RES Microgrids: Theoretical aspects and applications

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Why microgrids?

- Primarily environmental (and cost) considerations
  - Increase of RES generation -> replenishable resources
  - Reduction of CO_2 emissions
  - Efficient use of energy

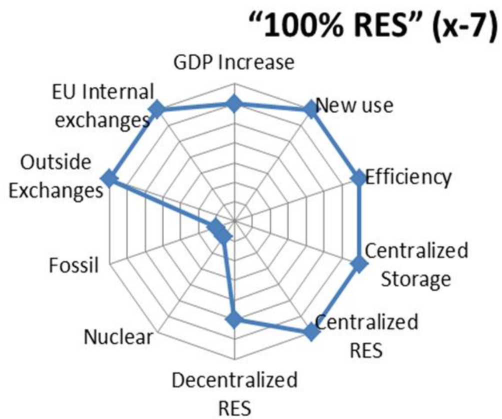
- Increased Security of Supply to end-users
- Optimal operation control of power systems and distribution grids
  - Clear-cut control capabilities, boundaries and responsibilities

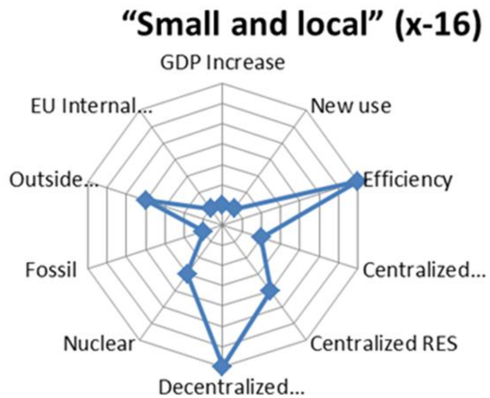
Environmental Considerations

- Short-term European targets of 2020
  - 20% cut in greenhouse gas emissions
  - 20% of EU energy from renewables
  - 20% improvement in energy efficiency

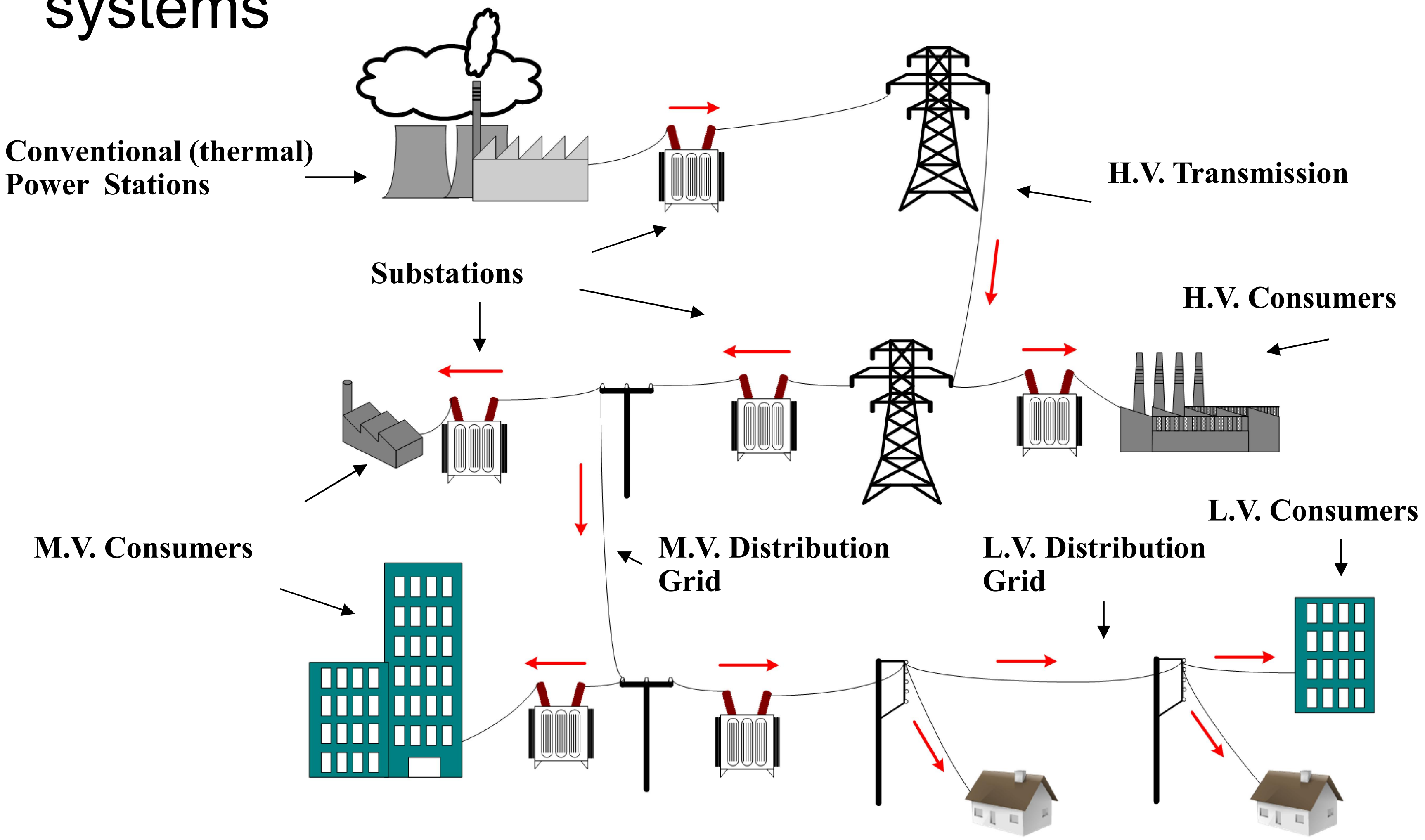
- Long-term targets (2050 and beyond)
  - e-Highway 2050: various future scenarios as possibilities

