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Industrial Electric Drive Systems: from Generation to AC Power Systems and DC Power Supplies

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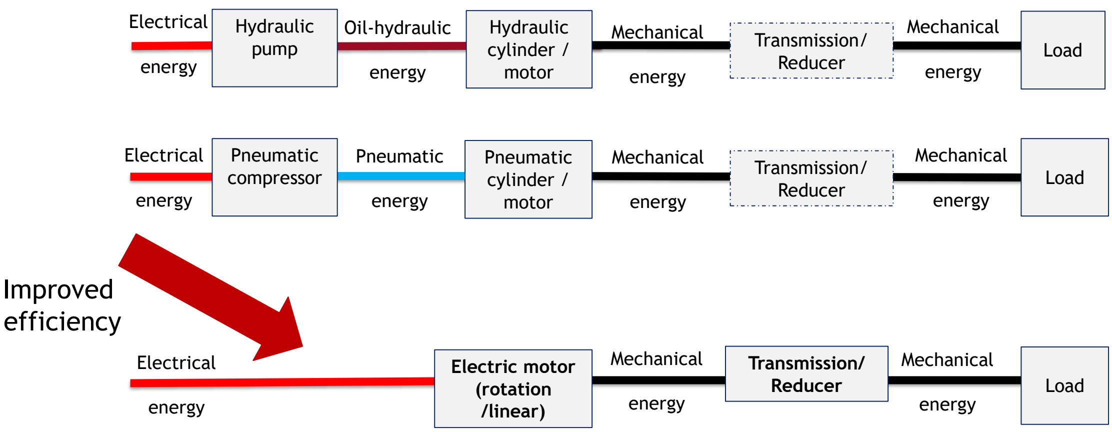
Energy Conversion Pathways in Drive Systems



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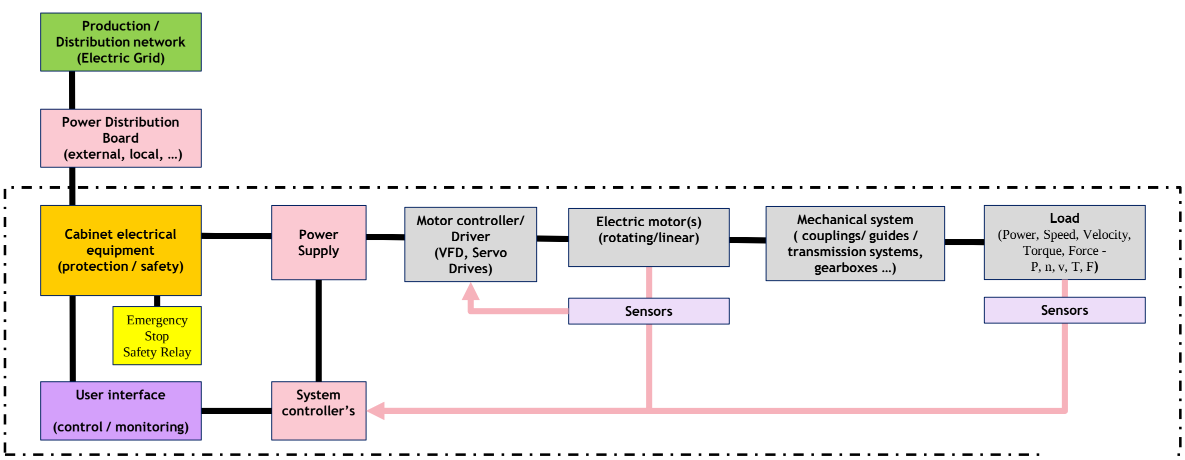
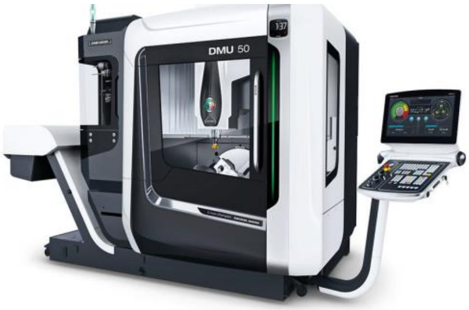
Electromechanical Drive Architecture Overview: from Grid to Load



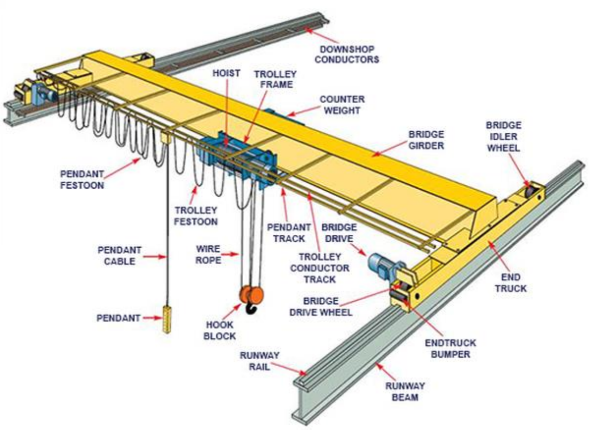
Example: Drive Systems in CNC Machines



Equipment: DMG MORI DMU 50 (5-Axis Mill)

https://www.dmgmori.co.jp/en/products/machine/id=1440

Example: Drive Systems in Industrial Cranes



https://www.craneskit.com/overhead-crane/

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Overview of Power Generation Methods

Sources of Electricity Production

- **Utility-Scale Power Generation**
  - Thermoelectric power plants (coal, fuel, gas)
  - Hydroelectric power plants
  - Nuclear power plants
  - Wind power plants (land and sea)
  - Photovoltaic plants

- **Decentralized Small Power Plants Generation**
  - Biomass station
  - Small-scale Hydroelectric
  - Photovoltaic solar panel

