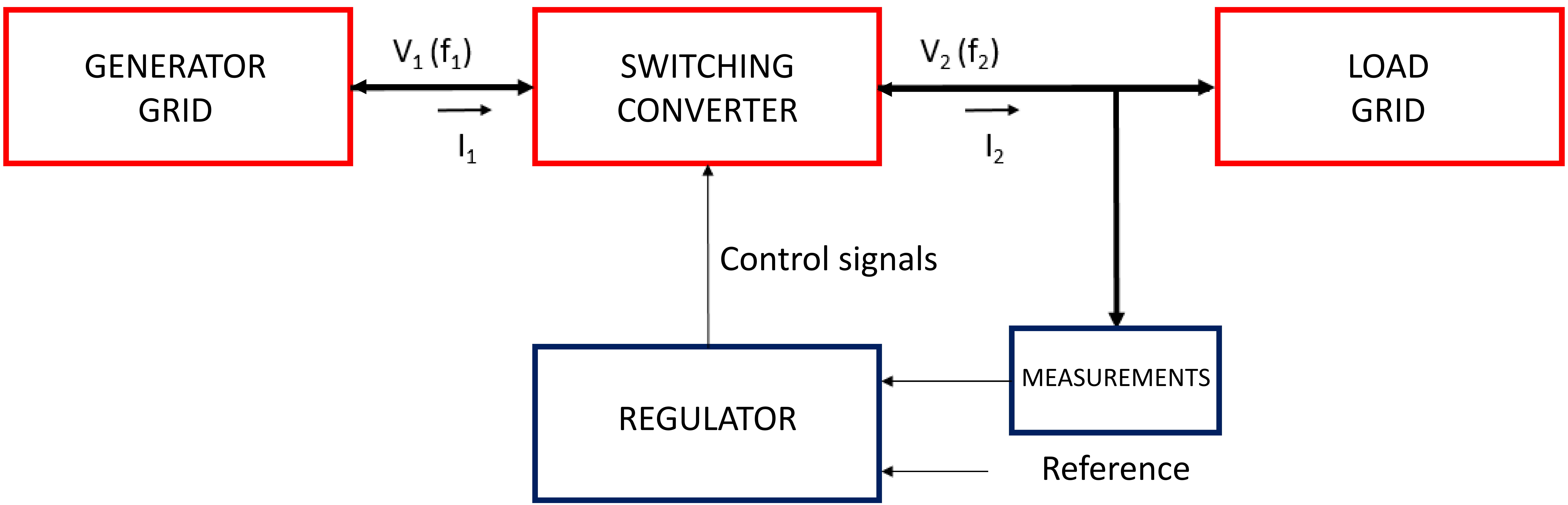
## Electric load forecast

| Name | Time Horizon |
|---|---|
| Long term | $\geq$ 3 years |
| Medium term | 15 days to 36 months |
| Short term | 1 to 14 days |
| Nowcasting | 1 to 60 minutes |

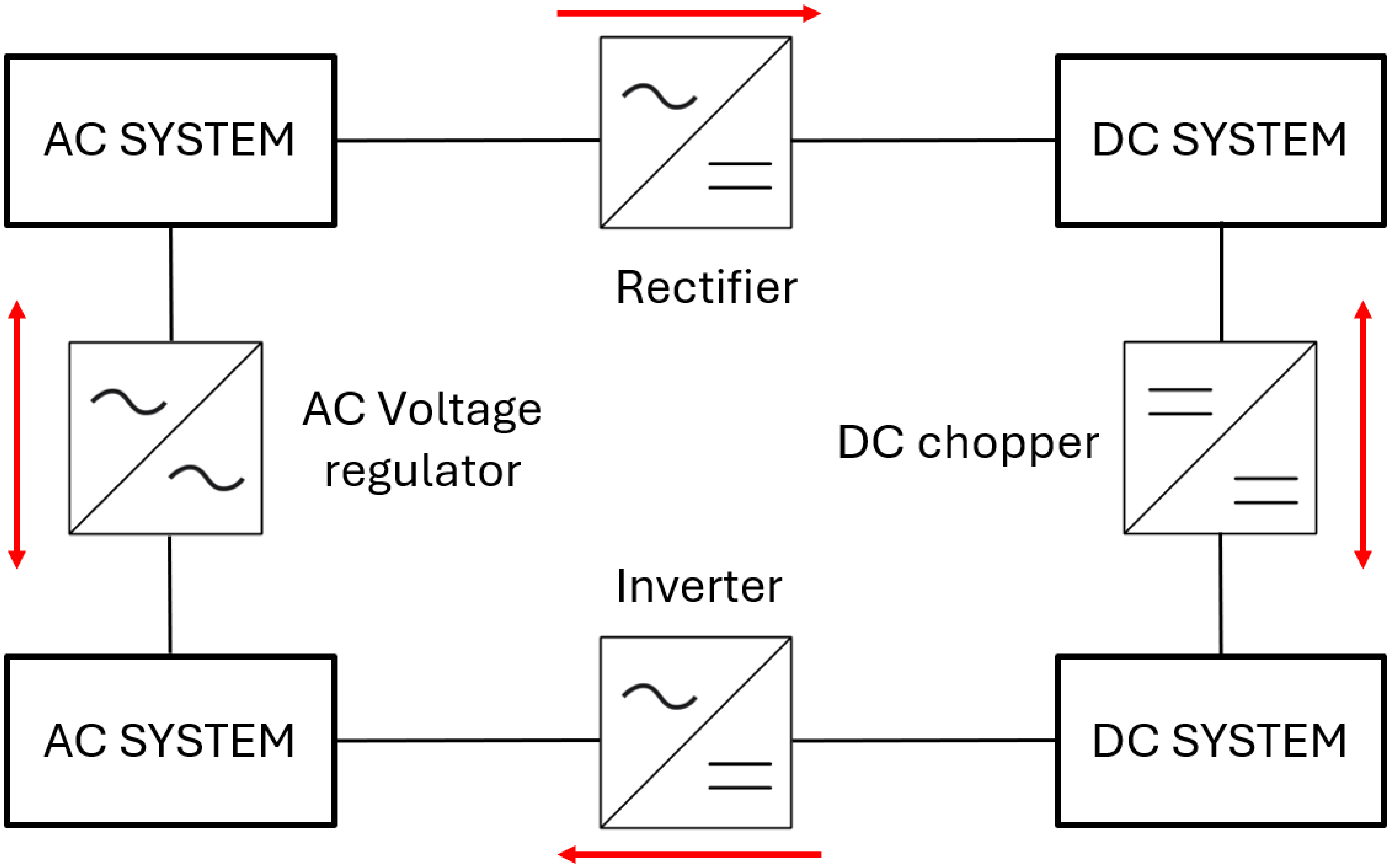
## RES forecast

| Term | Range | Application |
|---|---|---|
| Nowcast | Few sec. - 30' | Control & adjustment actions |
| Short | 30' - 1 day | Dispatch planning; electricity market; unit commitment |
| Long | 1 day - 1 week | Reserve requirements; maintenance schedule |