two out of five prospective scenarios:

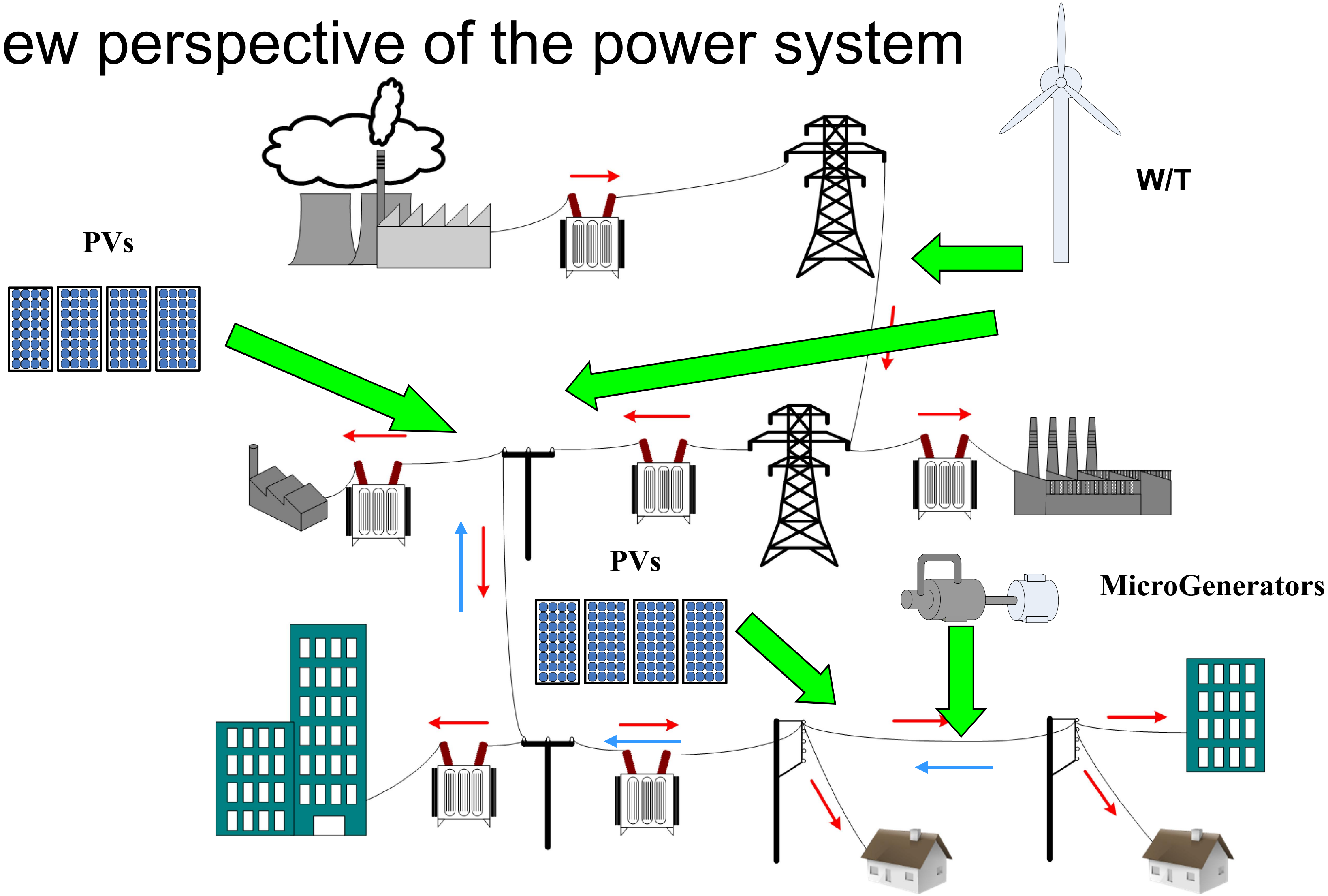




Conventional structure and operation of power systems



New perspective of the power system



Microgrids: Definition and main features

<u>Definition</u> (EPRI):

"A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and that connects and disconnects from such grid to enable it to operate in both grid-connected or "island" mode"

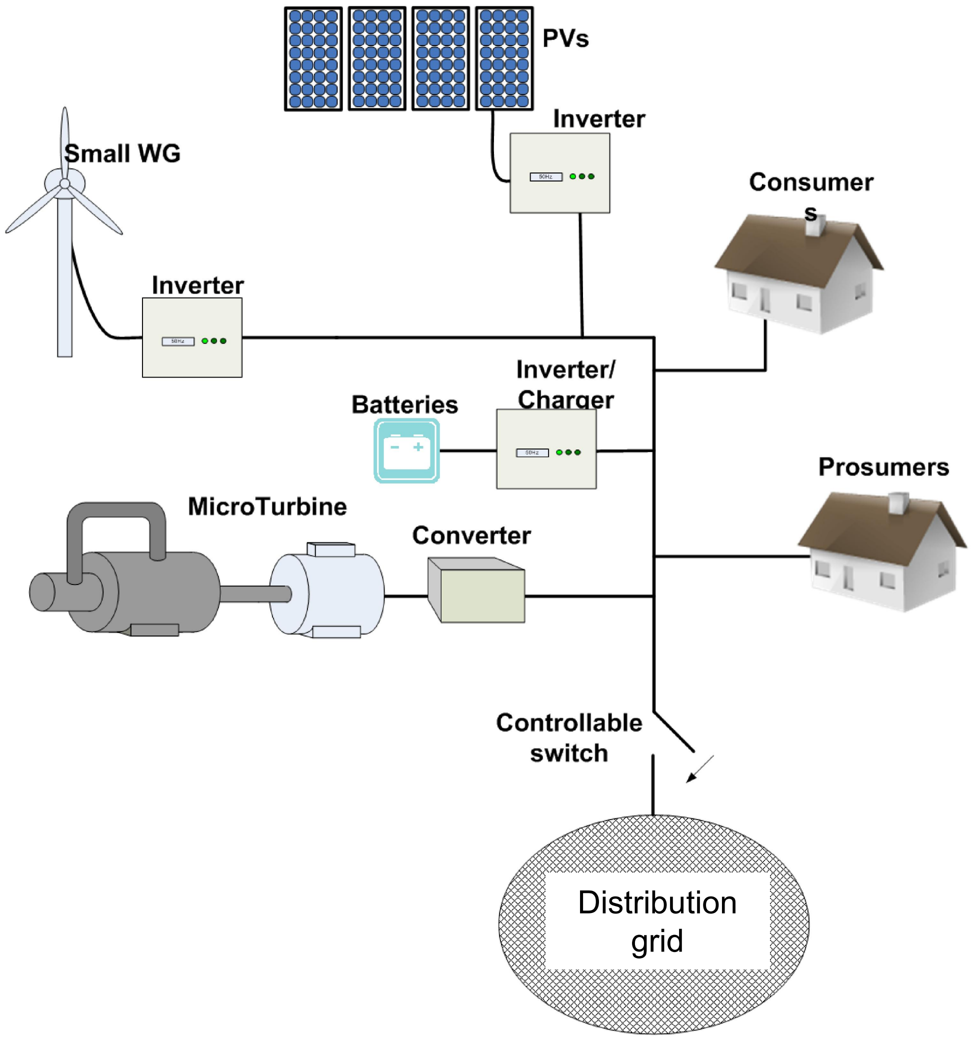
- Small scale LV power systems. Consist of parts of the distribution grid (PCC at MV/LV transformers)
- Purpose of use is the electrification of household communities, rural communities, mixed suburban environments
- Incorporate different types of resources such as:
  - MicroSources (MS) or MicroGenerators (MG) (micro-turbines, fuel cells, PVs, etc.)
  - Storage devices i.e. (flywheels, energy capacitors and batteries)
  - Controllable loads

