Microgrids

Microgrid architectures

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Content of this lecture

In this lecture we review microgrids architectures, that is which components form a microgrid and how to interconnect them.

In the next lectures we will focus on the components themselves, on features that are important for operation, both from a technical point of view and from an economical point of view.

AC grids

An alternating current (AC) microgrid is a microgrid where components are coupled through one AC bus (if there is only one voltage level).

- Most microgrids are AC
- Typically, AC microgrids where the demand > 5kW are three-phase!
  - Required if you want to connect to the public grid (in Belgium)
  - Equipment in general require less components per unit of power transferred
  - Easy to generate a rotating field for motors
  - (Three-phase power transfer is a constant expression, if the phases are balanced)

Grid topologies

Most common: radial architecture

- Subject to availability issues (one single path to a load)

Alternatives:

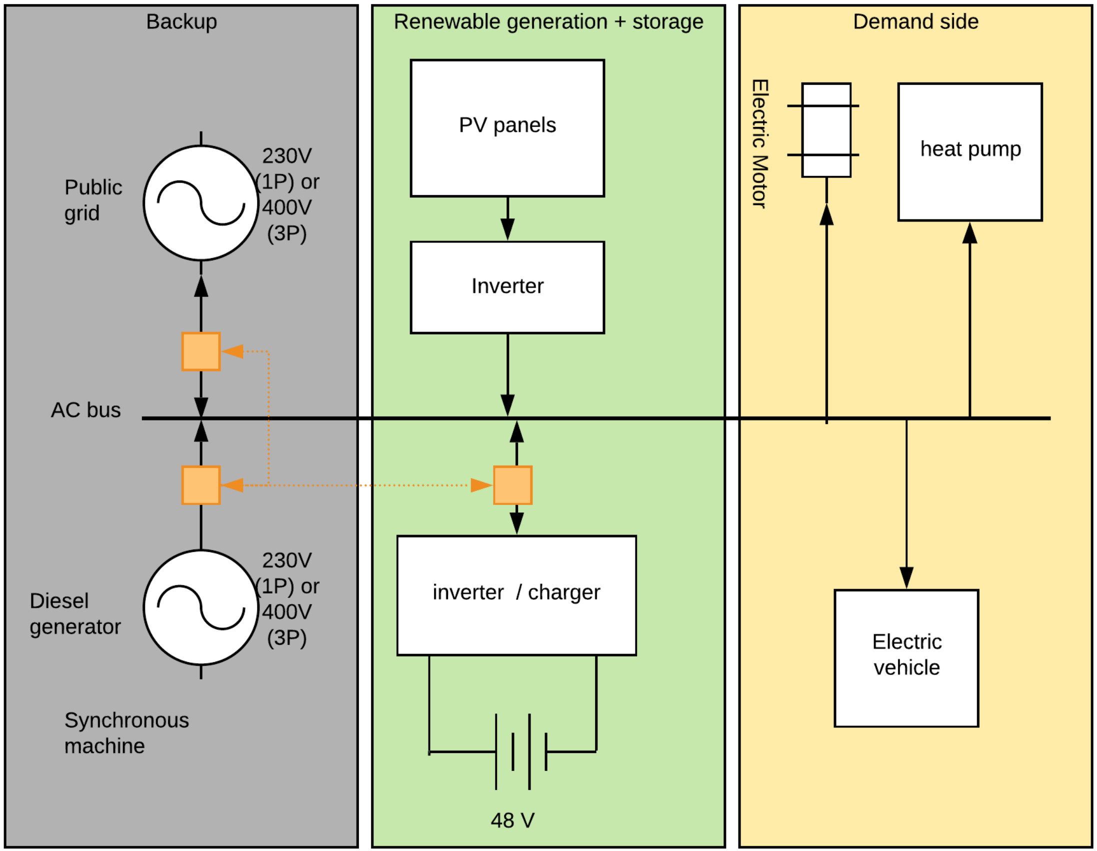
1. provide a redundant path to each load (more robust than radial)
2. provide spatially diverse paths (more robust than 1)
3. ring-type distribution (Can isolate a fault and still feed all but problematic zone)
4. ladder type distribution (yet more connection possibilities)

Note: a more complex system also needs more complex protection schemes.