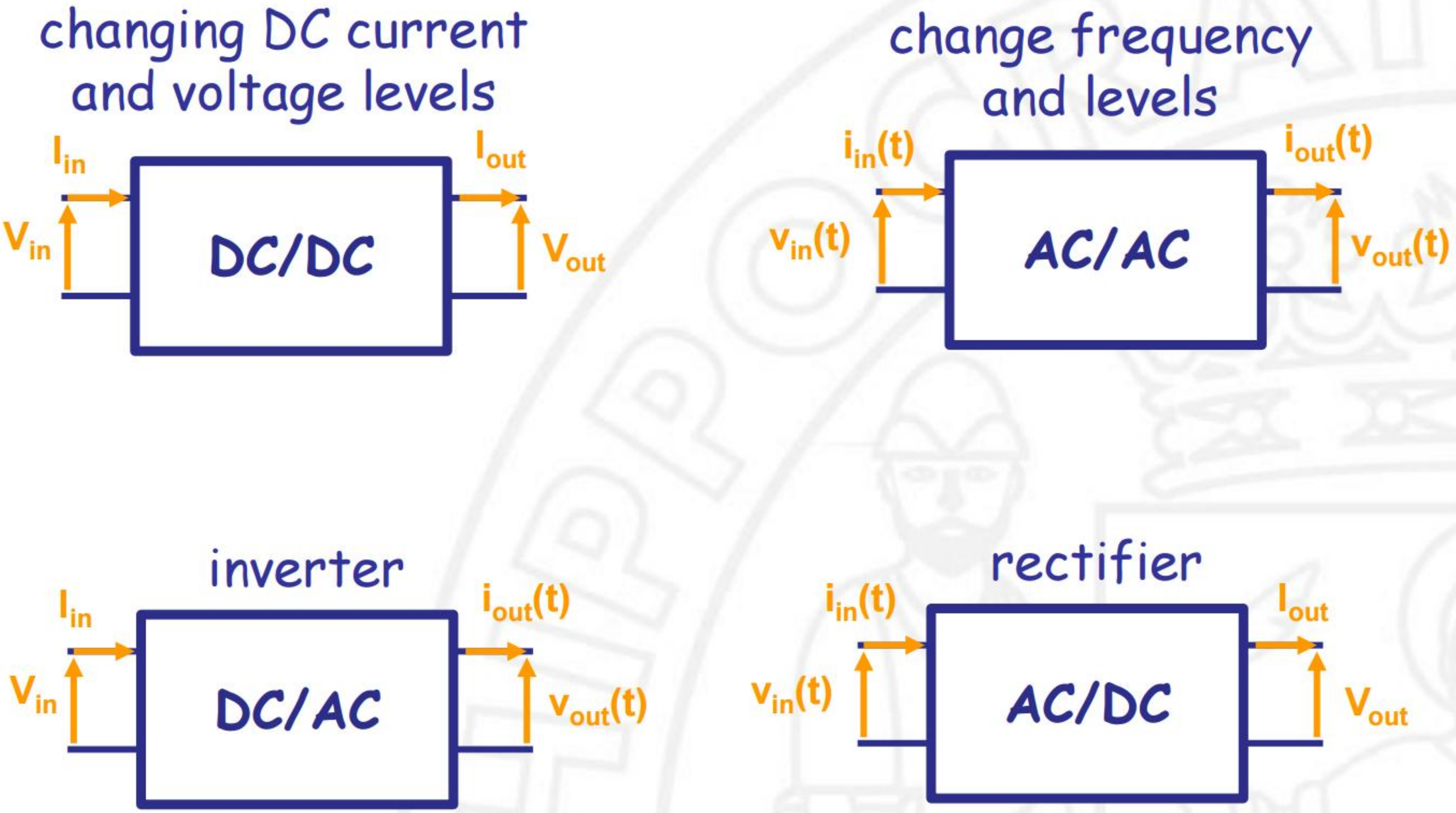
# Power electronics



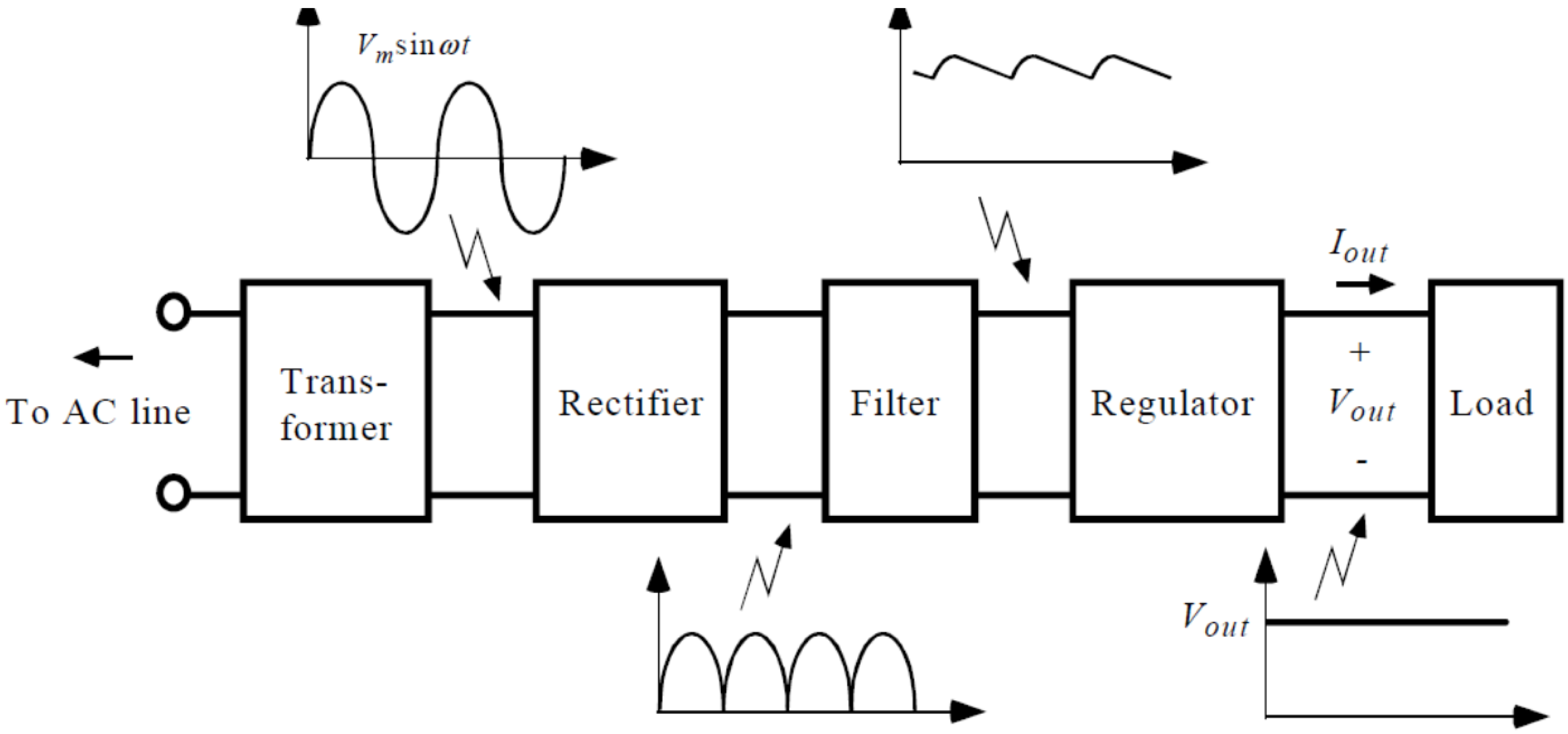
# Power electronics



# Switching converters categories



# Application example: power supply

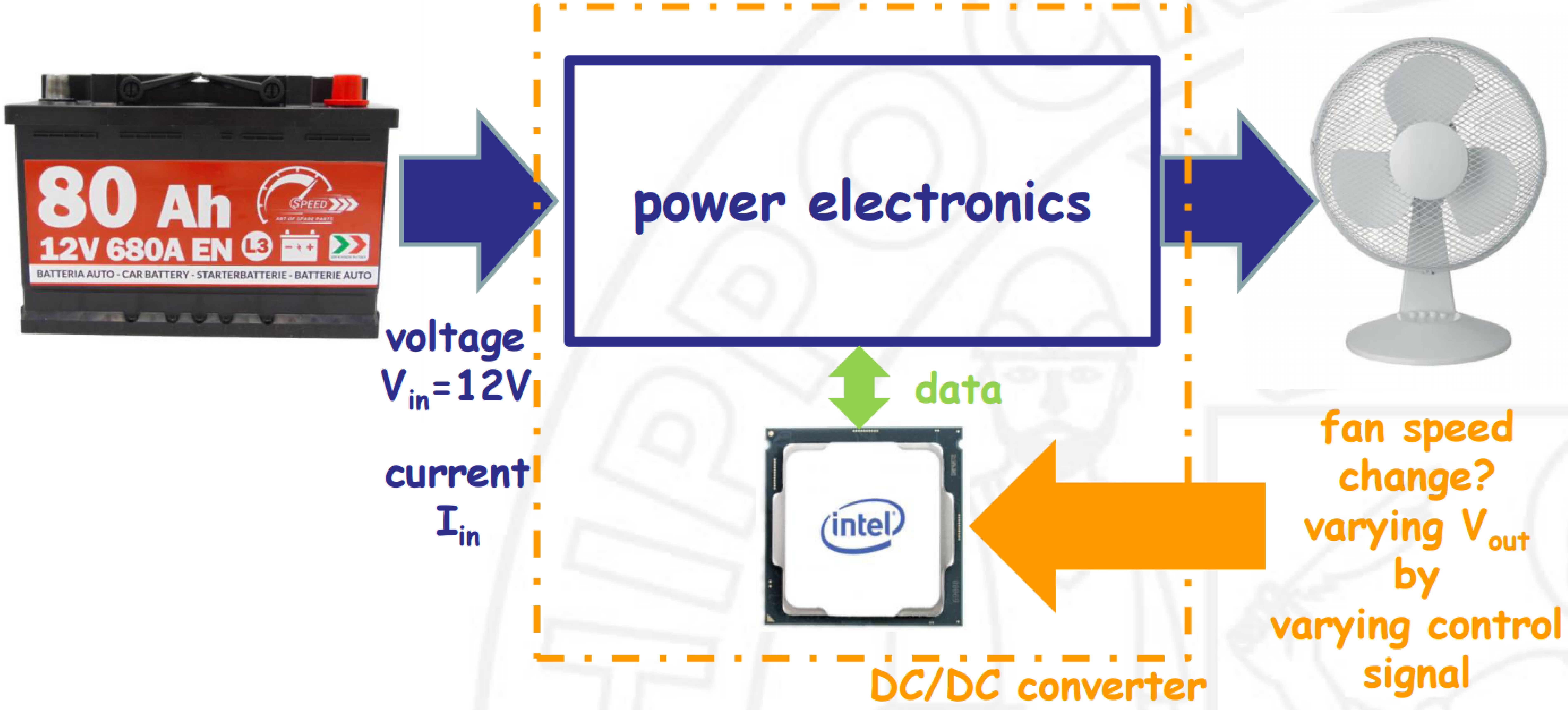



Components of a typical linear power supply

In real applications, waveforms are far from ideal DC and AC

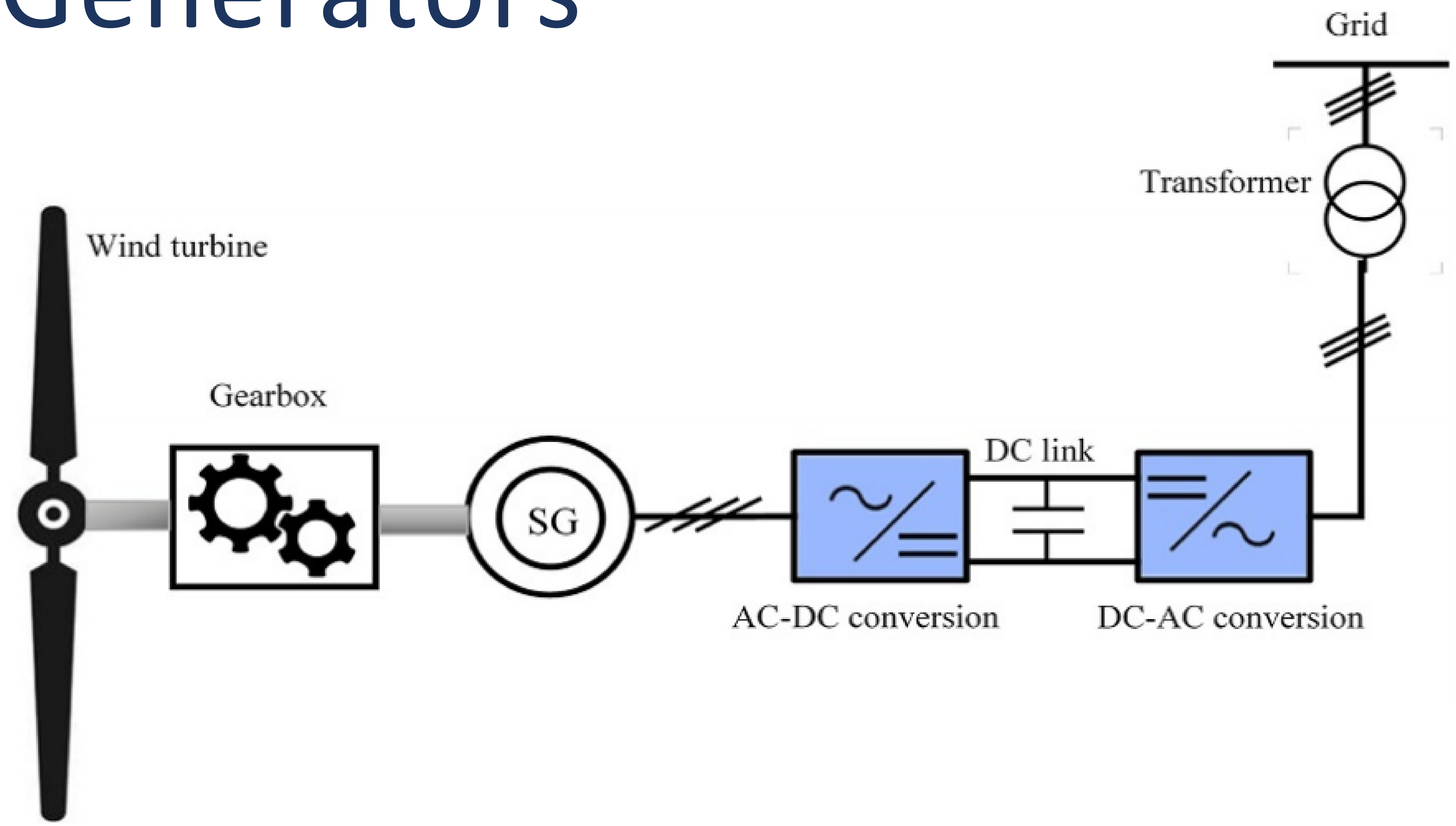
# DC-DC converter example

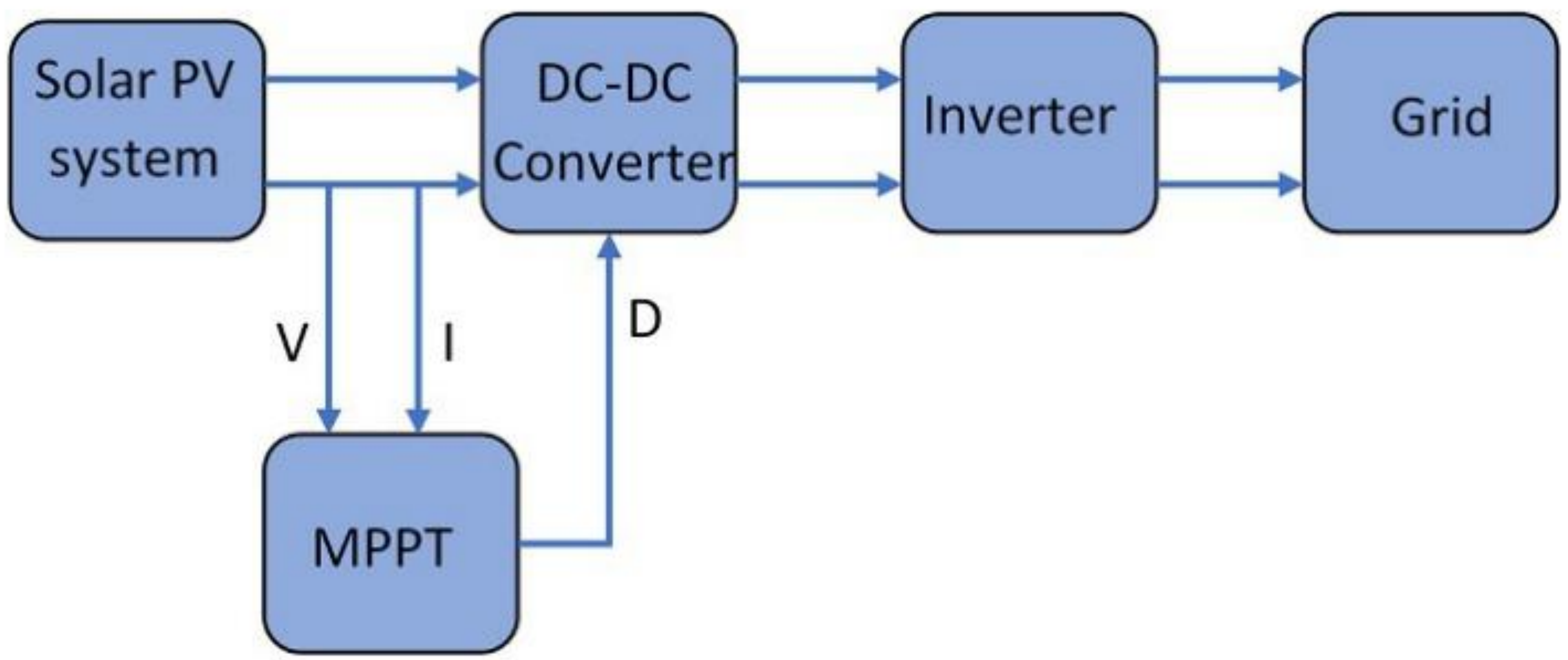
Transforms DC current/voltage in DC current/voltage

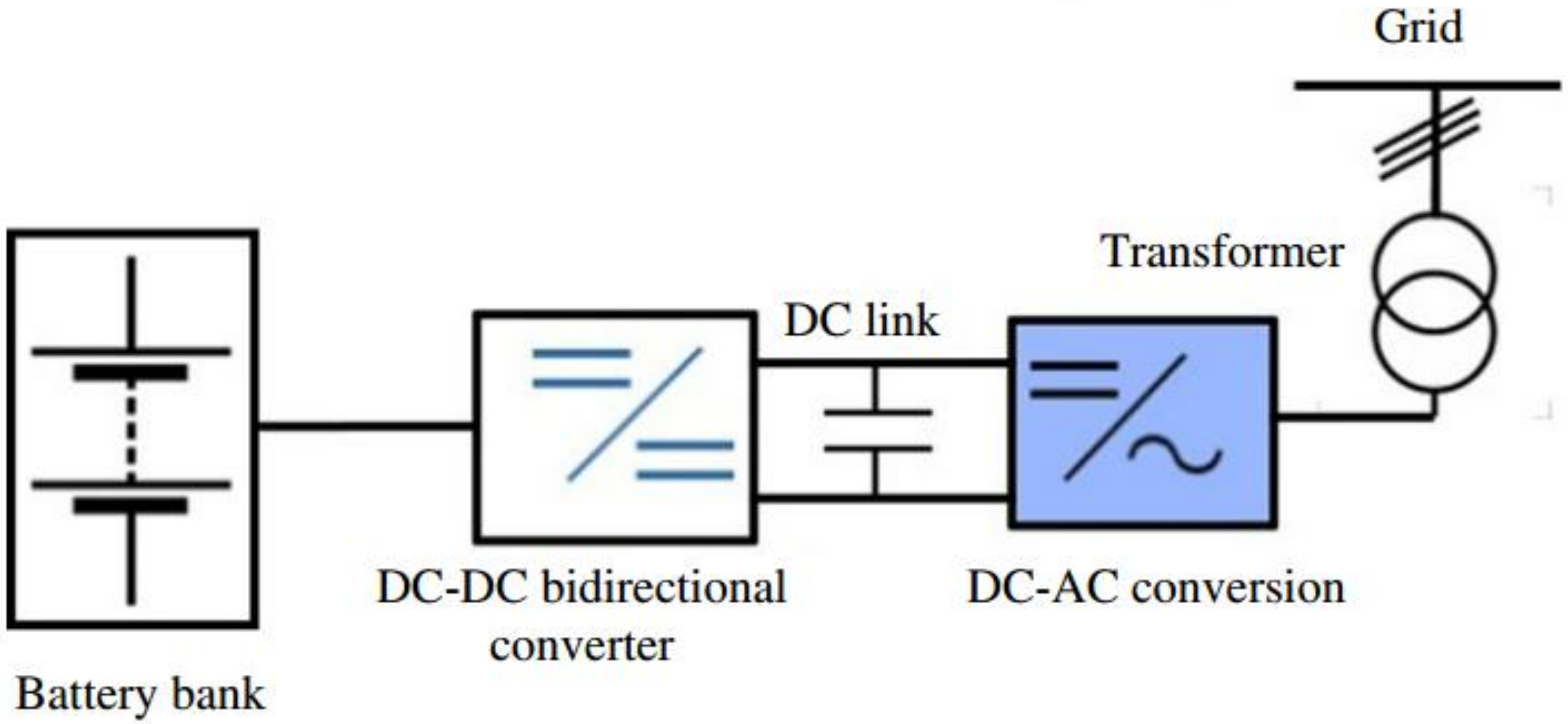



Input and output power are almost equal, different V and I

# “Generators”

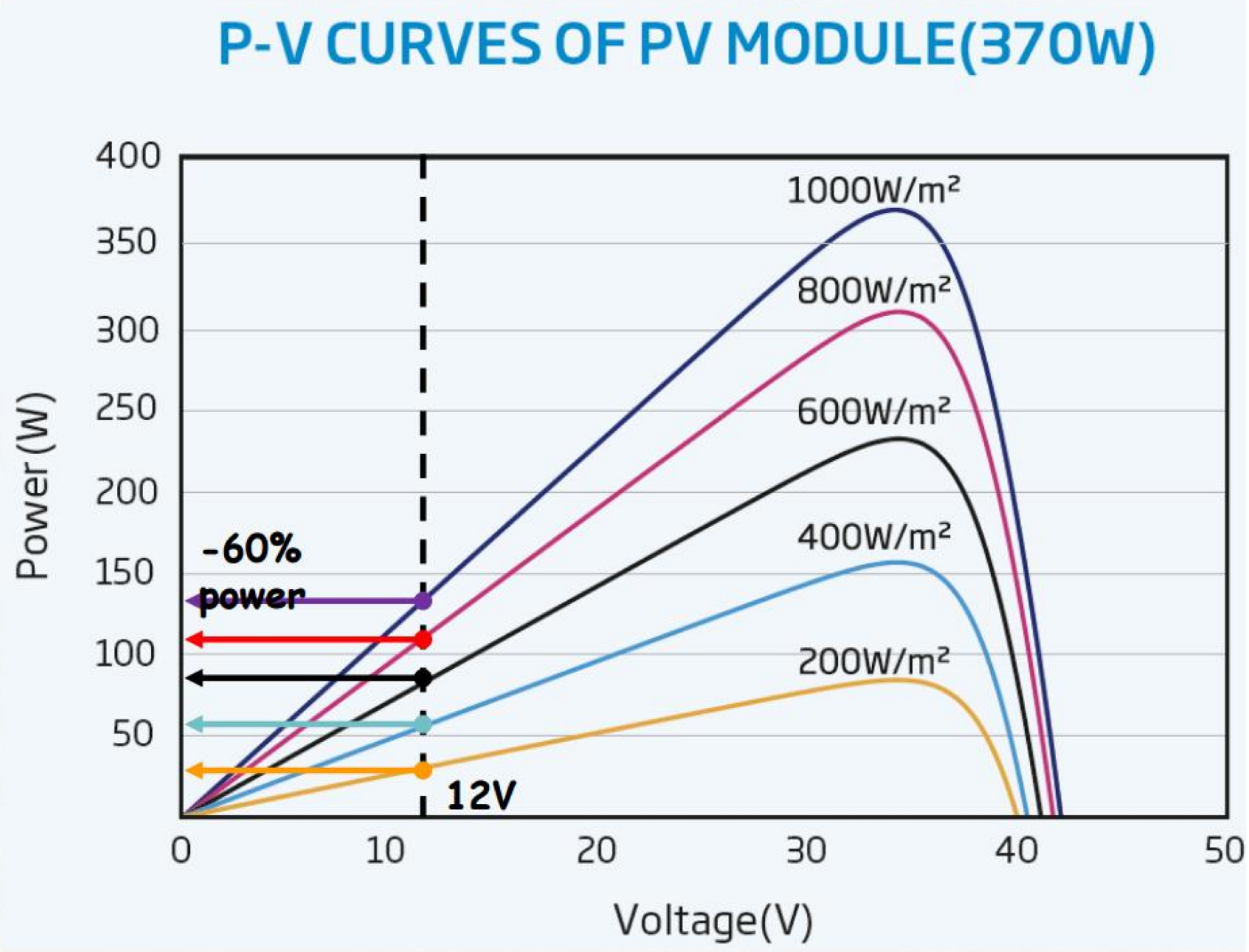

Grid
Transformer
Wind turbine
Gearbox
SG
DC link
AC-DC conversion
DC-AC conversion


Solar PV system
DC-DC Converter
Inverter
Grid
V
I
D
MPPT


Grid
Transformer
DC link
Battery bank
DC-DC bidirectional converter
DC-AC conversion