Microgrids- main features (cont'd)

- Increases the hosting capacity RES into LV distribution systems because it views the generation and associated loads as a subsystem.
- Increases energy efficiency since it favours local generation and thus, contribute to the reduction of transmission systems losses. This leads to economic and environmental benefits not only for operators but also for end-users.
- Increases reliability for end-users due to the fact that microgrids can operate in islanded mode in case of mains loss or other disturbances providing so an Uninterruptible Power Supply (UPS).
- Provide a substantial amount of flexible power that can be easily controlled in order to support DSOs and TSOs in terms of balancing, systems operation and provision of ancillary services. Hence, power quality and Security-of-Supply improvement

Simplified example of a microgrid

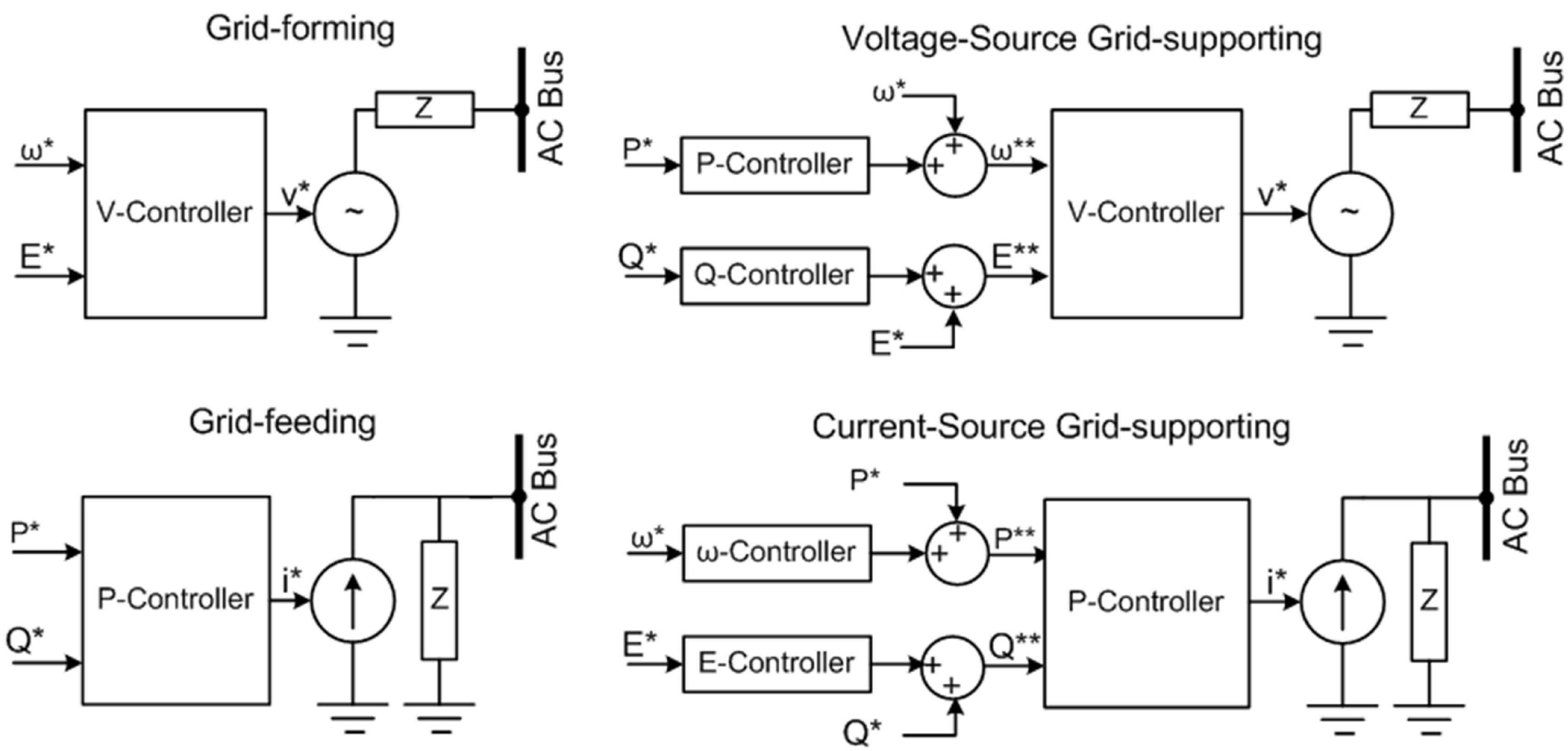
- RES (PVs, small W/Gs)
- Consumers
- Prosumers
- Battery storages
- Microturbines
- Power conversion
- Connection to a MV distribution network (DSO)



Classification of MicroSources

- Grid forming units:
    - Determine the microgrid's frequency in islanded mode. There is at least one such unit in a microgrid which acts as the "master" device and in this category belong diesel generators and inverter based battery storages.
- Grid parallel units:
    - Include uncontrollable or partially controllable MS like PVs and wind generators. Their purpose is to feed the system with the maximum possible power.
- Grid supporting units:
    - Feed the microgrid with active-reactive power. This category includes microturbines, fuel cells etc

Types and control strategies of MicroSources



Energy balance and interconnection issues

- Short and long-term energy/power balance between supply and demand
- Most critical in isolated mode due to absence of an external system to balance the energy

Thus:

- Proper design of the microgrid by selecting the most appropriate sources and storage units
- Local MS and Load control of frequency as well as central supervisory control is necessary
- Energy management should be bilateral:
  - Generator control in order to decrease/increase production when necessary
  - Load control by shedding non-critical loads when we have overload or supply deficit, or shifting loads so as to achieve load levelling

Interconnection requirements

- A microgrid is necessary to have interconnection ability so as to ensure power balancing via the grid
- Static switches are the most appropriate equipment for this function
- Control of the interconnection switch should be done through both central and local controller
- Compliance with interconnection rules in order to minimize faults

Proposed microgrid architectures

Objectives:

- Minimum efforts and modifications of the existing distribution grids
- Reduction of operation risks
- Addition of Distributed Generators without causing operation conflicts