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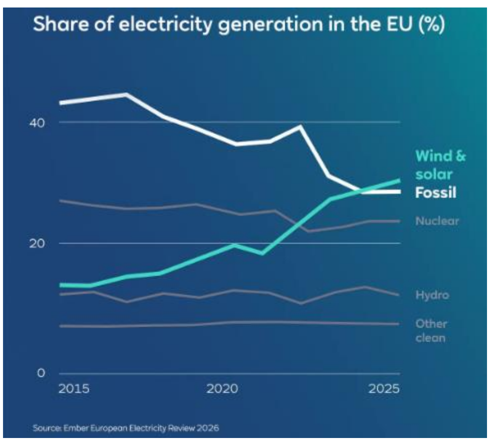
Power Generation Methods in Europe



Wind and solar generated more power than fossil fuels in the EU for the FIRST time ever. In 2025, wind and solar made up a record 30% of EU electricity, up from 20% just five years ago

Reference: EMBER

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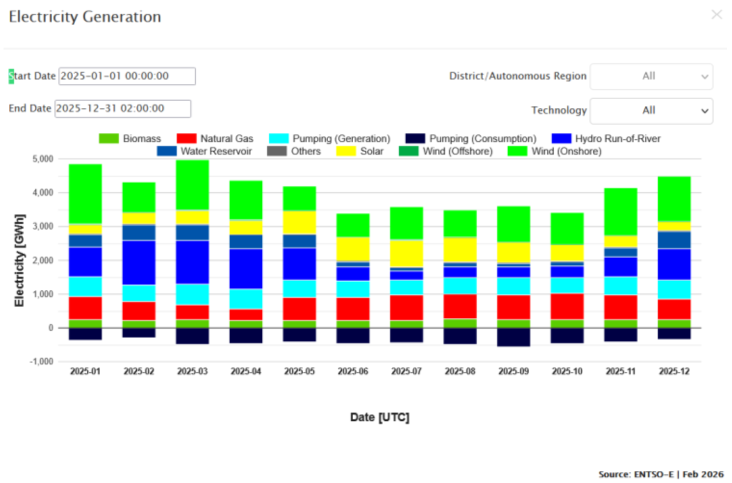
Sources of Electricity Generation in Portugal Jan. 2025 - Dec. 2025



References:

http://e2p.inegi.up.pt/

Portugal: electricity production 2024, by source | Statista

APREN - Production

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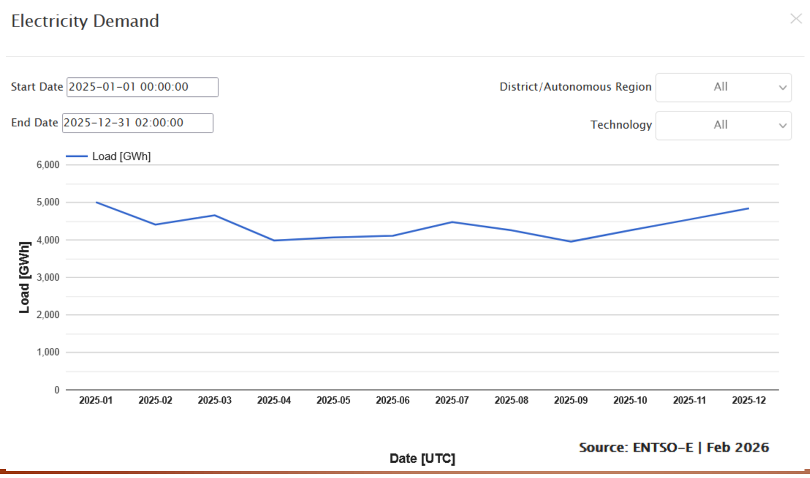
Sources of Electricity Demand in Portugal Jan. 2025 - Dec. 2025



Reference:

http://e2p.inegi.up.pt/

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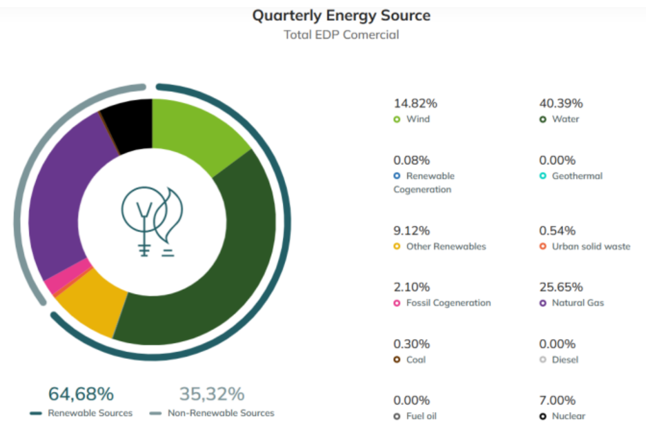
Sources of Electricity Sold by EDP Comertial Last Quarter of 2025

EDP *Commercial*, 4th quarter 2025



https://www.edp.pt/origem-energia/

Other reference:
/portugal.edp.com/pt-pt/edp-portugal/producao-hidrica-e-termica

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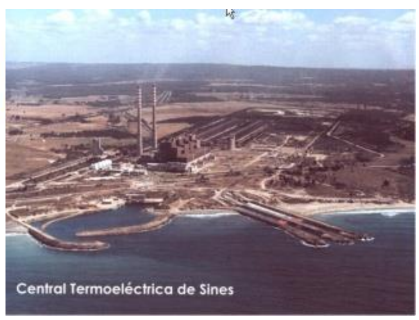
Sources of Electricity Production in Portugal Thermoelectric Power Plants

- **Combustible: natural gas, fuel (total phase-out of coal!)**
- **The Sines power plant (coal) that had a total of 1256 MW production capability, had a total daily consumption of about 11000 tons of coal, closed in 2021.**
- **Transition to Green Hydrogen: Sines power plant to be used for a project to produce 100 MW of green H2 (www.greenh2atlantic.com)**
  - **Currently finalizing the installation of the 100 MW alkaline electrolyze modules; planned to entry into operation in may 27**
- **The Lares Thermoelectric Power Station (natural gas), 2 x 430 MW, located in Figueira da Foz**
- **The Fisigen Thermoelectric Power Station, (natural gas), 24 MW, located in Barreiro**
- **The Tapada do Outeiro (natural gas),990 MW, located in Medas**
- **The Pego (natural gas) 830 MW, located in Pego**