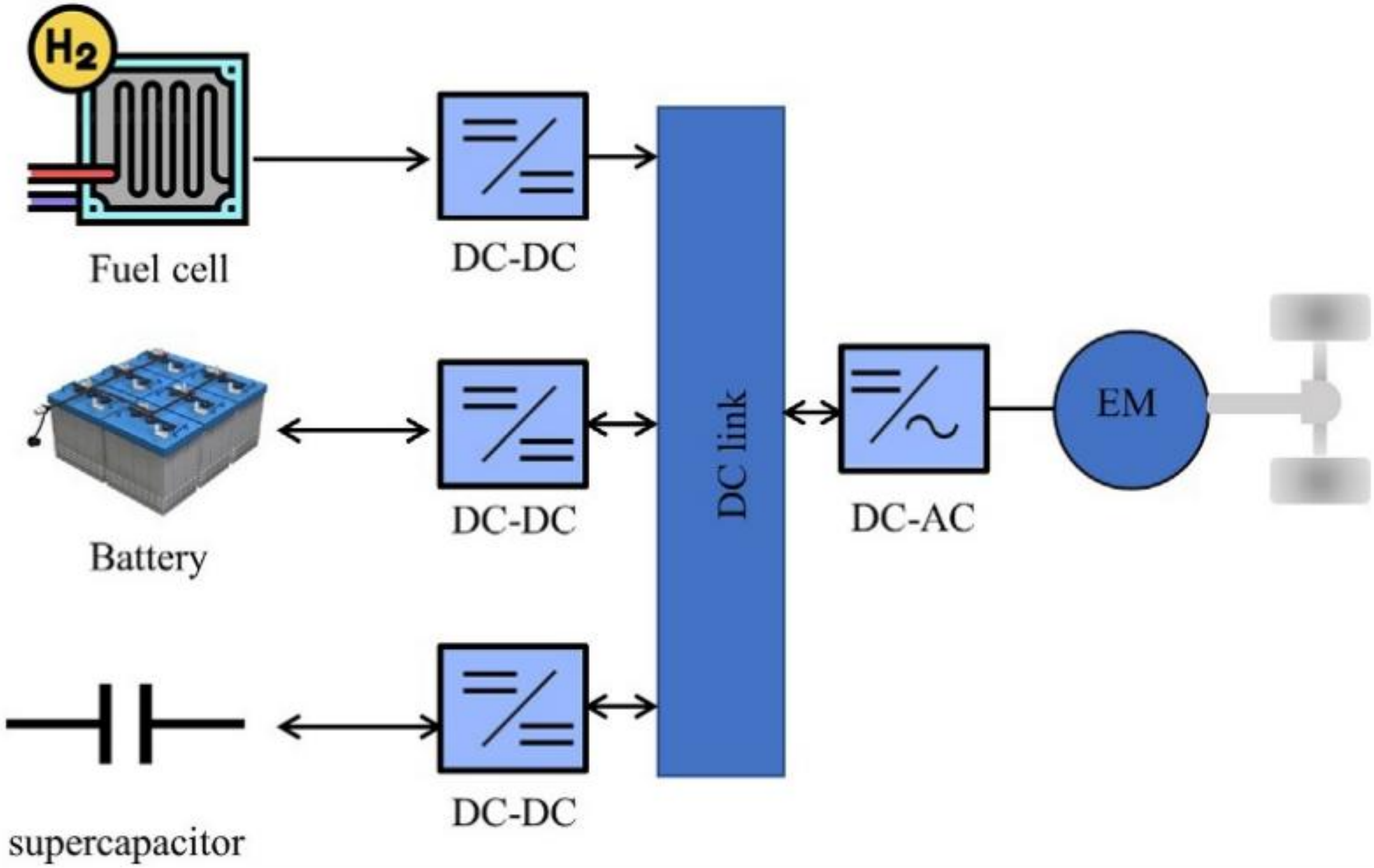
# DC-DC converter example

Take a module from the market and connect it to the battery DIRECTLY! NO DC/DC converter in the middle.


G. Spagnuolo

# Electrical vehicles

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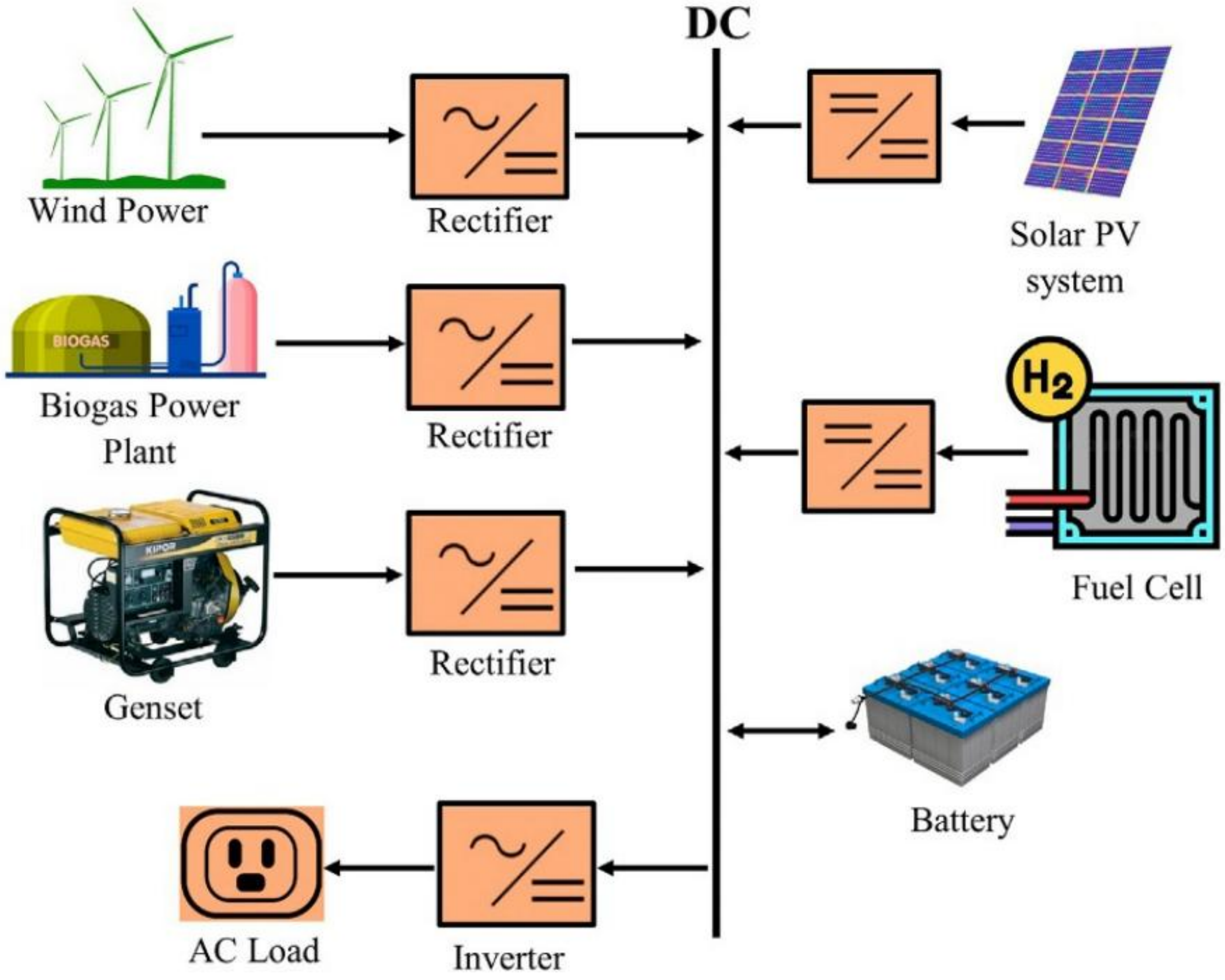
# Hybrid systems

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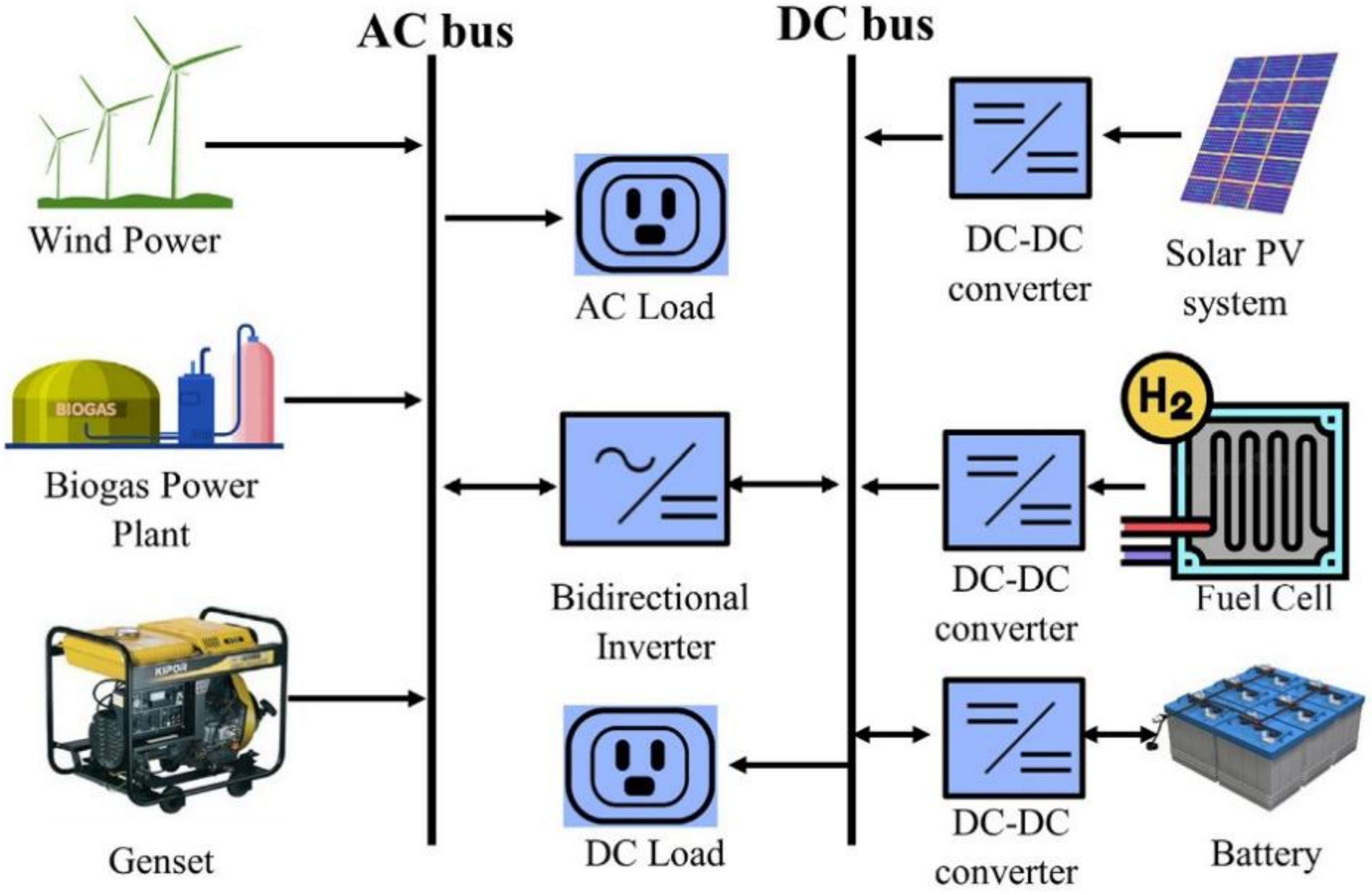
# Hybrid systems

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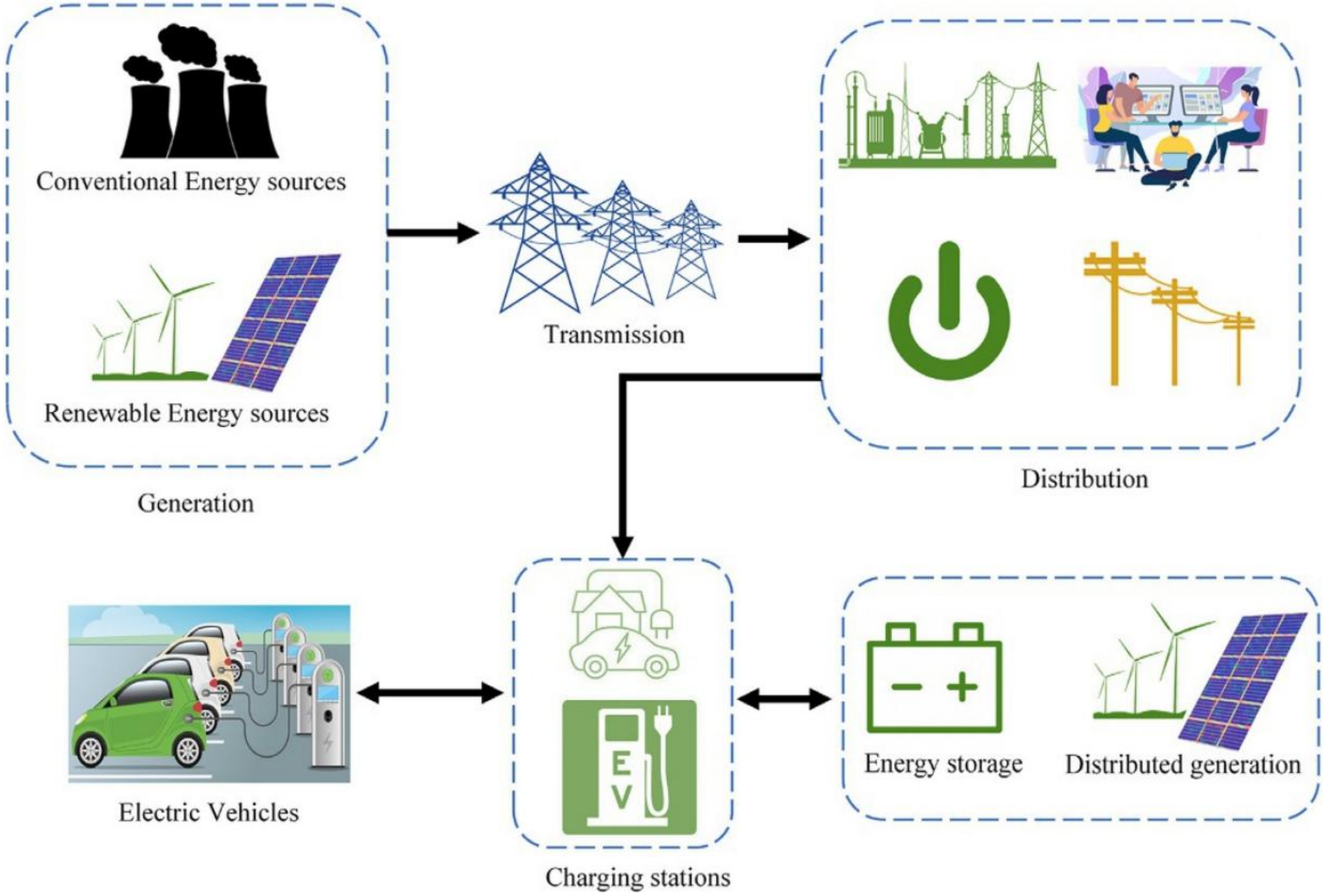
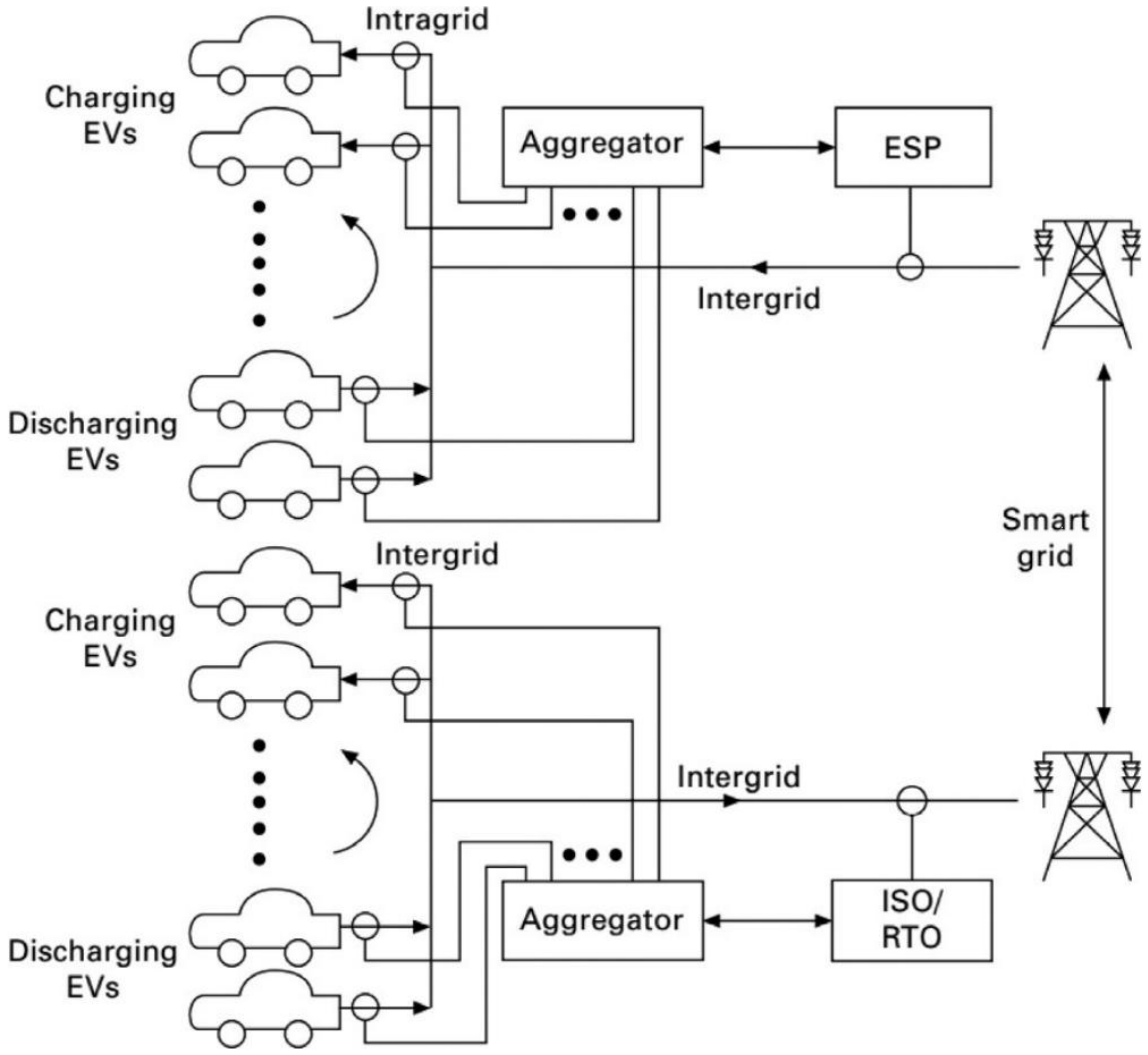
# EVs integration