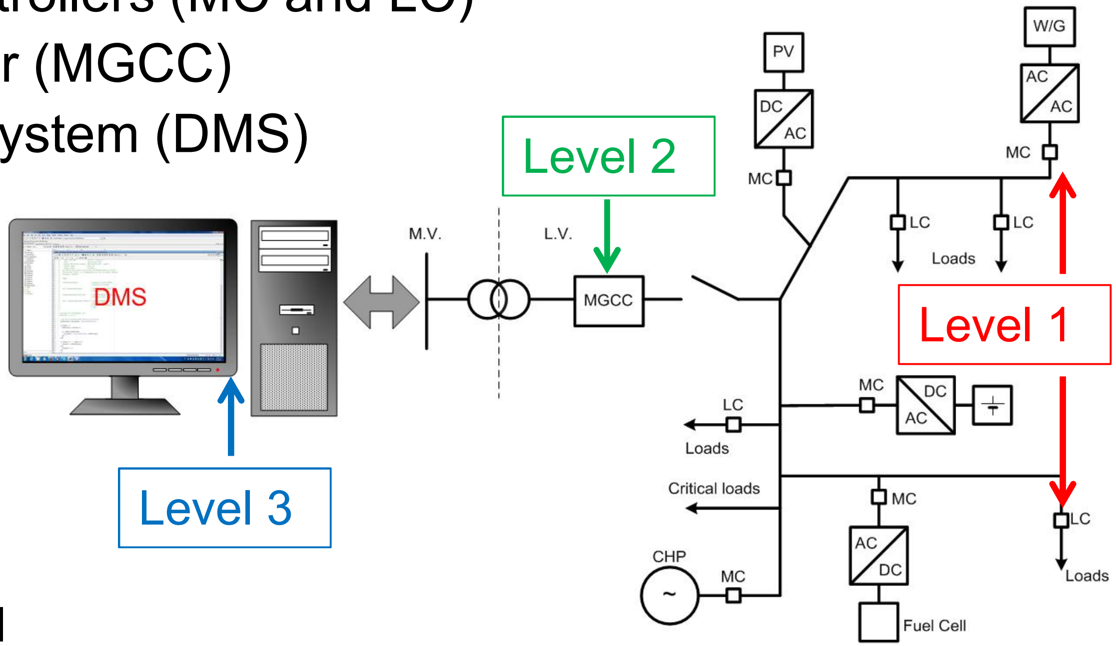
Proposed architectures :

- Peer-to-peer model
- Plug-and-play model

Microgrid control scheme

Hierarchical control scheme, based on different layers, each of which is assigned with specific responsibilities

- Microsource and Load Controllers (MC and LC)
- MicroGrid Central Controller (MGCC)
- Distribution Management System (DMS)



<u>Controlled quantities</u>

- Voltage/frequency locally
- Coord. Voltage/frequency control
- Energy management

Standardisation of microgrids controllers

- IEEE P2030.7: Standard for the Specification of Microgrid Controllers:
  - Microgrid Energy Management System
  - Functions that allow for autonomous/grid connected operation
  - Exchange of power/provision of ancillary services
  - Control approaches independent of topology, configuration or jurisdiction

- IEEE P2030.8: Standard for the Testing of Microgrid Controllers:
  - Set of testing procedures for verification and quantification of controllers

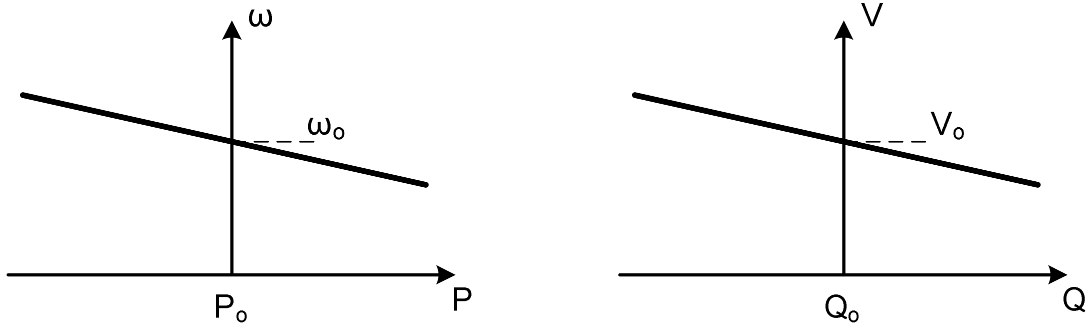
Voltage and frequency local control

- Most of the MS are inverter based systems
- Voltage and frequency can be regulated locally by local controllers
- Control of inverters:
  - Active-Reactive power control: inverter operates in a grid-connected mode, feeding with power the microgrid but without being able to form grid by itself
  - Voltage Source Inverter (VSI) control: inverters feed with specific voltage and frequency values the connected loads