News 15 Jan 2021: The Sines plant that came to supply 1/3 of the electricity consumed in Portugal, closes.
The other coal-station of Pego closed in November 2021.
Portugal without any coal-station today since 2022)

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Sources of Electricity Production in Portugal Thermoelectric Power Plants

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- The Ribatejo power plant: gas
  - Total installed power of 1200 MW (3 groups)
  - Combined cycle (gas turbine Brayton cycle+ steam turbine - Rankine cycle) for maximum thermodynamic efficiency (cogeneration)
  - Pilot project for the production of hydrogen at the Ribatejo Combined Cycle Power Station "officially started in April 2020"

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Sources of Electricity Production in Portugal Hydroelectric Power Plants

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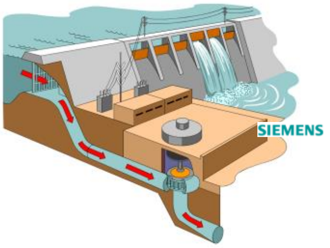
- The Alqueva power plant, Portugal
  - Generation: 520 MW Hydro (2 x 260 MW Groups) + 5 MW Floating Solar
  - Pumped-Storage Operation: Reversible cycle with Pedrogão dam using surplus wind energy for water storage
  - Key Advantage: acts as a grid stabilizer (Water Battery) and utilizes shared grid infrastructure for hybrid solar production



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Sources of Electricity Production
Nuclear Power Plants

Nuclear power plants

- **Almaraz Nuclear Power Plant in Spain**
  - **Capacity of 2.2 GW**
  - **Operational Status:** Authorised to operate up to 2028

Notes:

- **Proximity:** located near the Tagus River, Almaraz is geographically **close to the Portuguese border**, making it a key factor in regional energy security and safety discussions
- Almaraz is a major contributor to the electricity imported by Portugal

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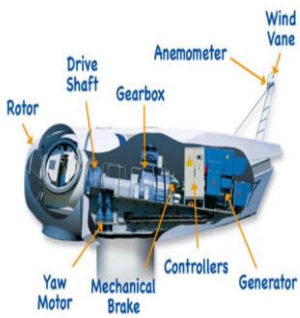
Sources of Electricity Production in Portugal
Wind Power Plants

Wind power plants

- Land
- Sea

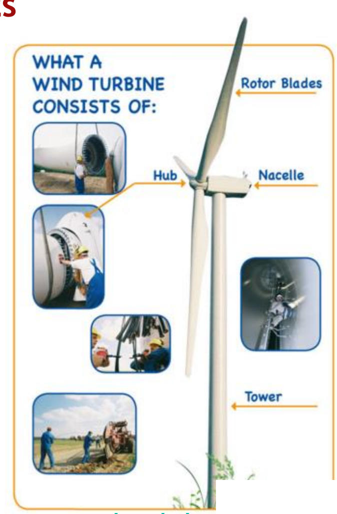
A complement to Hydroelectric power plants!

WIND PARKS (111 MW), SERRA DOS CANDEEIROS (SANTARÉM)



www.abo-wind.com/

Note that there are turbines (like Enercon E-82) that are gearless (Direct Drive). They use a synchronous generator with a large diameter, eliminating the need for a gearbox



www.abo-wind.co

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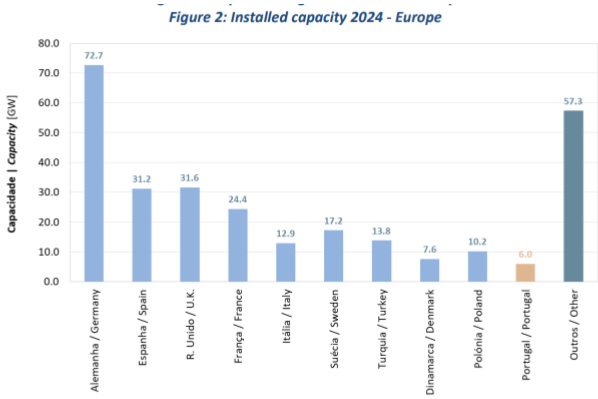
Sources of Electricity Production
Wind Power Plants

- Installed capacity in Portugal: 6 GW
- Currently, a critical topic in wind energy management, especially for a country like Portugal, which was an early adopter of the technology, is Repowering:
- Repowering often involves replacing three or four old turbines with a single modern one. Modern turbines have larger rotor diameters and higher hub heights, allowing them to capture more consistent, higher-velocity winds
- Result: it is possible to triple the energy output of a park while actually reducing the number of physical structures on the landscape



Fonte | Source: WindEurope (Wind energy in Europe: 2024 statistics and the outlook for 2025-2030), APREN, INEGI

Ref: e2p, parques eólicos em Portugal, 2024

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Sources of Electricity Production in Portugal
Photovoltaic plants

- The Amareleja (Moura, Portugal) power plant
  - Installed capacity of 46 MW (annual production of around 93 thousand MWh)
  - Occupied area of 250 hectares
  - 2,520 azimuth solar trackers installed, equipped with 104 solar panels each
  - Note: the plant was, in 2008, the largest in the world, in terms of total installed capacity and production capacity
- Solara 4 Power Station, Alcoutim, with 220 MW (400 hectares)
- Iberdrola 13.5 MW Conde Power plant (Palmela, Setubal), and 27 MW Algeruz II plant (Setubal)

Photovoltaic power plant,
Amareleja, Portugal

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Photovoltaic Systems: Power Conversion and Grid Dynamics