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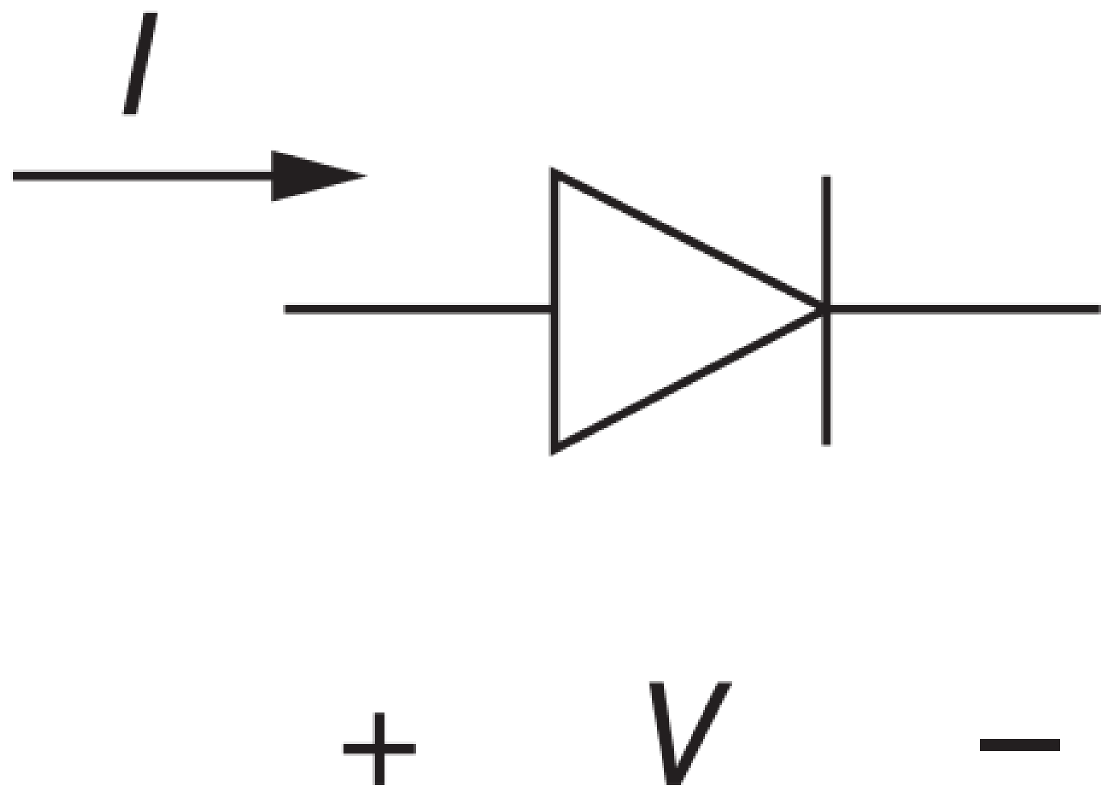
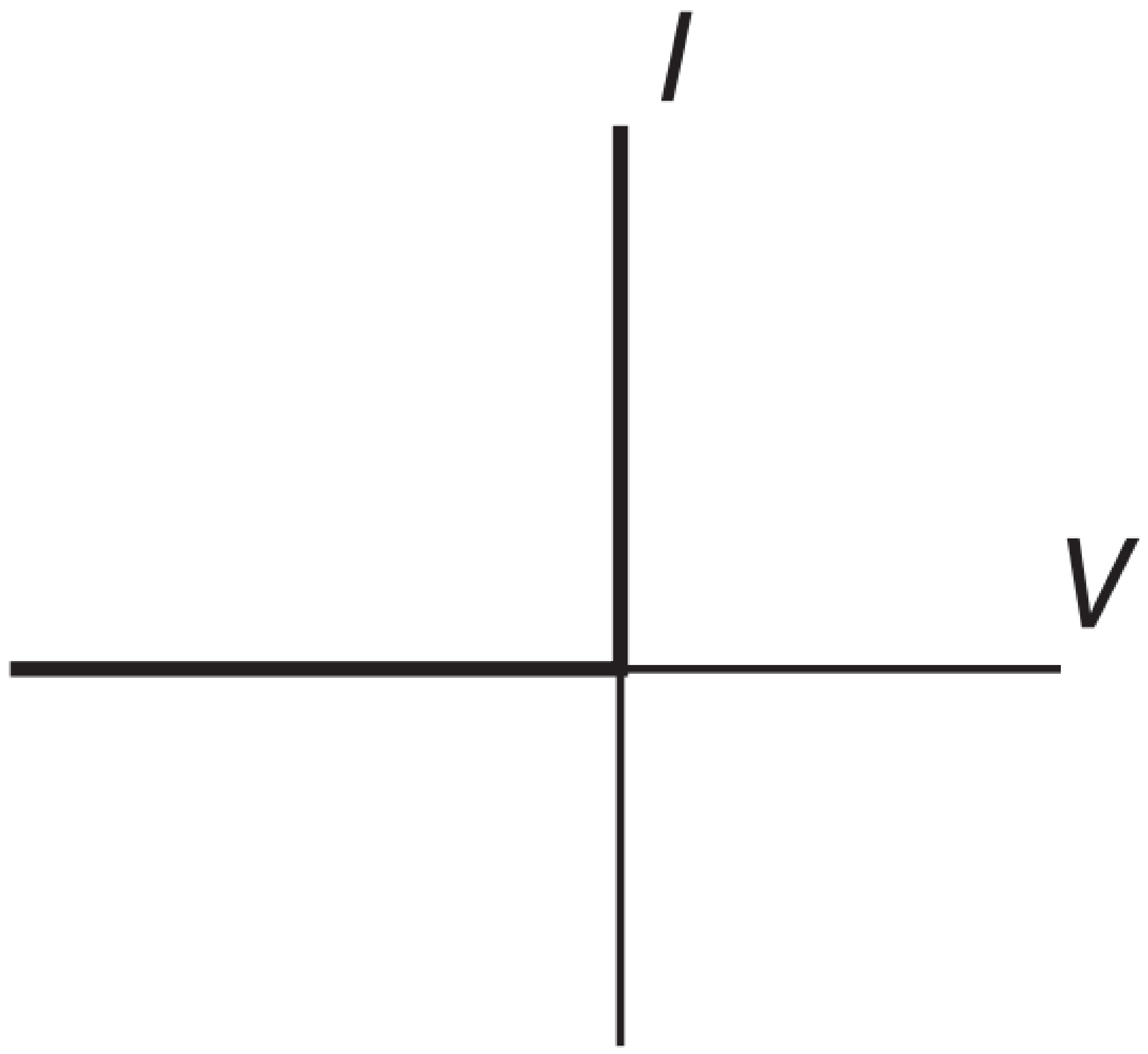
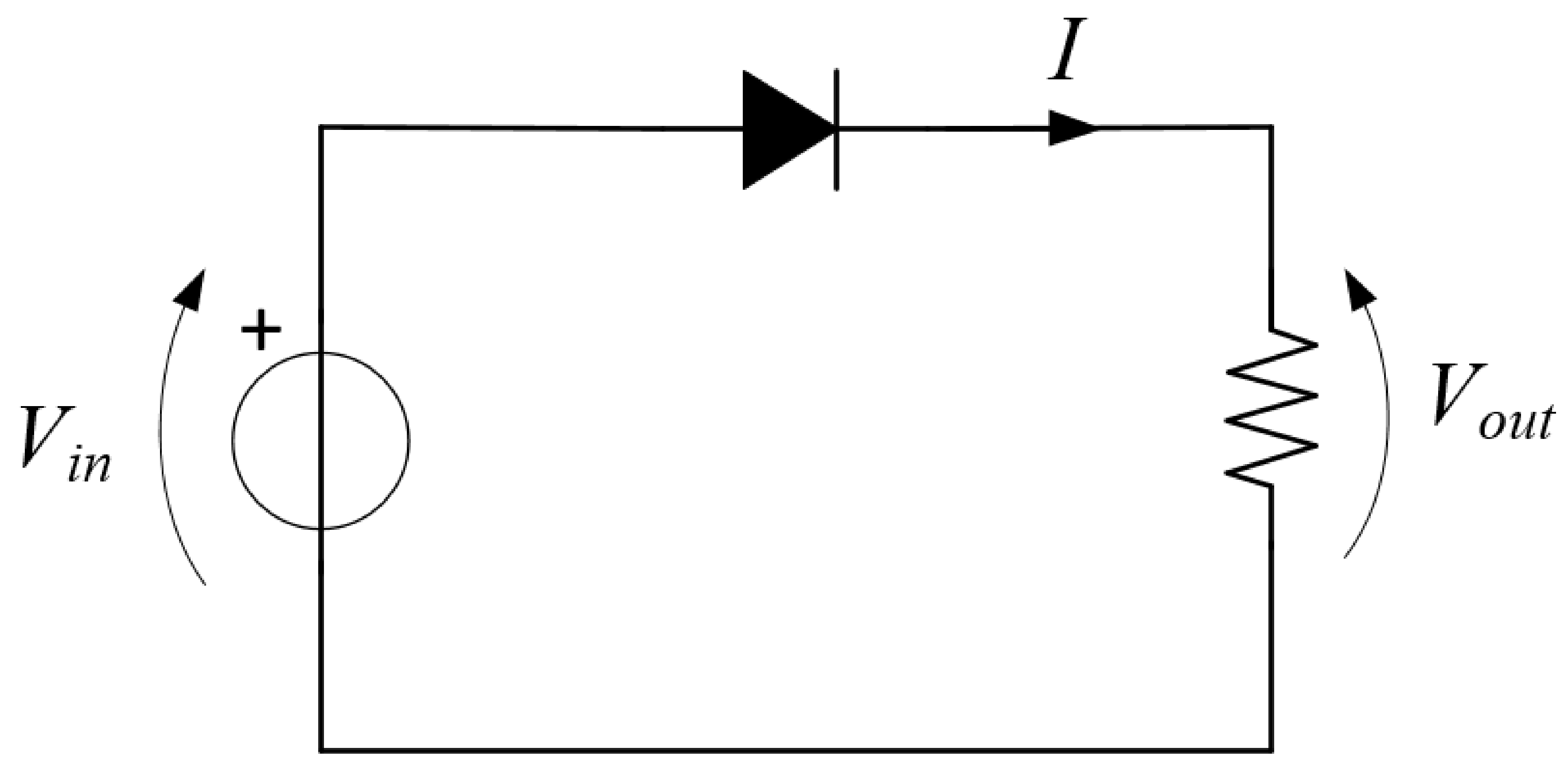
# Switching devices: diode

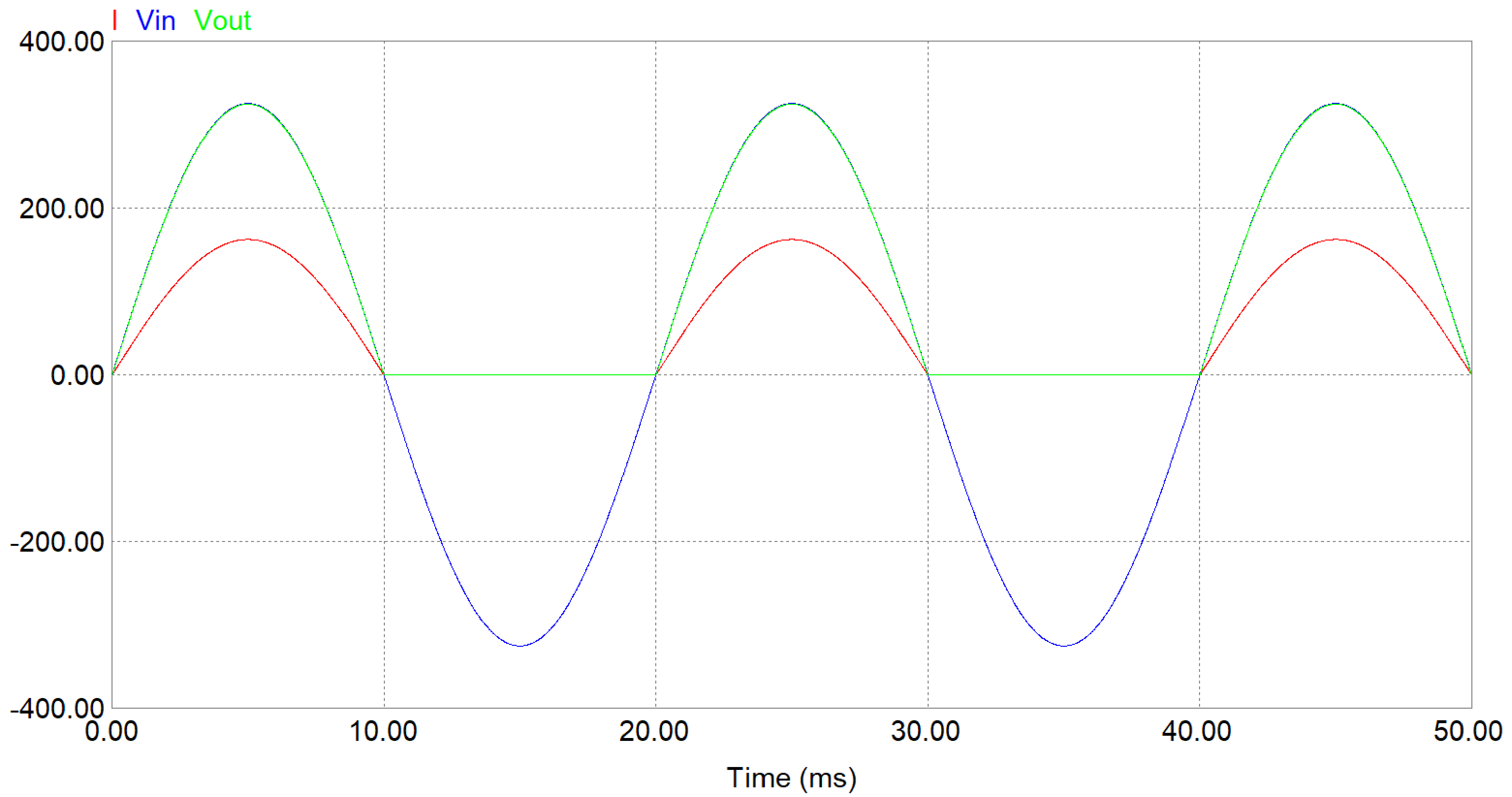



- Current can flow in one direction only
- When the voltage across the diode is positive
- The I-V characteristic shown here is of an ideal diode
- Solar cells …
- LED …