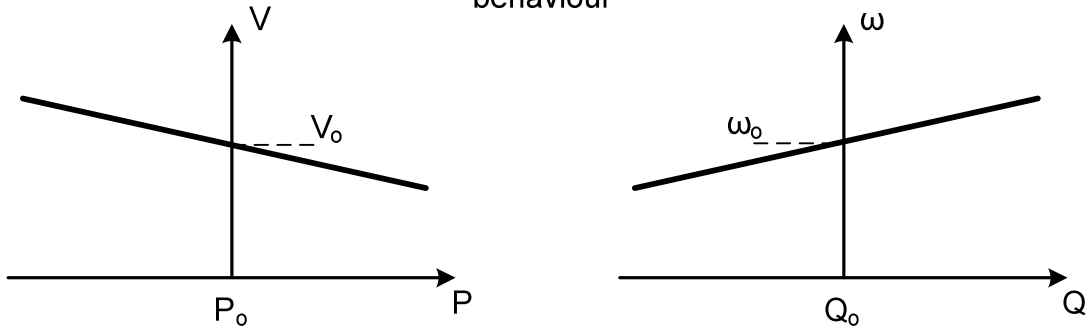
The technique widely used in order to control the output power of the MS inverters is based on the droop characteristics

Local Control Strategies: Droop control

Droop characteristics for grids with mainly inductive behaviour



Droop characteristics for grids with mainly resistive behaviour



Mixed behaviour:

Coordinated voltage and frequency control

- In isolated operation it is critical that the frequency and voltage is kept within specific limits
- Under transient conditions storage devices like batteries, ultracapacitor and flywheels should act according to the frequency changes
- Under steady state any drifts of frequency should not enforce the storage devices to act
- Central frequency control-Intelligent Load Management Controllers (ILMC)
- PQ inverters are used in order to support reactive power while the voltage is regulated in the VSI connection point.
- Set-points for such a strategy are obtained from the MGCC

Energy management

- Balance between demand and supply from the MS as well as the MV grid
- Centralized and distributed decision-making processes
- Distributed:

  Responsibility is assigned to the microgenerator Controllers (MCs) that compete to maximize their production (or profits) in order to satisfy the demand. This approach can be based on distributed multi-agent system technology (MAS)

- Centralized:

  In centralized control, the MCs follow the orders of the MGCC, when connected to the power grid, and have the autonomy to perform local optimization of the micro source active and reactive power production, and fast load tracking following an islanding situation

Static switch and synchronisation requirements

- Advantages:
  - Absence of moving parts → longer lifetime
  - Easier to deploy control schemes that require fast response
- Connection requirements:
  - Ideally zero voltage across the switch
    - Equal frequencies
    - Equal magnitude
    - Same phase sequence
    - Zero phase angle difference

Disconnection conditions:

- Low voltage quality, e.g. due to load imbalances
- Frequency drop
- Voltage sags longer than the critical loads and operating limits
- MV grid faults
- Specific current flows from the MV to the microgrid

The Multi-Microgrid concept[1]

- Distribution Networks with increased microgrids penetration
- New control architecture for full exploitation
- Combined with MV-connected flexibility
- Intermediate control level: Central Autonomous Management Controller-CAMC
- Key issues addressed by this control architecture:
  - Coordinated V/Q control for normal operation
  - Coordinated f/P control for islanded operation
  - Local black-start; restoration of the MV grid following a blackout

[1]N. Hatziargyriou et. al., “Microgrids: Architectures and Control”, Wiley-IEEE Press, 2014

Thank you for your attention

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