Photovoltaic Systems: Power Conversion and Grid Dynamics

1. **Power Conversion: DC to AC:** photovoltaic (PV) panels generate Direct Current (DC). Integrating this into the electrical infrastructure requires power electronic converters:
   - Central Inverters: high-capacity units (MW scale) used in utility-scale plants like Amareleja
   - String Inverters: multiple smaller units that manage specific rows of panels, improving redundancy and Maximum Power Point Tracking (MPPT) efficiency
2. **Inverter Control Strategies:** the behavior of the "Driving System" depends on the control logic programmed into the inverter:
   - **Grid-Following (Standard):** acts as a "Current Source." It requires a stable grid signal to mirror (Phase-Locked Loop). For safety, these units feature Anti-Islanding protection, automatically shutting down if the grid frequency or voltage disappears
   - **Grid-Forming (Advanced):** acts as a "Voltage Source." Using an internal high-precision oscillator, it creates its own frequency (50 Hz) and voltage (230V/400V) reference. This technology is essential for microgrids or for restarting the main grid after a blackout (Black Start capability)
3. **System Balancing: The "Duck Curve" Challenge:** solar production is inherently intermittent, creating a challenge for grid operators:
   - **The Phenomenon**: a massive energy surplus occurs at midday, while production drops to zero just as residential demand peaks in the evening
   - **The Solution**: to "flatten" the curve, use
     - **Energy Storage Systems: BESS** (Battery Energy Storage): Fast-response chemical storage
     - **Pumped Hydro** (e.g., Alqueva): large-scale mechanical storage, using midday solar surplus to pump water for evening generation

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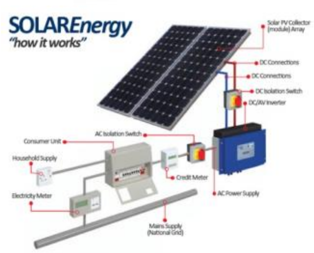
Sources of Electricity Production
Decentralized power plants

- **Decentralized power plants - Low-power plants:**
- **Biomass station**
  - **Forest waste centre Mortágua (9 MW)**
- **Mini-Hydroelectric**
  - **Strategic Update: hybridization, with solar panels on-site**
- **Photovoltaic solar panels**
- **Geothermal**
  - **Azores power plant (São Miguel, geothermal often provides over 40% of the island's total electricity demand)**

References:
Biomass Power Plants in PT Portugal (Map) | database.earth

Mortágua, 8.6 MW

Mini-hydroelectric, Ponte do Bico, river Cávado, 2,4 MW



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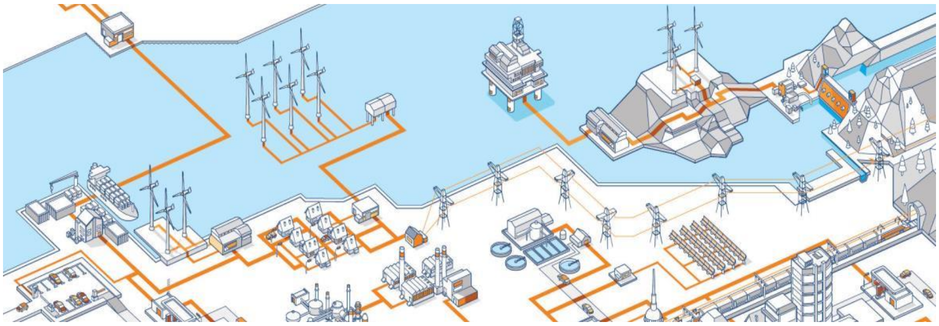
Energy Distribution Networks



www.abb.com

SMARTGRIDs (*A Smart Grid is an electricity network that uses digital technology to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users"*.

https://www.youtube.com/watch?v=Ft8nAo5hzdQ

Efacec https://www.youtube.com/watch?list=PL5F3E984115DF32BC&v=Mhx8iHp64Mk

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Energy Distribution Networks
Iberian Peninsula massive blackout on 28th April 2025

1. **The Trigger (Overvoltage & Initial Trips):** at 12:32:57 CEST, the event began with the tripping of a generation transformer in Granada due to overvoltage protection. Within 20 seconds, a rapid cascade of generation trips followed across Andalusia, Badajoz, and Segovia, totaling over 2,500 MW of lost power
2. **The Phenomenon (Voltage Instability): u**nlike most blackouts caused by low frequency, this was an unprecedented overvoltage-driven incident. The grid was operating with an 82% renewable mix; because renewables were not then legally required to provide dynamic voltage control, the system could not dampen the rising voltage levels triggered by the initial trips
3. **The Collapse (Islanding & Load Shedding):** as frequency plunged to 48.0 Hz, automatic load-shedding failed to stabilize the system. To protect the rest of Continental Europe, the interconnector lines with France automatically disconnected, leaving the Iberian Peninsula as an "electrical island" that collapsed entirely by 12:33:24 CEST
4. **The Recovery (Coordinated Restoration)**: restoration took approximately 16 hours, utilizing Black Start procedures at hydroelectric and gas plants in both Spain and Portugal. The system was assisted by re-energizing tie-lines with France and Morocco, with Portugal fully restored by midnight and Spain by 04:00 the following day

https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/

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Energy Distribution Networks
Iberian Peninsula massive blackout on 28th April 2025

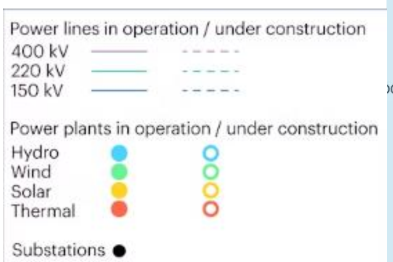
Key lessons from this incident

1. **Mandatory Grid Support**: renewable sources must provide dynamic voltage and frequency regulation to prevent minor faults from cascading
2. **End of "Islanding":** increased interconnection with Europe is vital to absorb power oscillations and stabilize the Iberian grid
3. **Protection Systems:** demonstrates why "Equipment Cabinets" must have high-speed protection to prevent permanent hardware damage during grid collapses
4. **Resilient Recovery:** success depends on robust "Black Start" capabilities and automated load-shedding to prevent total system collapse

https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/

Energy Distribution Networks in Portugal

Electric network and active electricity suppliers in Portugal, 2022



Portugal Electricity Security Policy – Analysis - IEA

See also
https://wwww.ren.pt/en-gb/activity/electricity

Electric Supply Types in Drive Systems

- **Direct current sources (DC)**
  - **Definition:** electricity that flows in a constant direction
  - **Role in Driving Systems:** DC is critical for the "intelligence" of a system, powering controllers, sensors, and high-precision motors
- **Alternating current source (AC)**
  - **Single-phase:** typically used for lower-power applications and standard household/office equipment.
  - **Three-phases:** the industrial standard; it is essential for high-power electric motors
  - **Polyphase systems:** these systems can be utilized because they enable the efficient production, transmission, and utilization of high-power electricity (Some large-scale wind turbines use 6-phase generators to handle high power levels more efficiently and reduce the size of the required power electronics)