# Single-phase uncontrolled rectifier with resistive load

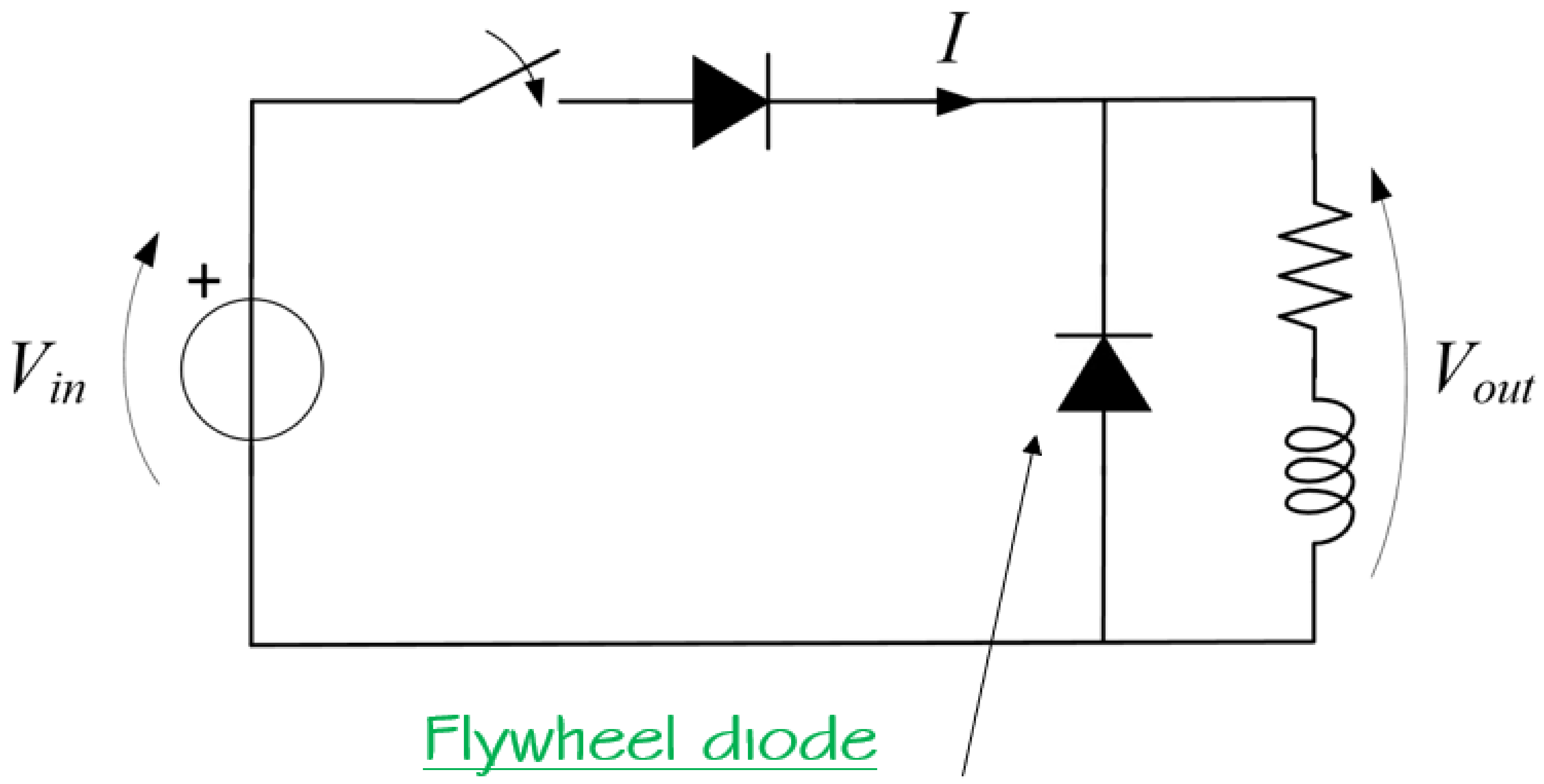


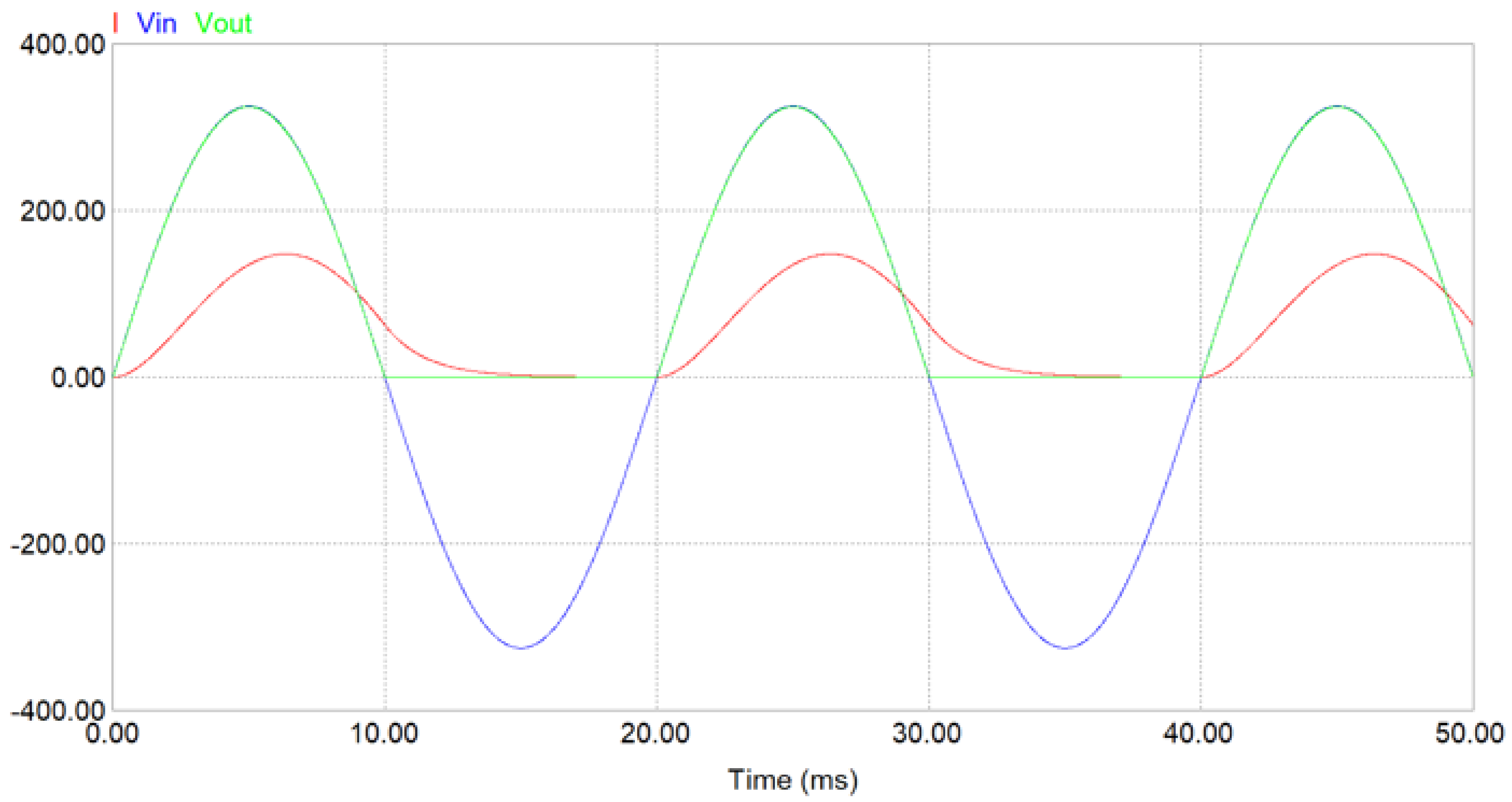




- When $V_{in}$ is positive, current flows through the diode in the direction shown by the symbol and the voltage is "copied"
- When $V_{in}$ is negative, no current flows at all and the voltage is zero
- Not widely used
- The AC current ($I_{in}$) is problematic

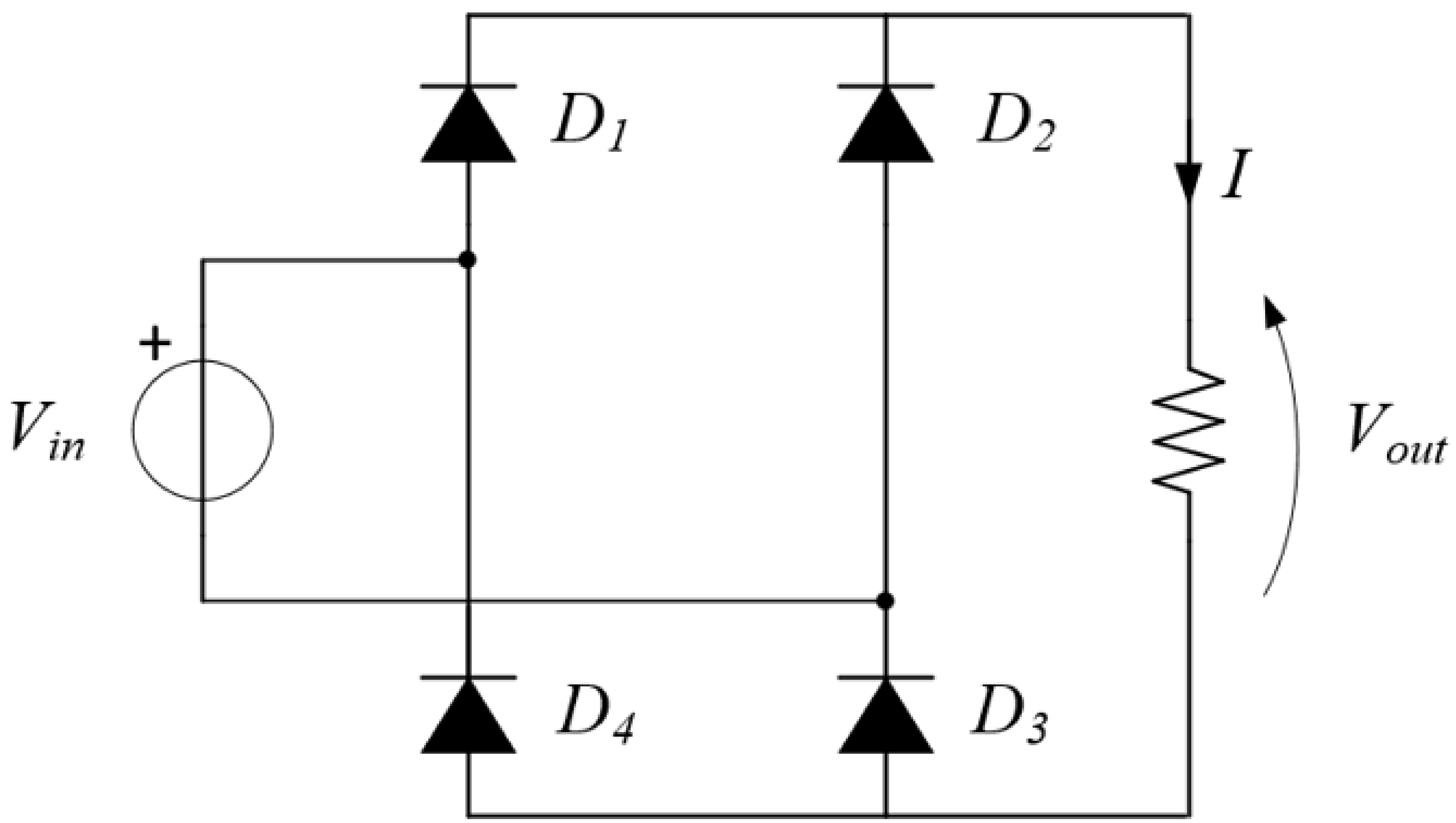
$$V_{out} = \frac{1}{2\pi}\int_0^{\pi} V_{in} \sin \omega t \, d(\omega t) = \frac{V_{in}}{\pi} = 0{,}318 V_{in}$$

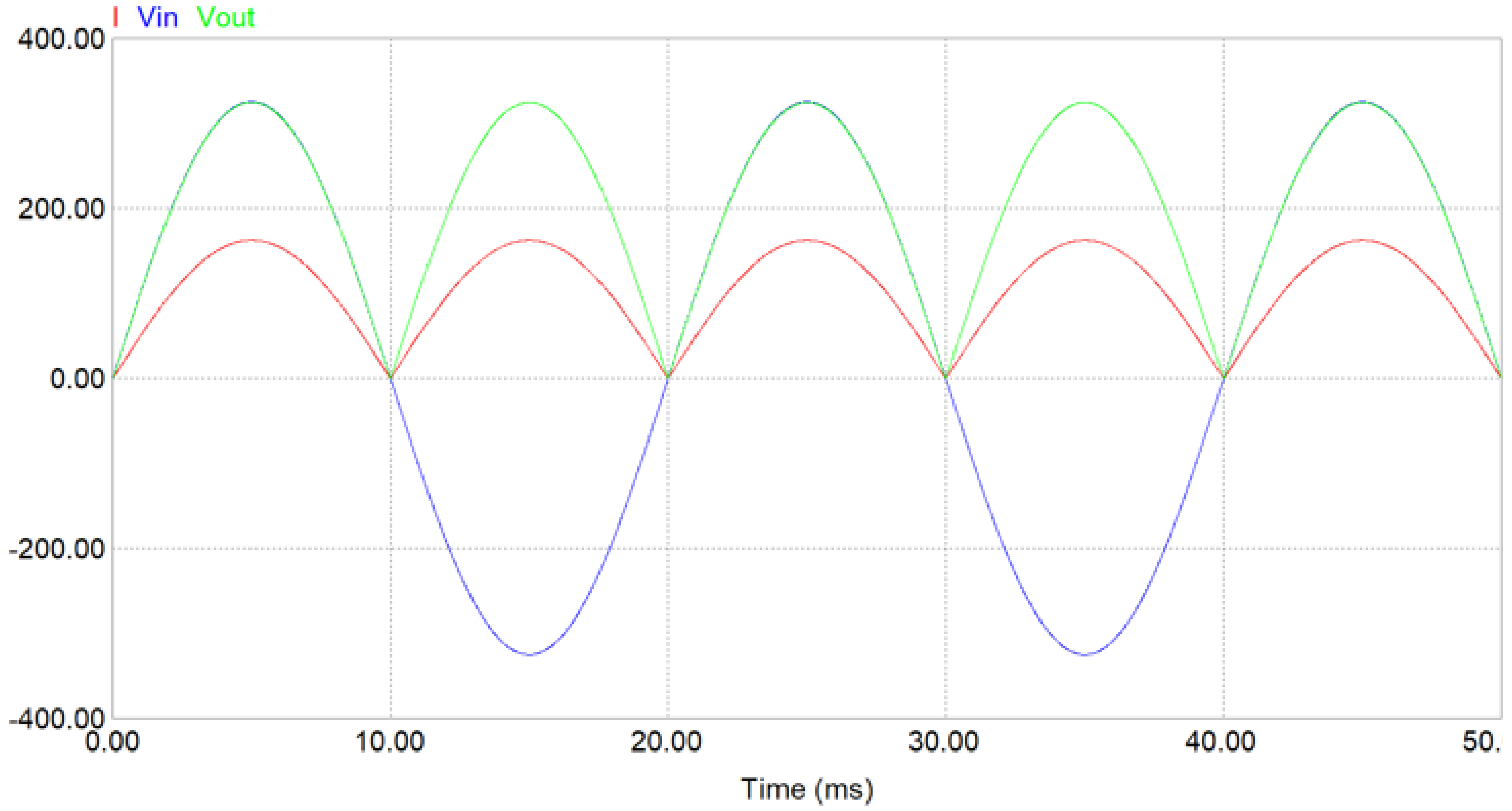
# Single-phase uncontrolled rectifier with inductive load



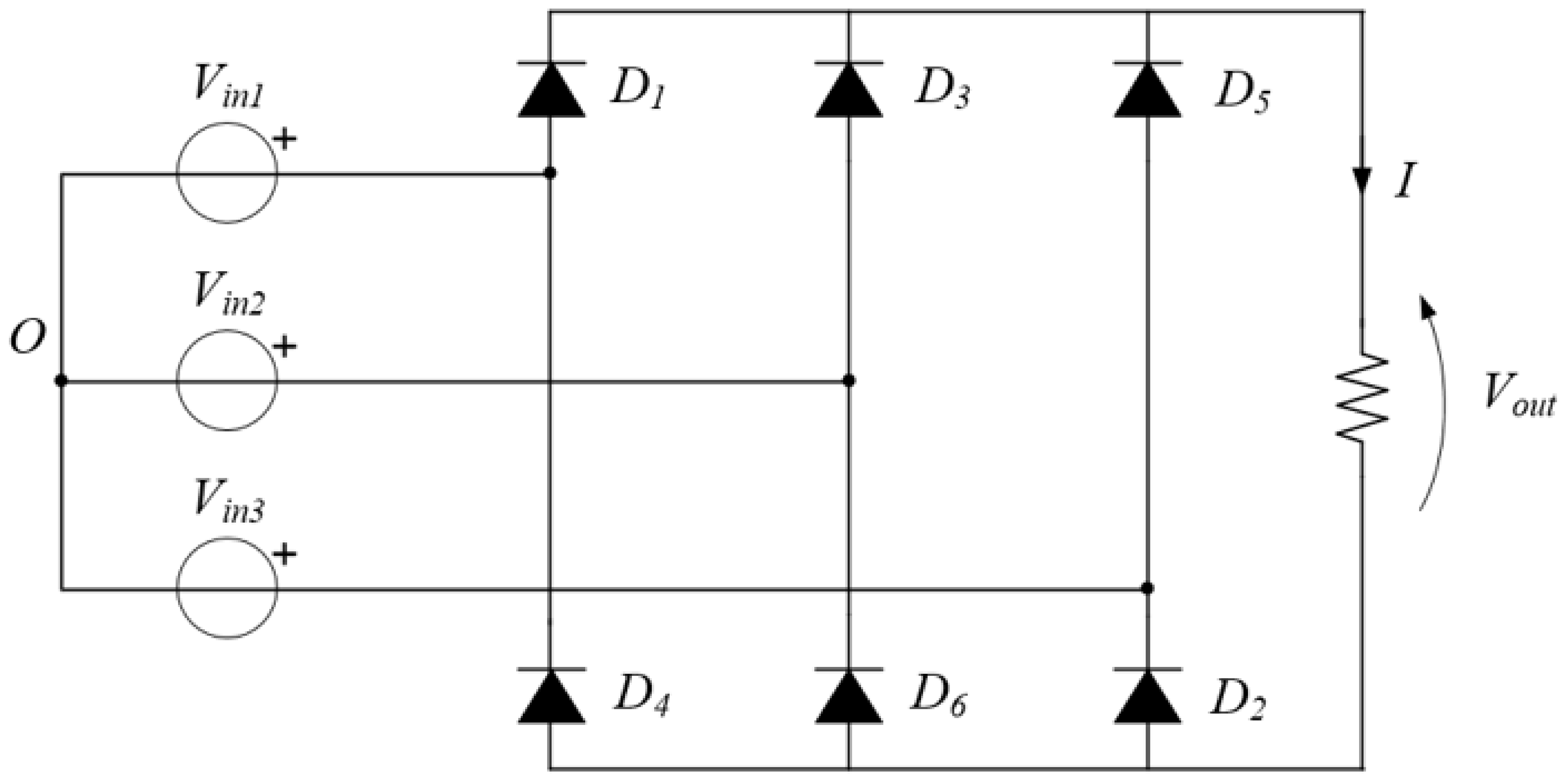
# Full-wave rectifier

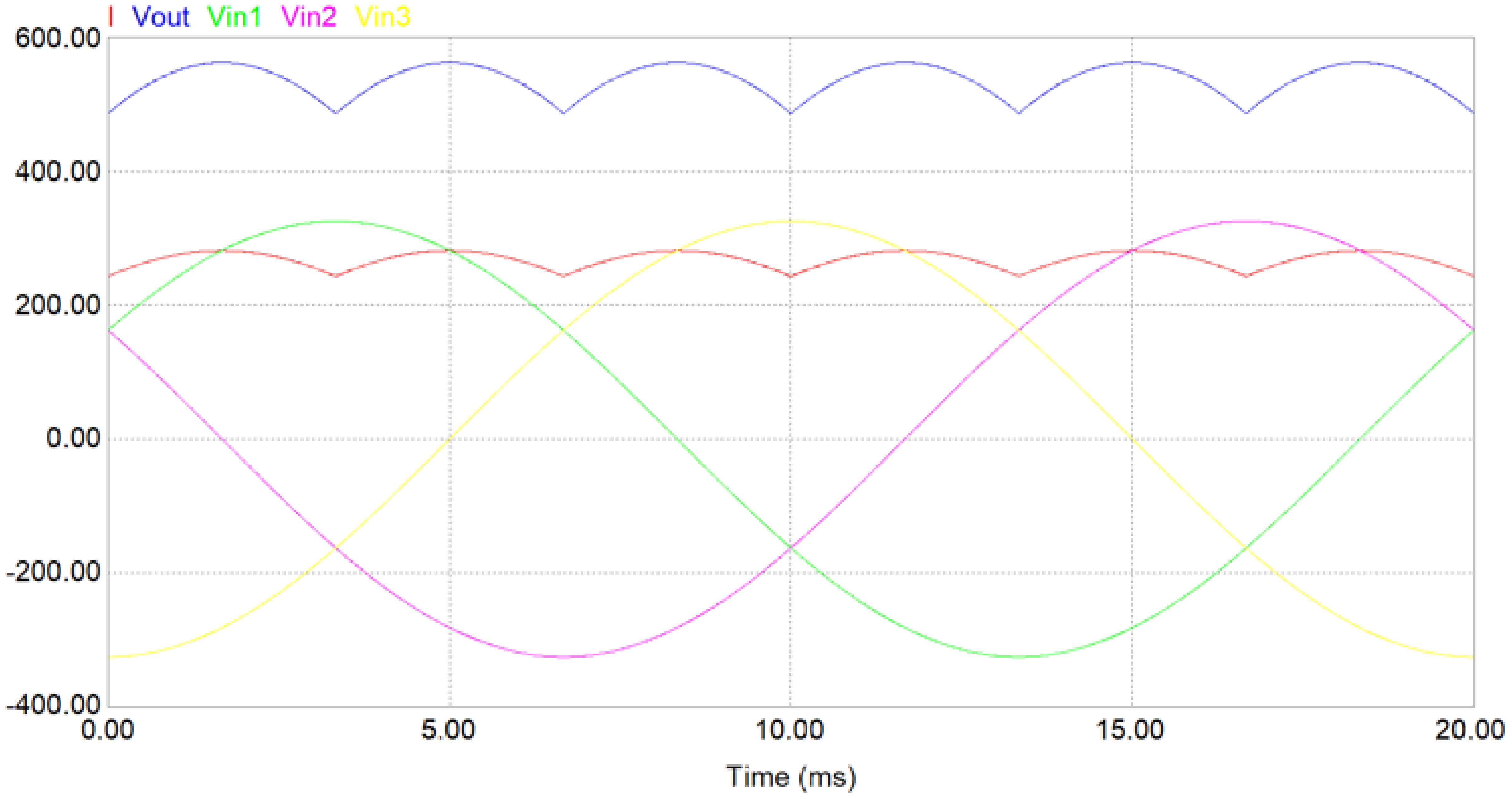


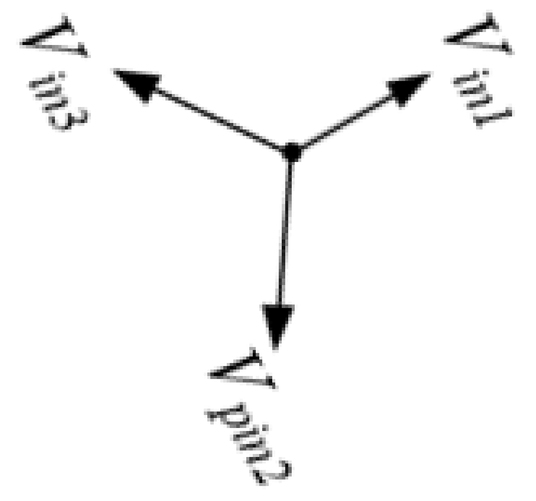




$$V_{out} = \frac{2V_{in}}{\pi} = 0{,}6366V_{in}$$

# Three-phase rectifier

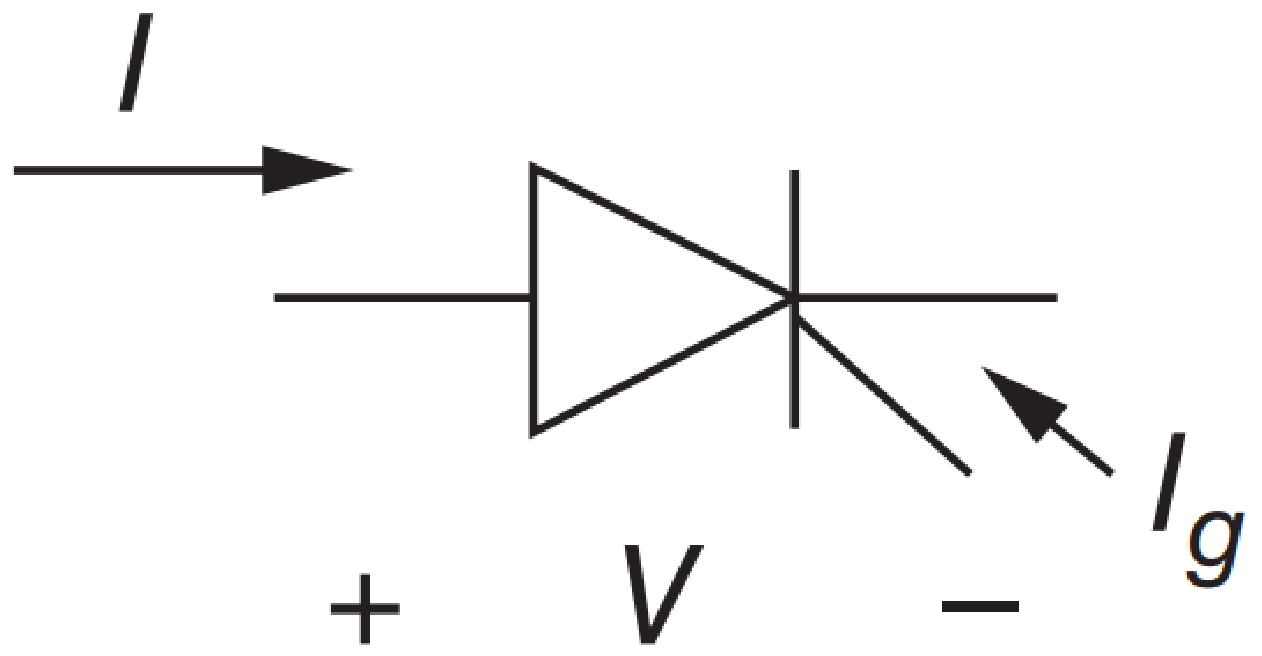


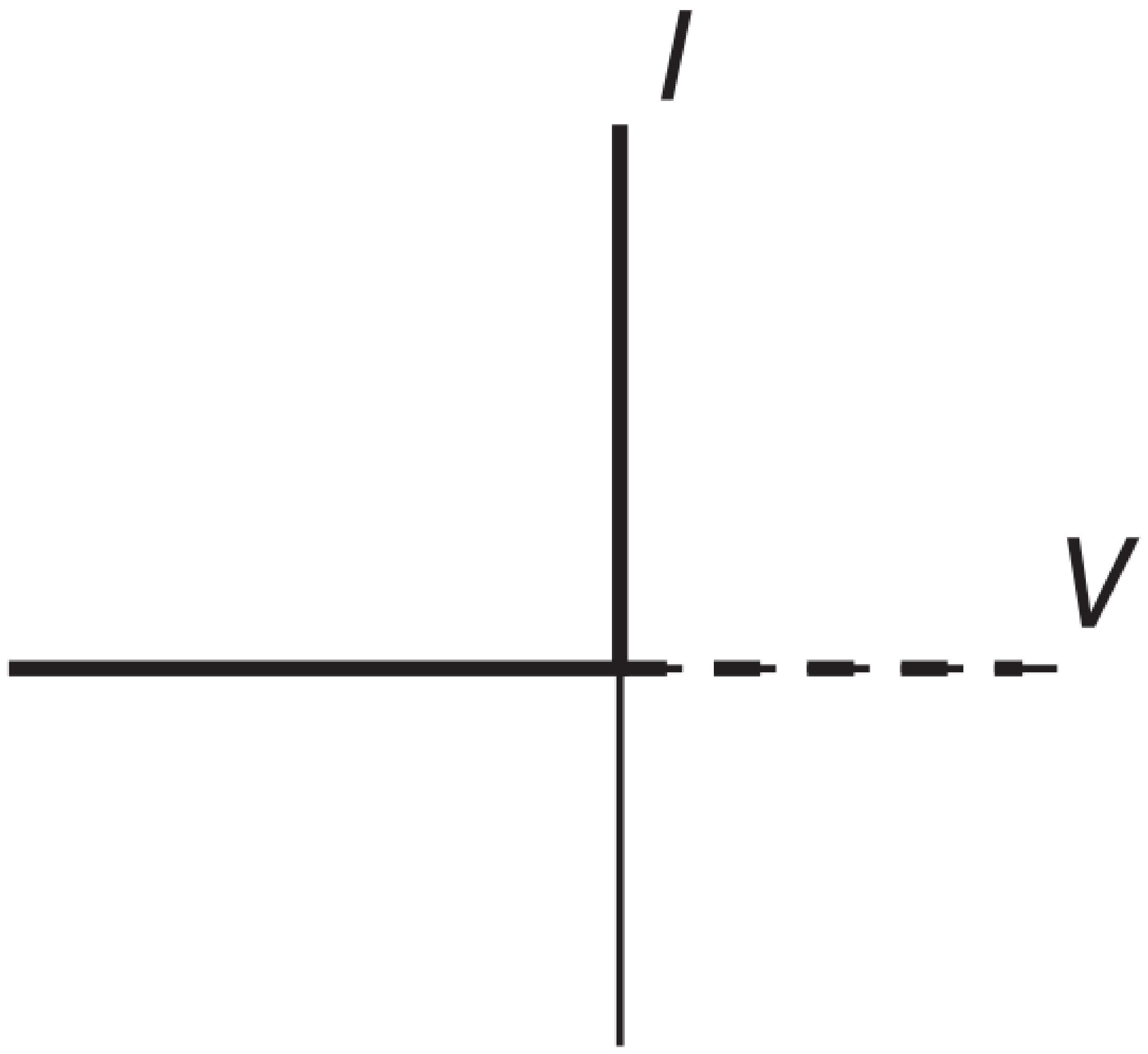




$$V_{out} = \frac{3\sqrt{3}}{\pi} V_{in} = 1{,}654 V_{in}$$

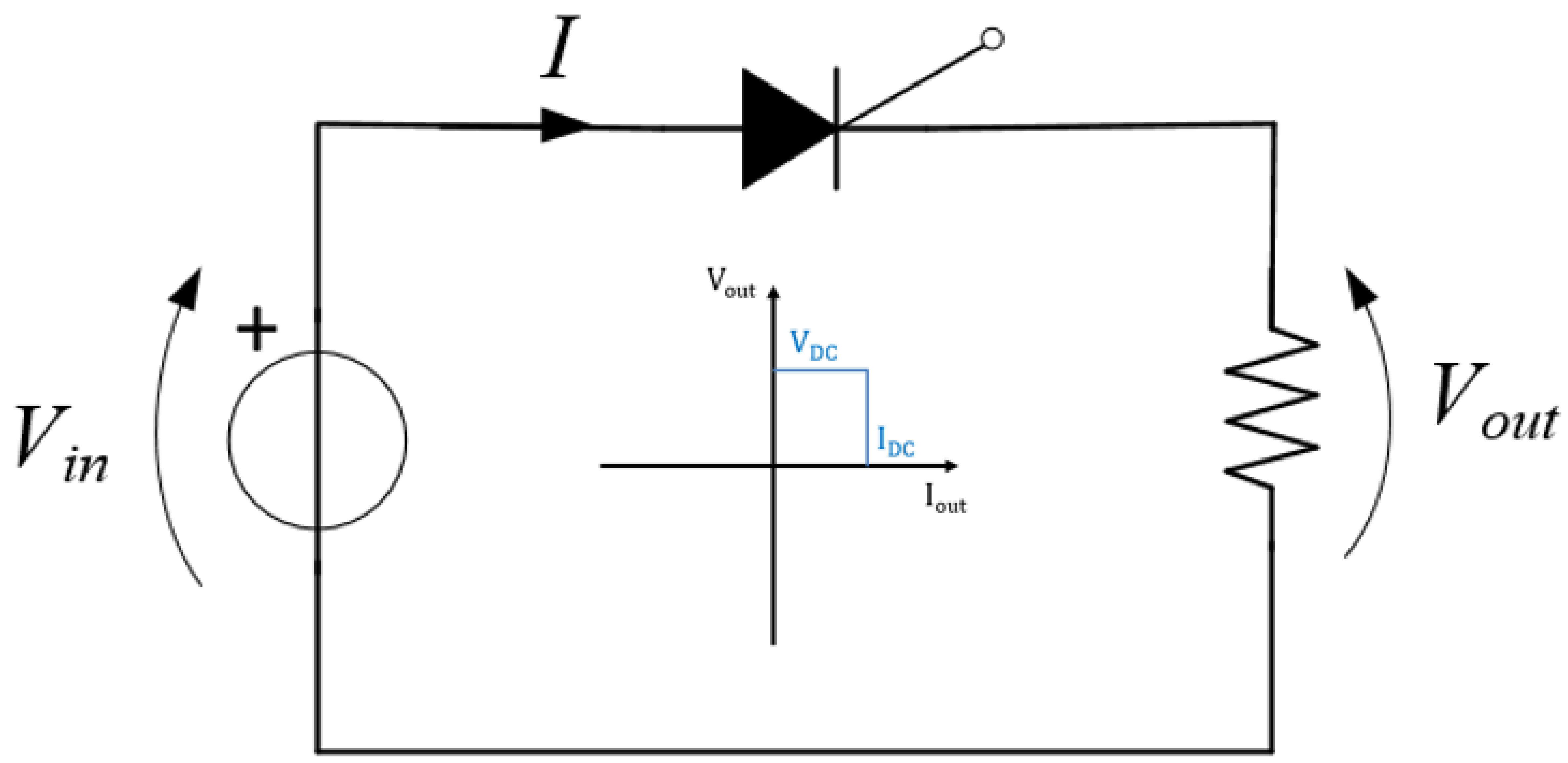
# Switching devices: thyristor

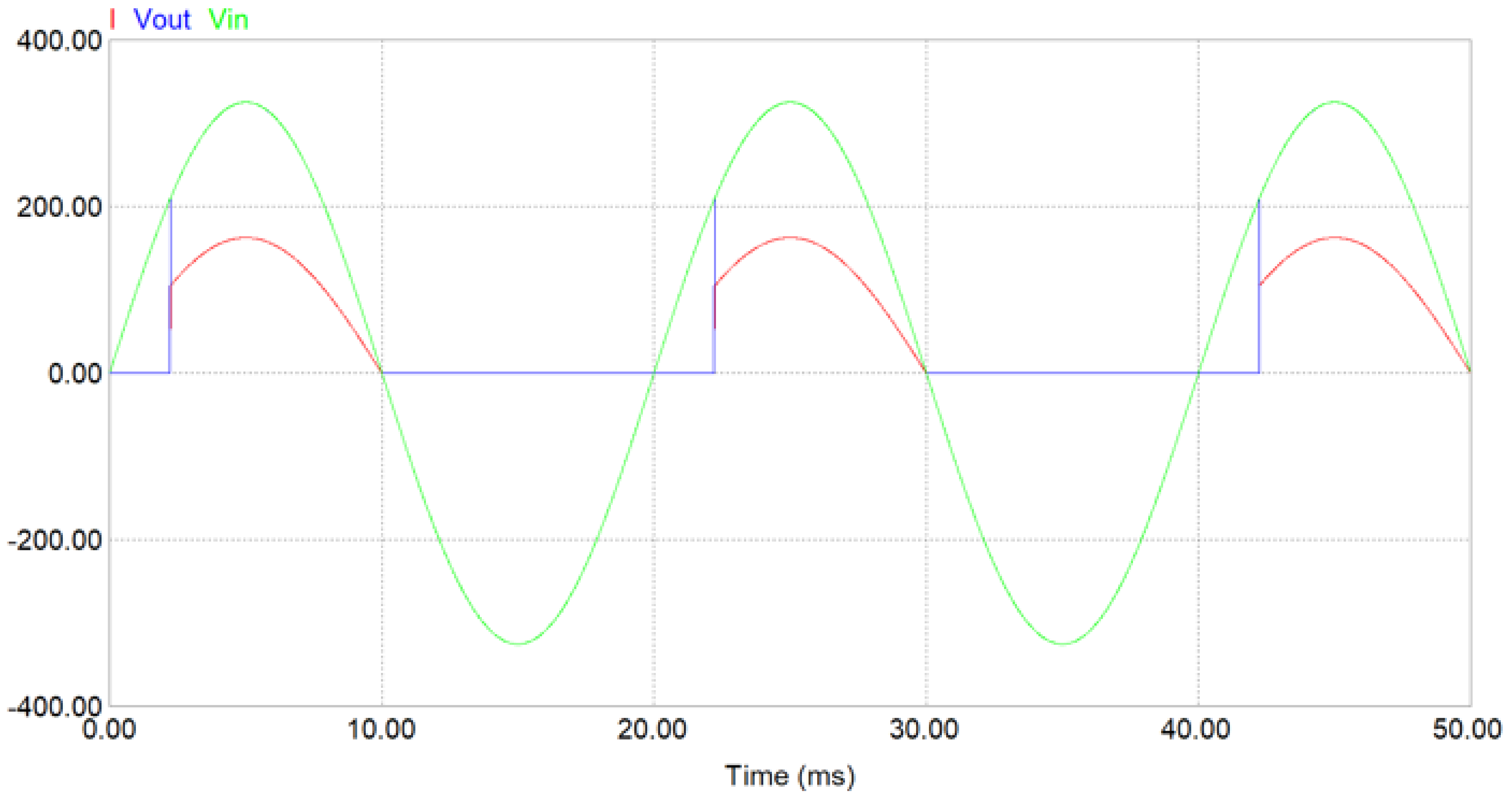



- Current can flow in one direction only