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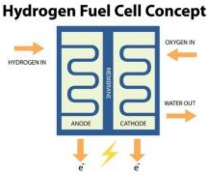
DC Electric Power Sources

- **Available sources**
- **Photovoltaic cells**
- **Fuel cells**
  - Hydrogen cell
- **Batteries and accumulators**
  - Storage and conversion of Chemical energy in electric power



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DC Electric Power Sources

Available sources

- **Batteries** - a direct transformation of chemical energy into electrical DC power
- **DC generators** (dynamos) - a mechanical energy transformation
  - With permanent magnets
  - With wounded stator and rotor (see CASEY)
- **Electronic AC/DC Conversion**
  - Voltage rectifiers
  - Controlled Converters (rectifier with controller)
  - Power supplies: Integrated units that combine several stages: AC-AC Transformers (to adjust voltage level) + Rectifier Bridge + Filter + Regulator (to ensure a stable, low-noise output)

Windstream ® Permanent Magnet DC Generators (windstreampower.com)

Rectifier
www.semikron.com

DC power source
Sinamics DCM
siemens.com

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AC Electric Power Sources and Inverters

Available sources for supplying alternating current (AC)

- **Directly from the grid, providing a fixed AC**
- **AC generator (in production), using mechanical energy transformation**
- **DC-AC converter (inverters), providing variable AC (voltage and frequency)**
  - **Examples:**
  - **Power inverters**
  - **Uninterruptible Power Supplies (UPS): these combine a charger, a battery (DC storage), and an inverter. In the event of a grid failure, the UPS uses its inverter to provide near-instantaneous AC power to the driving system to prevent a crash**
  - **Variable frequency drivers (VFDs): they take the incoming fixed grid AC (e.g., 50 Hz), convert it to DC, or directly fed by a DC source, and then use an inverter to output a variable frequency and voltage, widely used with electric motors**

power inverter

- DC-AC power inverter
- Pure sine wave model
- Input voltage of 12 V
- Output voltage of 230 V
- Continuous output power of 2000 W
- Intermittent output power of 2100 W
- Surge power of 4000 W
- Two output connections
- Chassis mounting
- Universal output connection type
- Efficiency of over 90%

Inverter (example of inverter for household solar panel installation)

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Benefits of AC Power in Electrical Power Systems

- **Transformability Using Transformers**
  AC voltages can be easily transformed to higher or lower values using transformers. This allows for long-distance transmission at high voltages and low losses, and low-voltage distribution for safe and efficient use in homes and equipment

- **Reduced Joule Effect Losses**
  For a given power (P=VI), increasing the voltage decreases the current, reducing the losses due to the Joule effect (P = I^2 * R). This makes AC transmission more efficient over long distances

- **Availability of a Wide Range of AC Motors**
  A diverse range of AC motors is available for various applications, offering versatility and efficiency in industrial, commercial, and residential settings

Benefits of AC Power in Electrical Power Systems

1. **Structural Advantages of AC**
   - **Transformability:** using transformers, AC voltages can be easily stepped up or down. This is the foundation of modern power systems, allowing for high-voltage long-distance transmission with minimal energy loss
   - **Efficient Transport:** by increasing voltage and reducing current, Joule effect losses (P = I^2 * R) are significantly minimized during transmission
   - **Ease of Production:** AC alternators are simpler to build and more reliable than DC generators because they do not require a mechanical commutator, leading to lower maintenance costs

2. **Industrial Versatility**
   - **Range of Motors:** a vast array of AC motors exists for nearly every industrial application, offering high efficiency and versatility
   - **Straightforward Conversion:** Converting AC to DC for specific applications (like electronics or variable speed drives) is highly efficient using rectifiers

Disadvantages of AC Power in Electrical Power Systems

- **Pulsated power**
  - Alternating current (AC) power can exhibit pulsations, leading to fluctuations in the power supplied. This is particularly noticeable in single-phase systems. To address this, three-phase systems are commonly used, providing a more consistent power output and reducing pulsations
- **Incompatibility with electronic devices**
  - Many electronic devices require direct current (DC) to operate. When these devices are supplied with AC power, rectification or an AC-DC converter is necessary to bridge the gap
- **Storage difficulty**
  - Storing AC power directly is challenging. Typically, AC power needs to be converted to DC to charge batteries or other storage systems. When the stored energy needs to be used, it often has to be converted back to AC, adding to conversion losses and complexity
- **Instability of long transport lines**
  - Over long distances, AC transmission can suffer from stability issues. For intercontinental power transport, high-voltage direct current (HVDC) systems are often preferred as they provide more stable and efficient long-distance power transmission

The Two Primary Types of AC Power Circuits

- **Single-phase system,** the standard for residential and low-power applications
  - **Wiring:** three wires - Phase or Line wire/Neutral wire /Protective earth wire
  - **European Standards:** 230 V AC, 50 Hz
  - **US Standards:** 110 V AC, 60 Hz

- **Three-phase system**
  - The most common type of polyphase electric supply, common in low-voltage industrial networks
  - **Wiring:** five wires - three phases (3 wires) + neutral wire + protective earth wire
  - **Technical Specifications (Europe):** frequency of 50 Hz, Voltage 230/400 Volts AC
    - Phase shift: 120º
    - Phase voltage: voltage between phase and neutral = 230V
    - Line-to-line voltage: voltage between any two phases = 400V

Balanced Loads: in industrial settings, we aim for a **balanced three-phase system**, where the voltages have the same frequency and amplitude but remain out of phase

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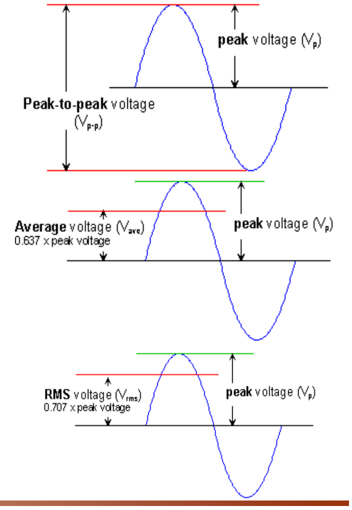
Sinusoidal Waveform in Alternating Current (AC) Power Systems