- When triggered by injecting current into its gate
- When the voltage across the thyristor is positive
- The I-V characteristic shown here is of an ideal thyristor

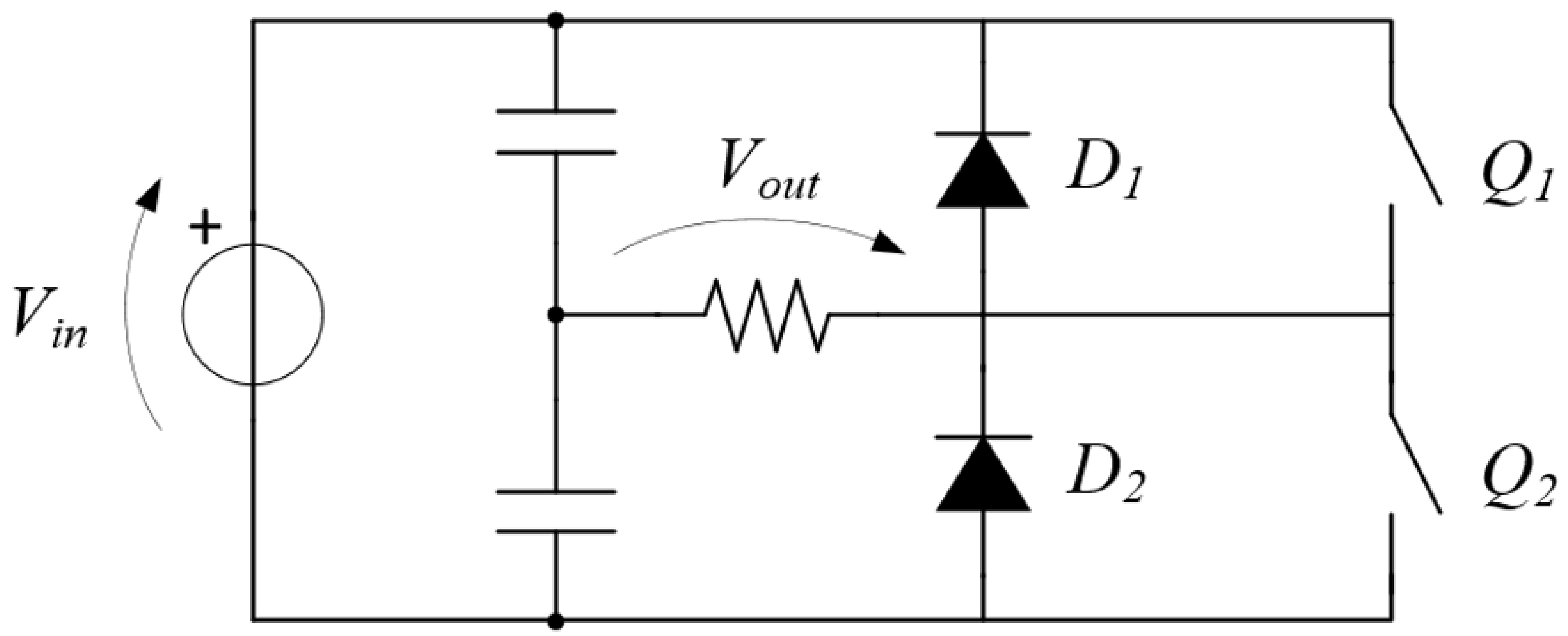
# Phase-control rectifier

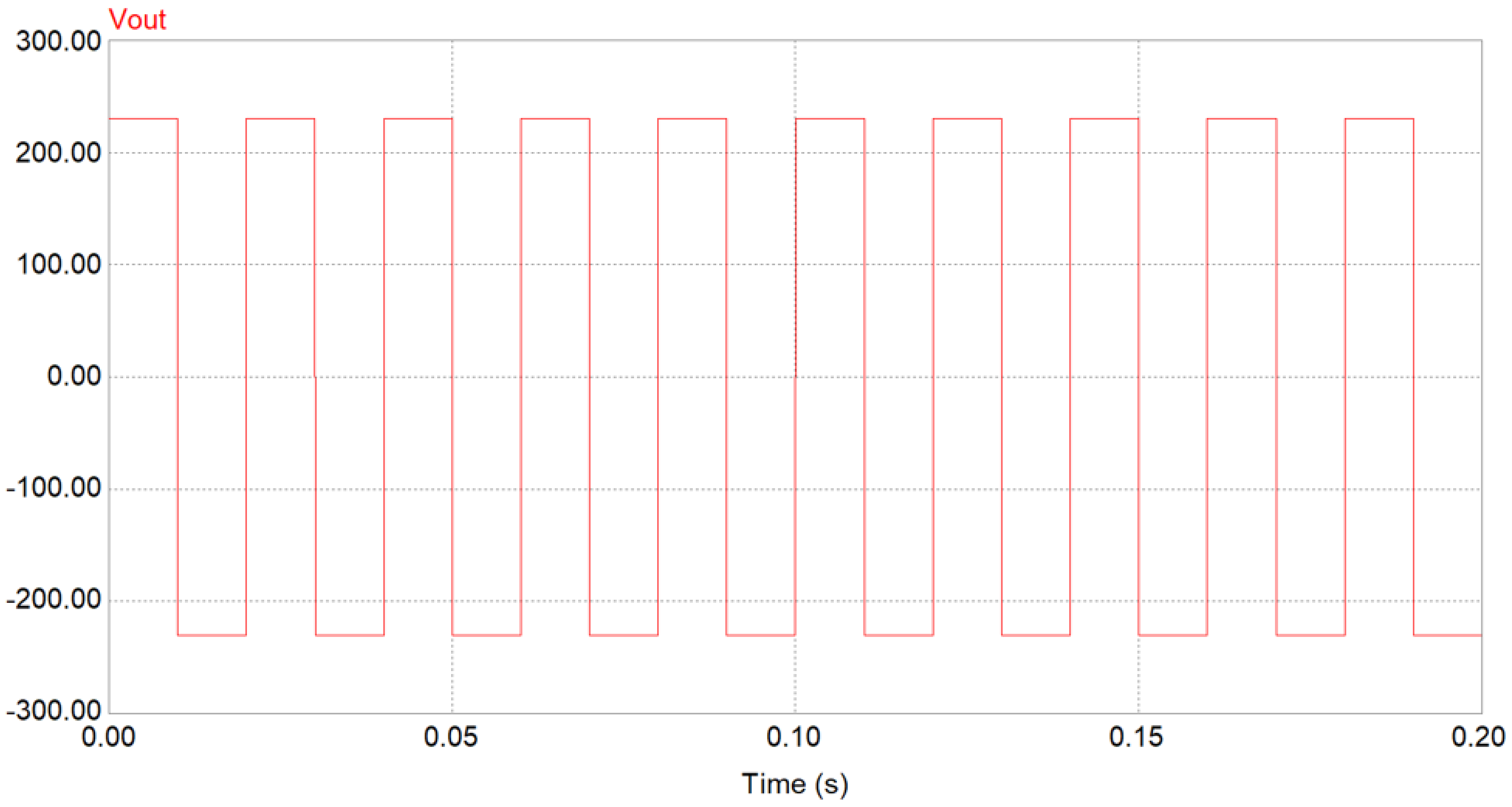



$$V_{out} = 0{,}159 V_{in} \times (1 + \cos\alpha)$$

# Inverter




$$V_{out,eff} = \frac{V_{in}}{2}$$

$$V_{out}(t) = \sum_{n=1,3,5,\ldots}^{\infty} \frac{2V_s}{n\pi} \sin n\omega t$$

# Inverter

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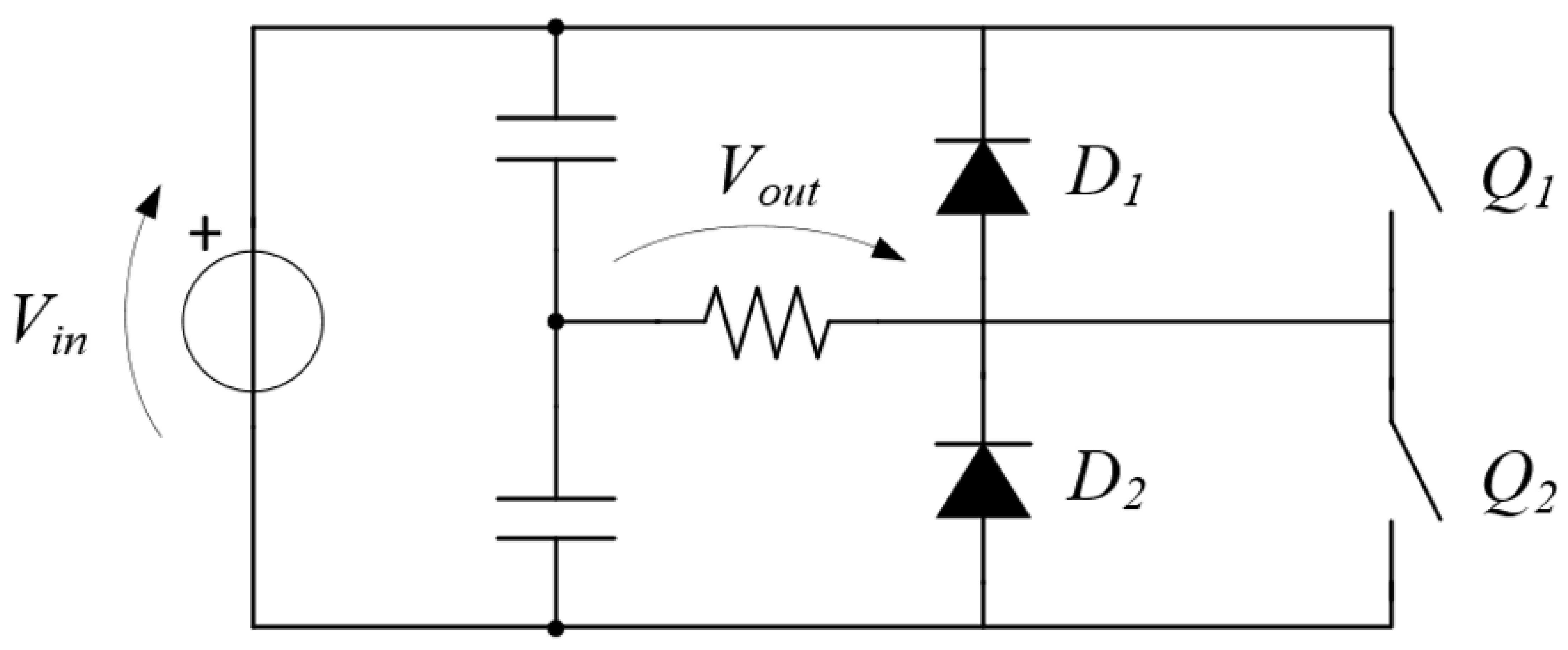


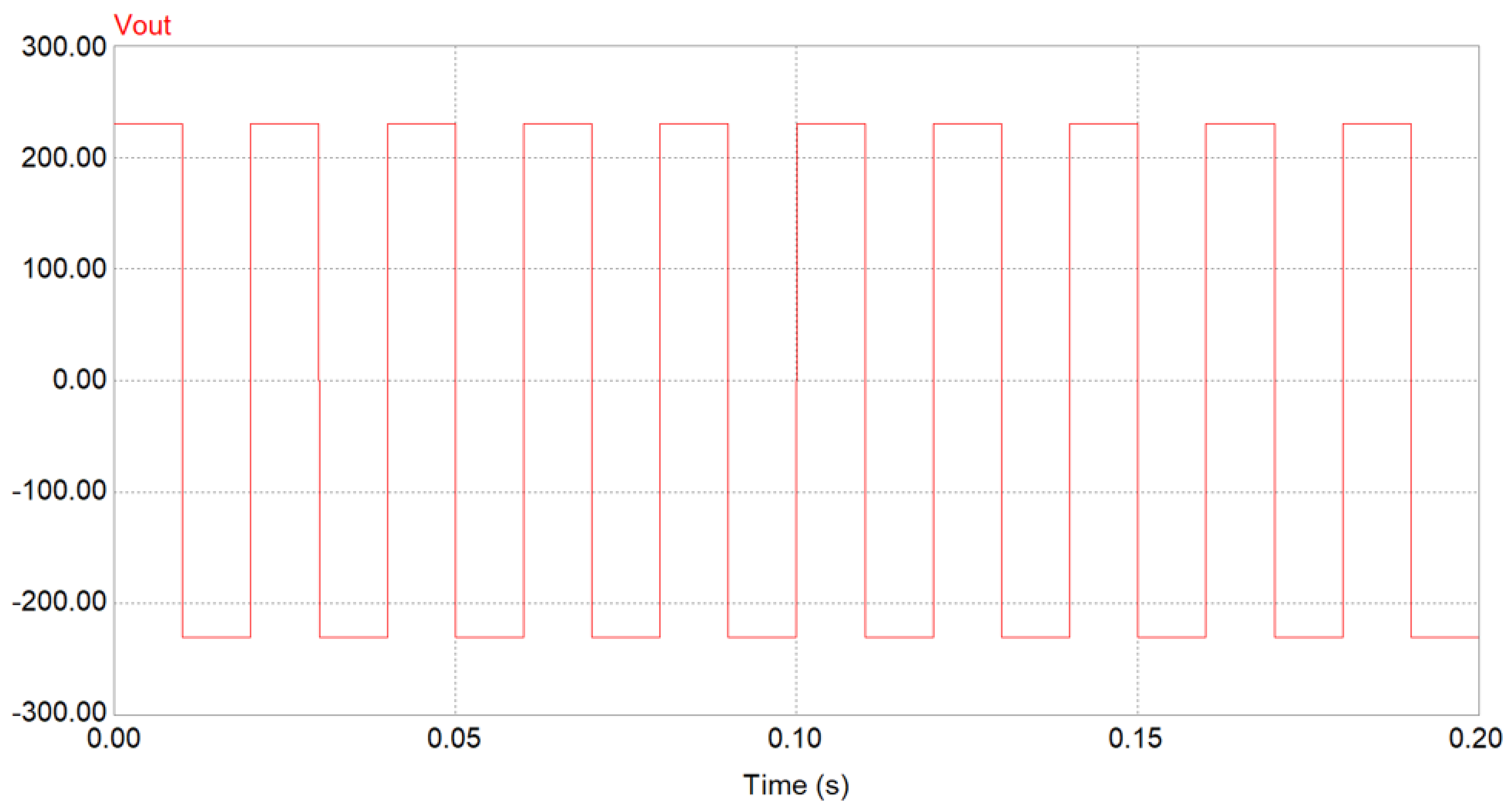


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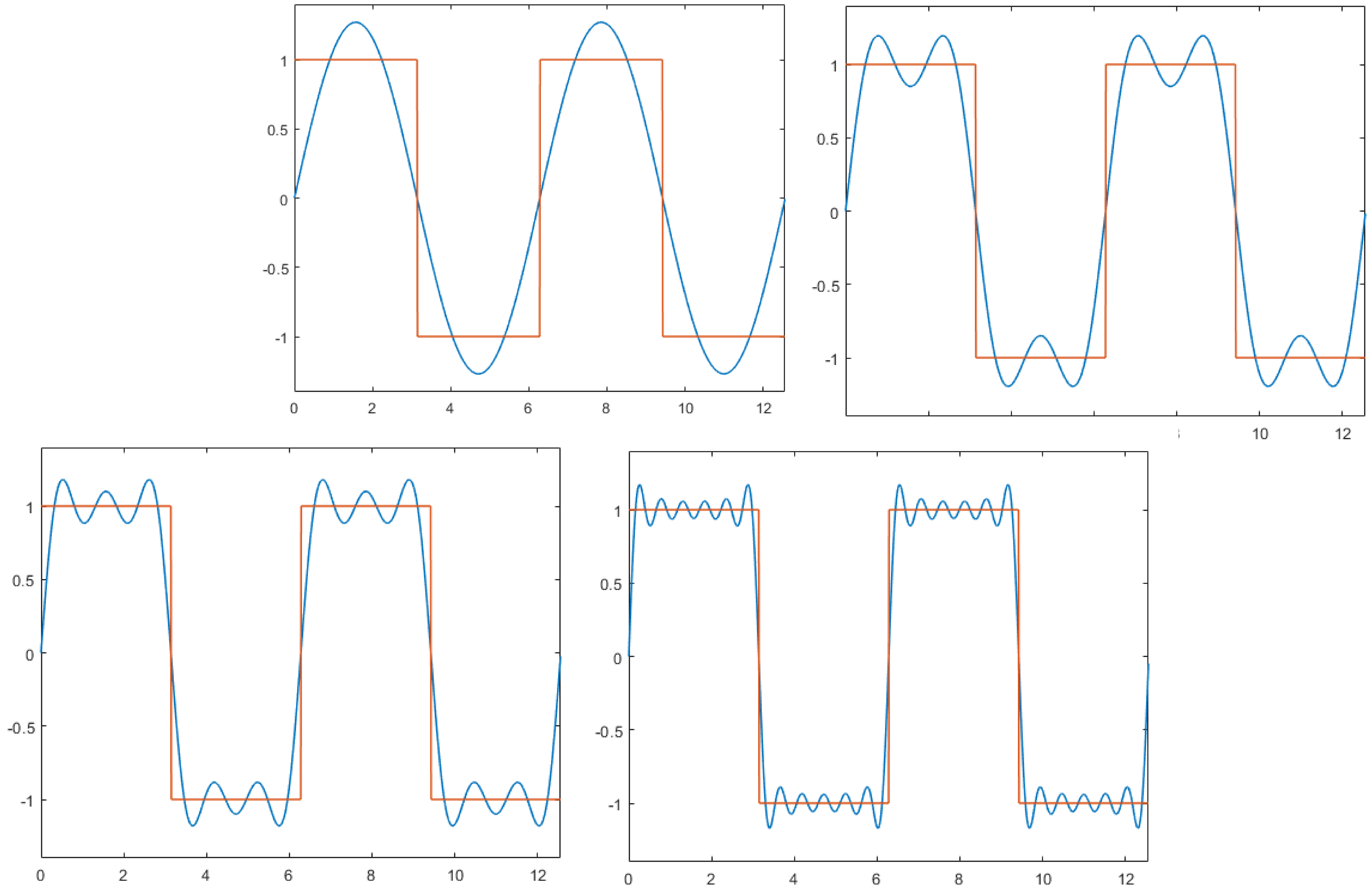
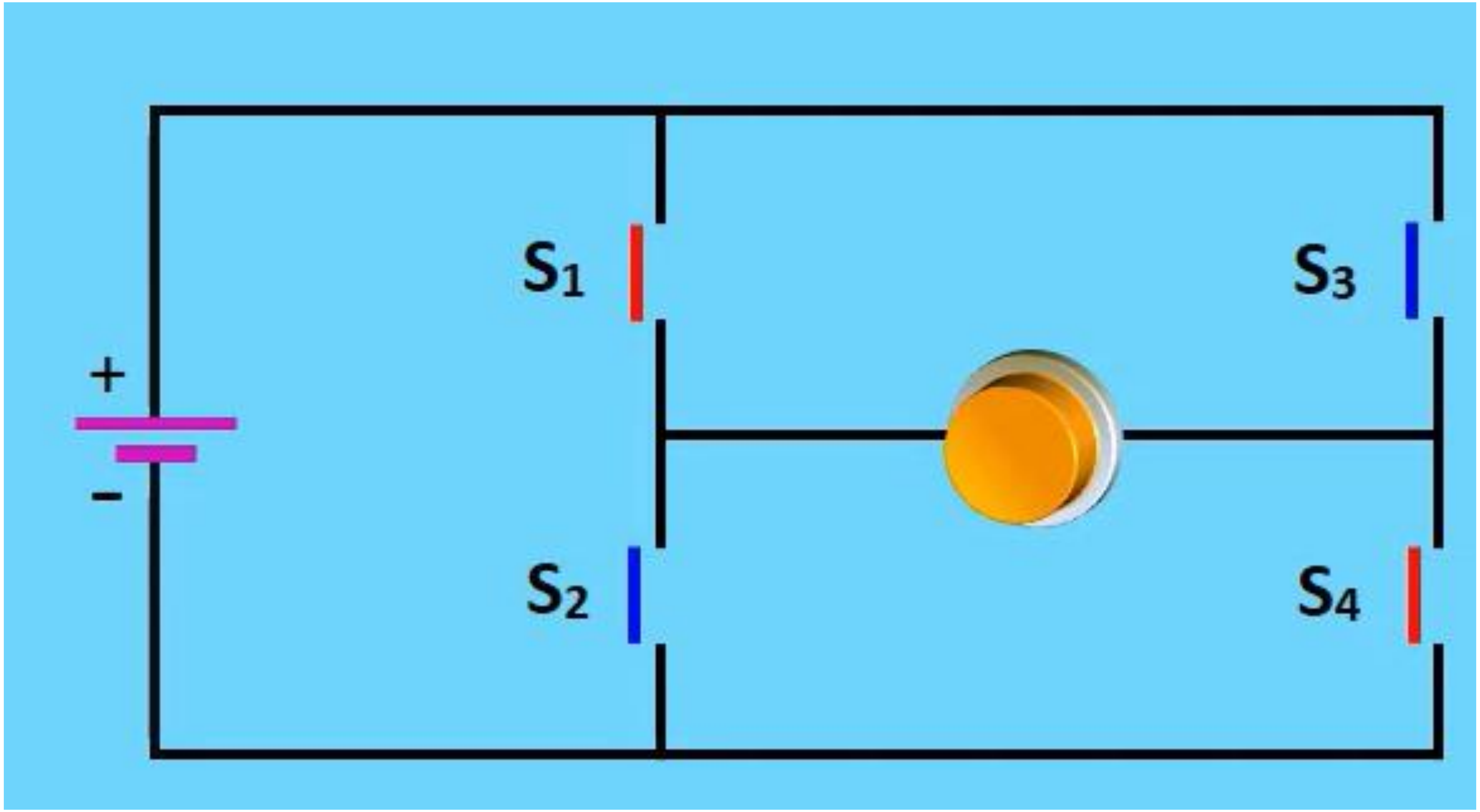
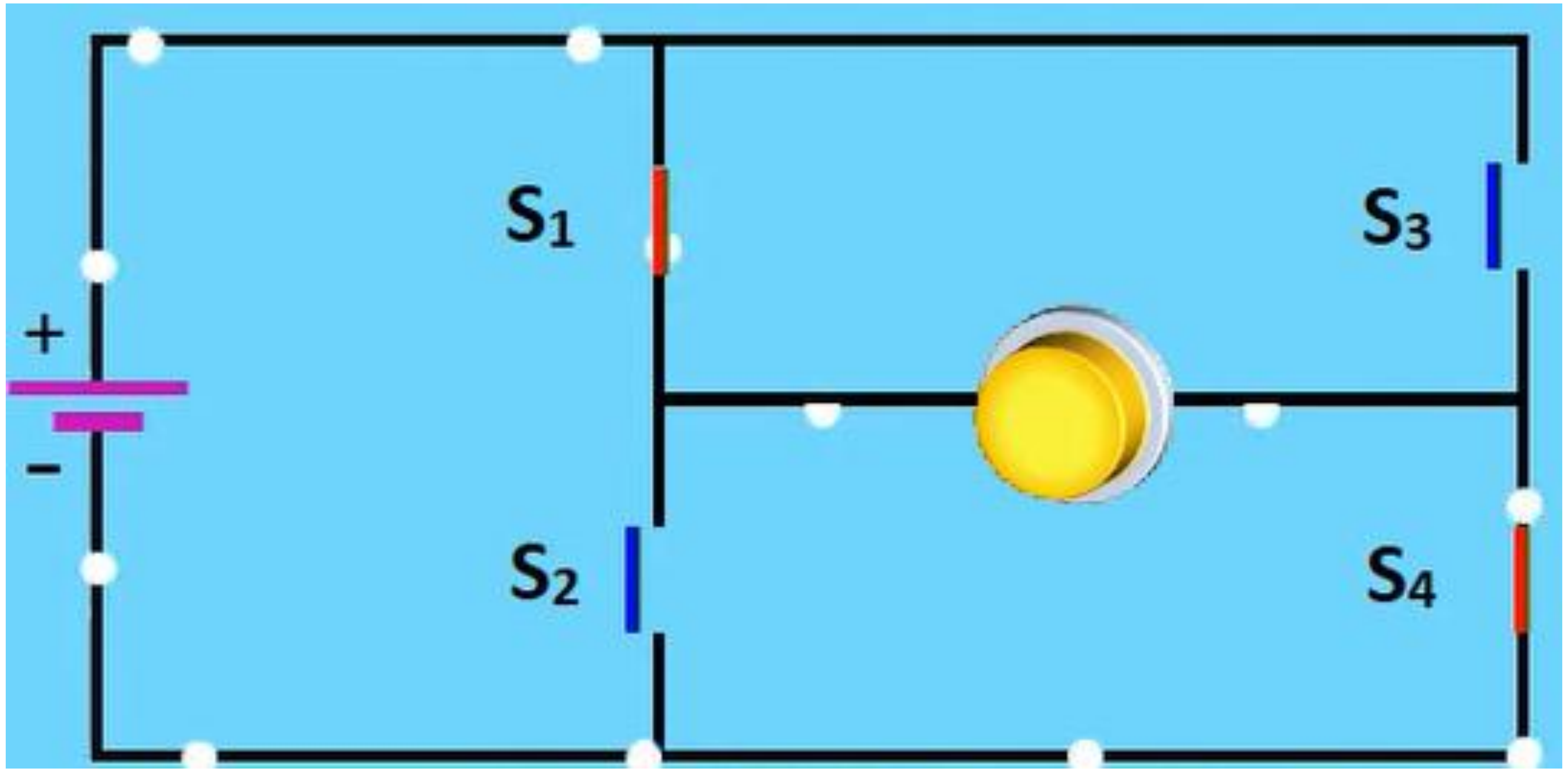
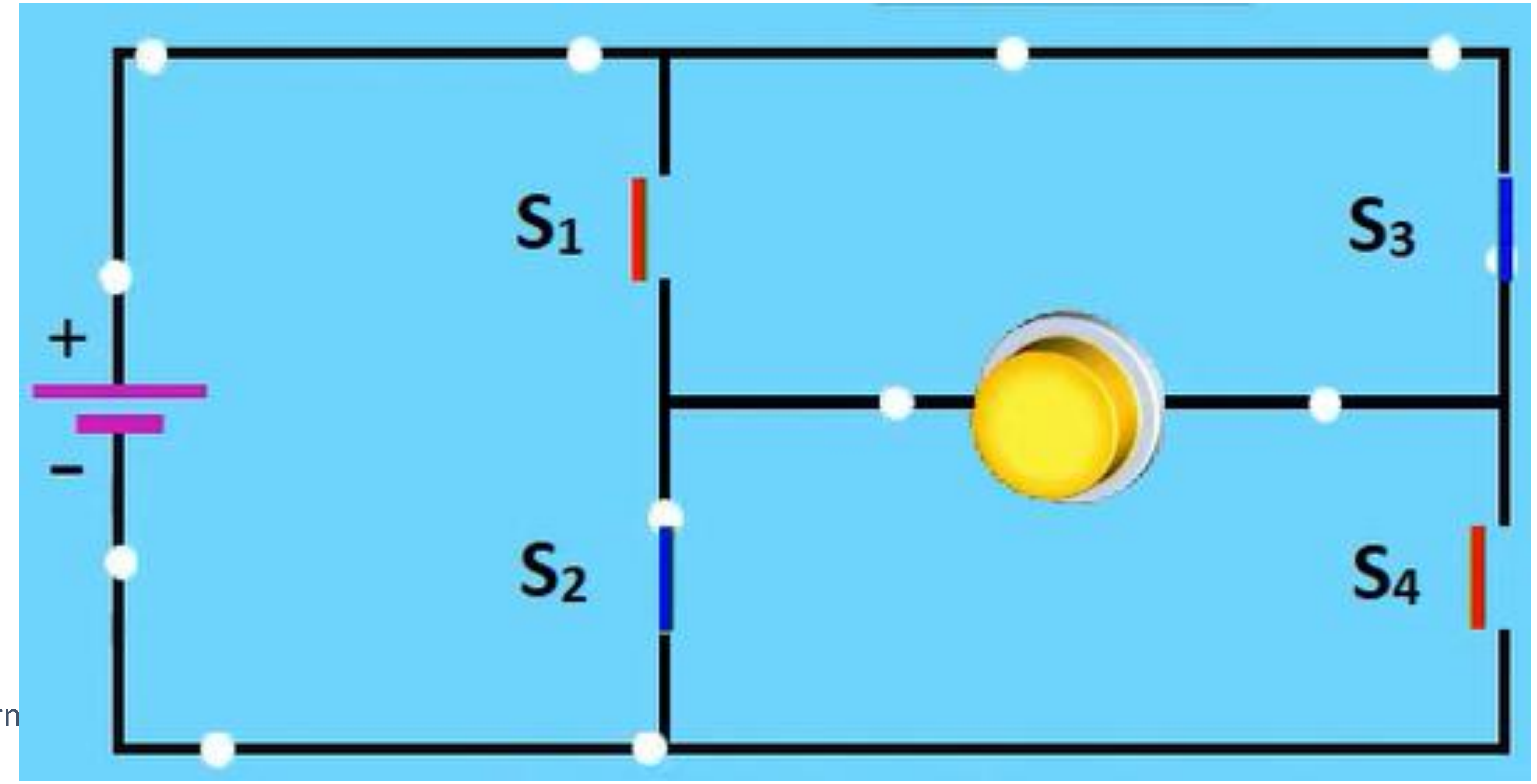
# Sine wave and harmonics



# Single-phase full bridge inverter




S1
S3
+
−
S2
S4


S1
S3
+
−
S2
S4