Key Waveform Parameters

- Peak value (Amplitude) (Vp)
- Peak-to-peak value (V_{p-p})
- Average value
- Effective or RMS (Root-Mean-Square) value (V_{rms})
- Frequency (f) and Period (T=1/f):
  - in a 50 Hz system, the T = 20 milliseconds



Understanding the RMS Value

- **RMS value** is defined as the constant DC voltage (or current) that would result in the same power dissipation as the equivalent AC voltage
- **Standard Reference:** in Europe, the standard 230 V AC represents the RMS value
- **The Calculation:** the peak voltage V_p for a 230 V system is actually significantly higher, calculated as:

$$V_p = V_{rms} \times \sqrt{2} \approx 325.32 \text{ V}$$

The multimeter reads the RMS value

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Three-Phase AC Power System

The Three-Phase Standard system

- The most prevalent power system is the **balanced three-phase**. In this system, the phases are equal in amplitude and are electrically shifted by 120º from each other
- A three-phase system provides constant power delivery, unlike single-phase power, which pulses and reaches zero voltage twice per cycle
- For the same amount of power delivered, a three-phase system requires less conductor material (copper or aluminum) than a single-phase system, which is a major factor in the cost-efficiency of industrial grids
- This three-phase system allows direct drive of three-phase induction motors without the need for auxiliary equipment. Three-phase motors can start rotating without the need for additional starting circuits or capacitors because the 120º phase shift naturally creates a rotating magnetic field

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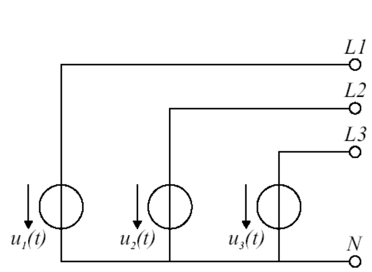
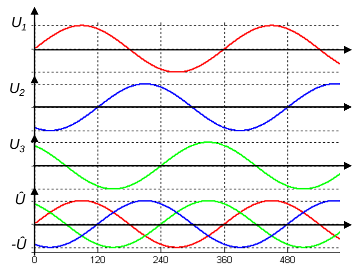
Three-Phase AC Power System

- **Balanced three-phase system**
  - **Uniformity:** the three voltages share the exact same frequency and amplitude
  - **Phase Separation:** each voltage is electrically offset from the others by **120º**
  - **Terminal Designations:** the power terminals are standardly labeled as **L1, L2, and L3** (the phases), with a common reference point known as the **Neutral node** (N)





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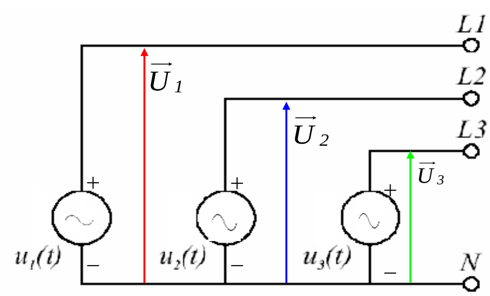
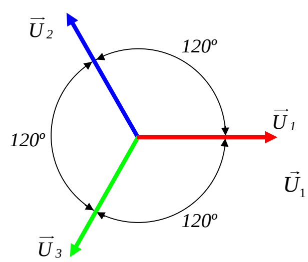
Three-Phase AC Power System

- **Phase voltage**
  - **Definition:** this is the voltage measured between any one phase line (L1, L2, or L3) and the neutral node (N)
  - **Measurement:** $U_1 = V_{L1} - V_N$
  - **Value:** in a standard European low-voltage network, this is 230V AC

$$U_{phase\_rms} = U_1 = U_2 = U_3$$





$$\vec{U}_1 + \vec{U}_2 + \vec{U}_3 = 0$$

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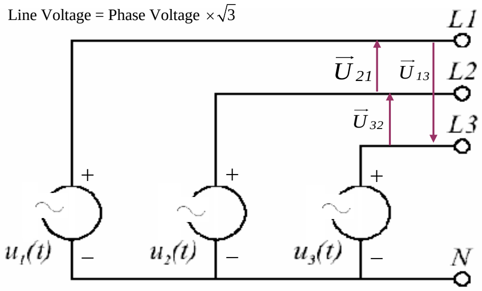
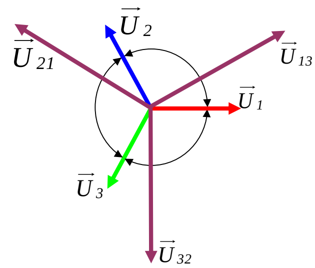
Three-Phase AC Power System

- **Line voltages (line-to-line voltages)**
  - **Definition:** also known as compound voltage, this is the voltage measured between any two phase lines (e.g., between L1 and L2).
  - **Measurement:** $U_{21}=V_{L2}-V_{L1}$, …
  - **Value:** in standard European systems, this is 400V AC

$$U_{compound\_rms} = U_{13} = U_{21} = U_{32} = \sqrt{3} \bullet U_{phase\_rms}$$

Line Voltage = Phase Voltage $\times\sqrt{3}$

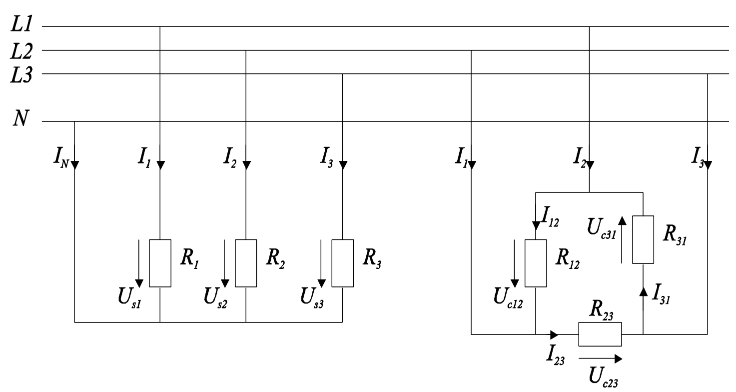




Three-phase balanced loads

Two ways to connect a load on a three-phase power system:

- Y (Wye or Star) Load
- Δ (Delta) Load



Y (Wye or Star) load

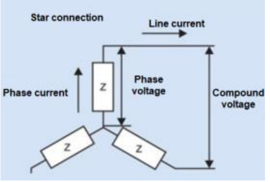
("Ligação estrela")

Δ Delta load

("Ligação triângulo")

Three-phase balanced loads – Y configuration

- In Wye (Y, star) load connection, each phase line is connected to one terminal of each load element, with the remaining load terminals being short-circuited (Y point)
- Voltage at each load element: Phase voltage (230V)
- The current at each load element (phase current) - Line current
- The system is said to be balanced when the impedances (loads) are identical (equal in module and argument)
- If the loads are identical, the common point is at 0V and the connecting conductor between the neutral points can be suppressed (neutral current is zero)



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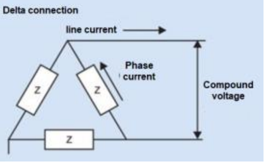
Three phase balanced loads - Δ Delta configuration

- With the Delta load connection, the loads are connected in series, with each junction point connected to a phase
- Voltage at each load element: Compound voltage (400V)
- The current at each load element (phase current) - Line current $/\sqrt{3}$
- Compound voltage = $\sqrt{3}$ phase voltage
- Line current = $\sqrt{3}$ phase current



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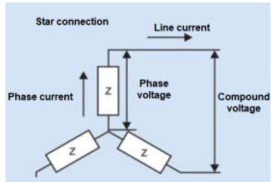
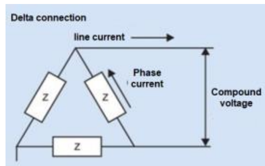
Power in a balanced load three-phase system

Feature	Wye (Star) Connection	Delta Connection
Voltage per Load	Phase Voltage (230 V)	Compound Voltage (400 V)
Current per Load	Equals Line Current	Equals $\frac{\text{Line Current}}{\sqrt{3}}$
Common Use	Soft-starting or lower power	High torque or full-speed operation



$$P = 3 \cdot U_{simple} \cdot I_{load} \cdot cos(\varphi)$$

$$P_{star} = \frac{1}{3} P_{delta}$$



$$P = 3 \cdot U_{comp} \cdot I_{load} \cdot \cos(\varphi)$$

$\cos(\phi) = $ Power factor

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Power in a Balanced Load Three-Phase System

- **Active Power (P):** the active power (also called real power) power in a balanced three-phase system represents the actual power consumed by the load

  $$P = \sqrt{3} \times V_{line} \times I_{line} \times cos(\varphi) \qquad \text{where}$$

  V_{line} is the line-to-line voltage
  I_{line} is the line current
  cos(φ) is the power factor
- **Reactive Power (Q):** the reactive power is the power that oscillates between the source and the load. It does not perform any useful work

  $$Q = \sqrt{3} \times V_{line} \times I_{line} \times \sin(\varphi)$$
- **Apparent Power (S):** the apparent power is the combination of active and reactive power. It represents the total power supplied by the source

  $$S = \sqrt{3} \times V_{line} \times I_{line}$$
- **Power Factor (PF):** the power factor is the ratio of active power to apparent power

  $$PF = cos(\varphi) = P/S$$

DC Power Supplies: Features and Selection

DC Power Supplies Core Applications

- **Control Circuits:** powering low-voltage components such as relays, contactors, and industrial sensors
- **Power Circuits:** providing energy for specialized DC motors, solenoids, and electronic valves
- **Laboratory Work:** used for workbench testing and system prototyping

Main Categories of Industrial Power Supplies

- Linear power supply: use of transformers (industrial use)
- Switching power supply: use of high-frequency switching and smaller transformers (industrial use)
- Programmable power supply: workbench power supply for laboratory use

- **Other DC power supplies**
  - Battery-based power supplies (DC Uninterruptible Power Supplies – UPS)
  - Solar power supplies using photovoltaic cells

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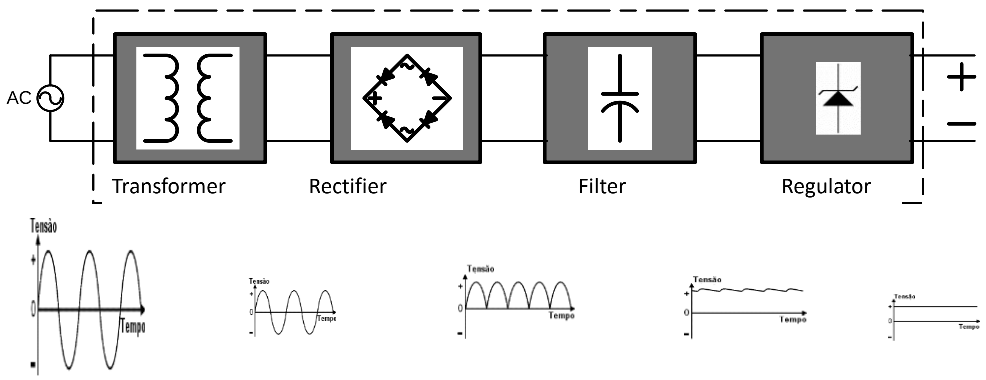
DC Power Supply: Linear

Linear or conventional, regulated power supply



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DC Power Supply: Linear

DC Linear power supplies

- **Without regul**ation (Simple transformer → rectifier → filter)
  - Simpler circuits,greater durability
  - Output voltage varies with input and load
  - Dimensioned for fixed voltage and current values
  - Used where precise regulation is not needed
- **With regulation** (transformer, rectifier, filter, and linear regulator)
  - More consistent voltage signals, with noise filtering
  - Adjustable voltage or current
  - Fonts with better characteristic, providing very low noise, high stability, and fast response
  - Less efficient and physically larger due to the transformer
  - More complex and expensive

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DC Power Supply: Linear

DC Linear power supply with regulation

- Robust and safe
- Residual ripple
- Less noise than switching power supplies

- Low efficiency
- Need for heat dissipators
- Size and weight high
- More expensive than switching power supplies

Schneider ABL8FEQ24020 , 24 V, 2A

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DC Power Supply: Switching

- **High Efficiency**
  Switching power supplies achieve high efficiency, typically in the range of 80-90% or higher. This is due to their ability to minimize power losses during the conversion process
- **Compact Size**
  They are smaller and lighter compared to linear power supplies because they use smaller transformers and components, thanks to the high-frequency operation
- **Wide Input Voltage Range**
  They can operate over a wide range of input voltages, making them versatile and suitable for various applications
- **Regulated Output**
  Provide a stable and regulated DC output voltage, which is crucial for sensitive electronic devices and equipment
- **Thermal Management**
  These power supplies are designed to manage heat effectively, often incorporating cooling mechar heatsinks and fans

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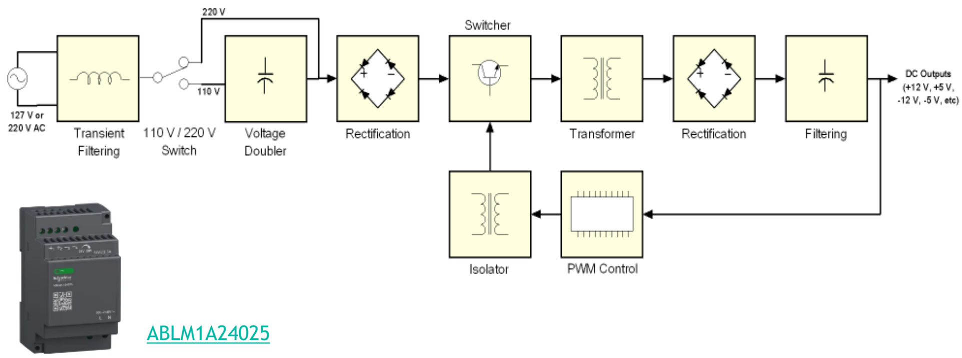
DC Power Supply: Switching

DC Switching power supply



ABLM1A24025

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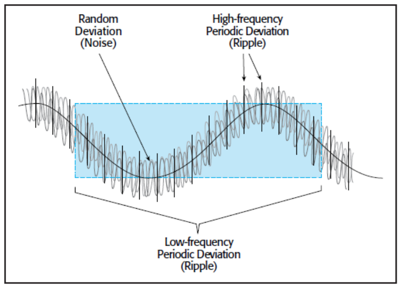
DC Power Supply: Switching

DC Switch power supply

- Small dimensions and low weight
- Wide range of input voltages
- High switching frequency
- Less expensive than linear ones
- Complex circuits
- High efficiency, compact size
- High noise

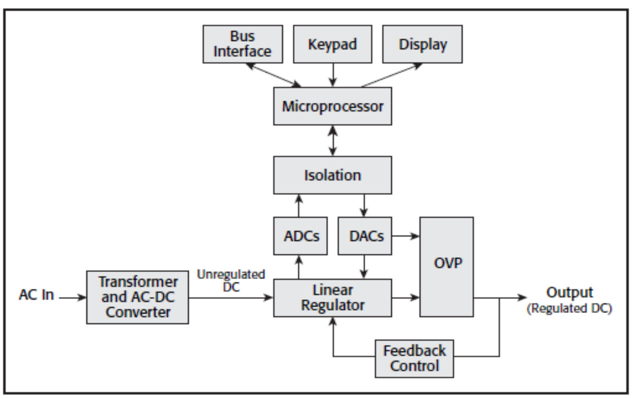


Noise on the voltage output

https://pt.mouser.com/new/meanwell/meanwell-lrs-family-powersupply/

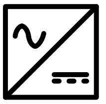
DC Power Supply: Programmable

Programmable power supply, workbench power supply for R&D laboratory use



http://www.tek.com/sites/tek.com/files/media/document/resources/Ser2200LinPwrSuppySpecsAppNote.pdf

DC Power Supply: Programmable



Programmable power supply, workbench power supply for laboratory use

- Variable voltage (V) and current (I)
- Constant Current (CC) mode, Constant Voltage (CV) mode, Remote control (USB, RS-232, LAN, SCPI)
- High Accuracy and resolution
- Stability (input AC voltage/current; load)
- AC characteristics (noise; ripple; transient response)

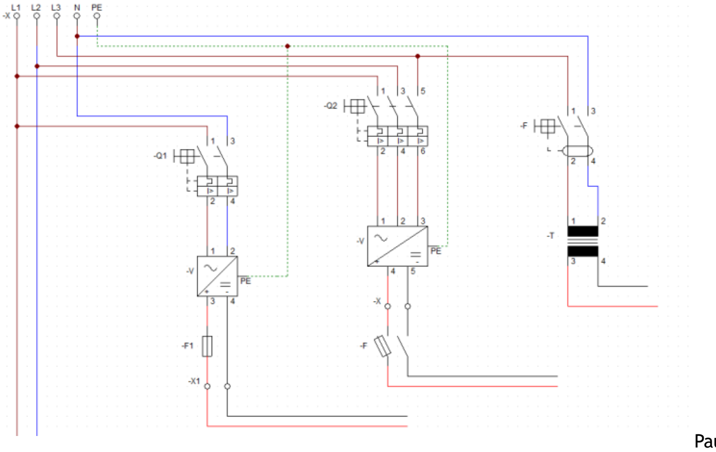
- Efficiency
- Internal impedance or resistance

- Number of channels and isolation/interconnection between them
- Programmability
- Protection features/security: overload, short circuit, and thermal protection to safeguard both the power supply and the connected devices http://www.tek.com/sites/tek.com/files/media/document/resources/Ser2200LinPwrSuppySpecsAppNote.pdf
- Monitoring

Power Supplies: Symbols

Examples:

- Single-phase AC/DC power supply
- Three-phase AC/DC power supply
- AC transformer



Paulo Abreu ®