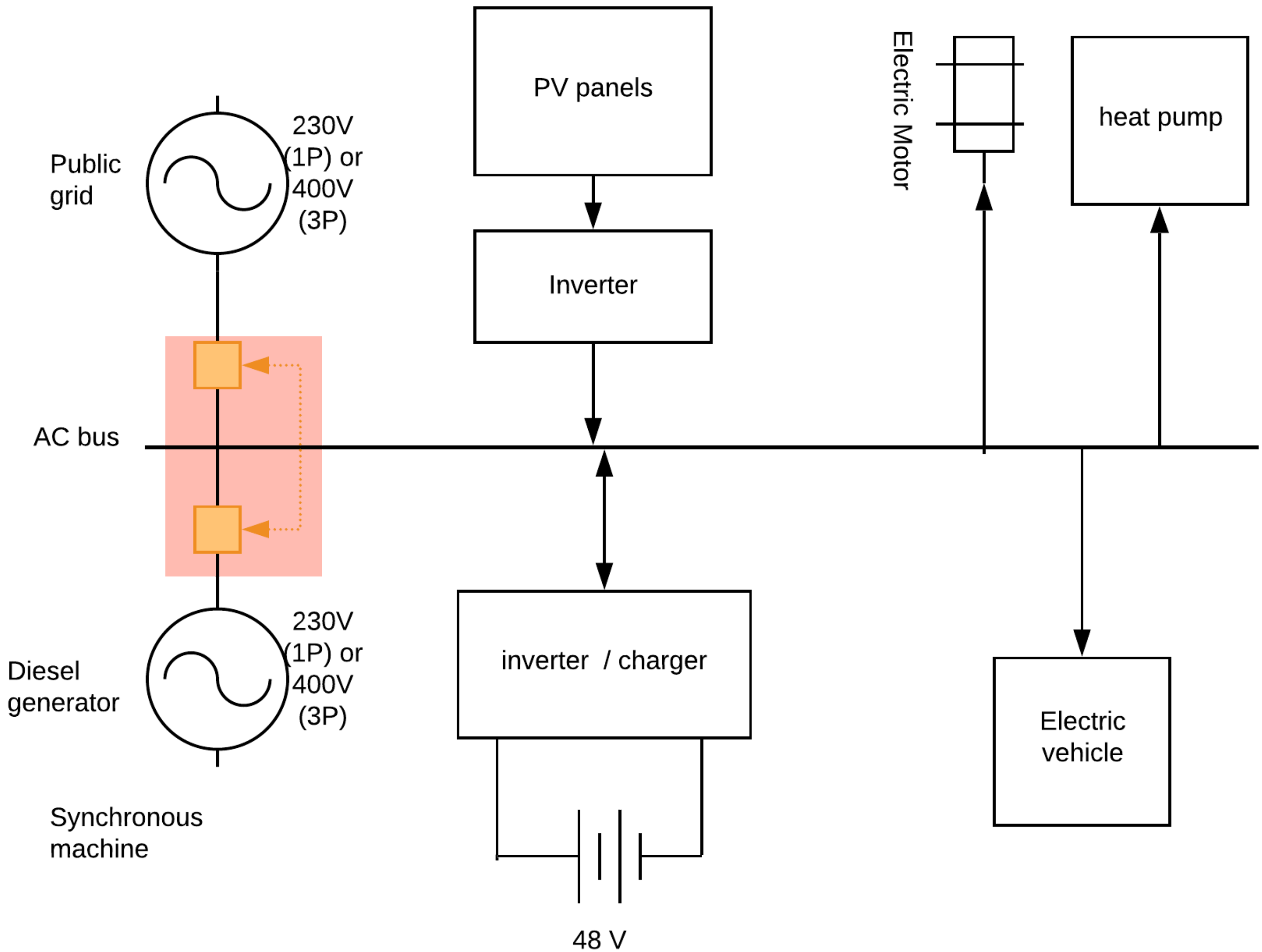
See chapter 7 of [1] for more information.

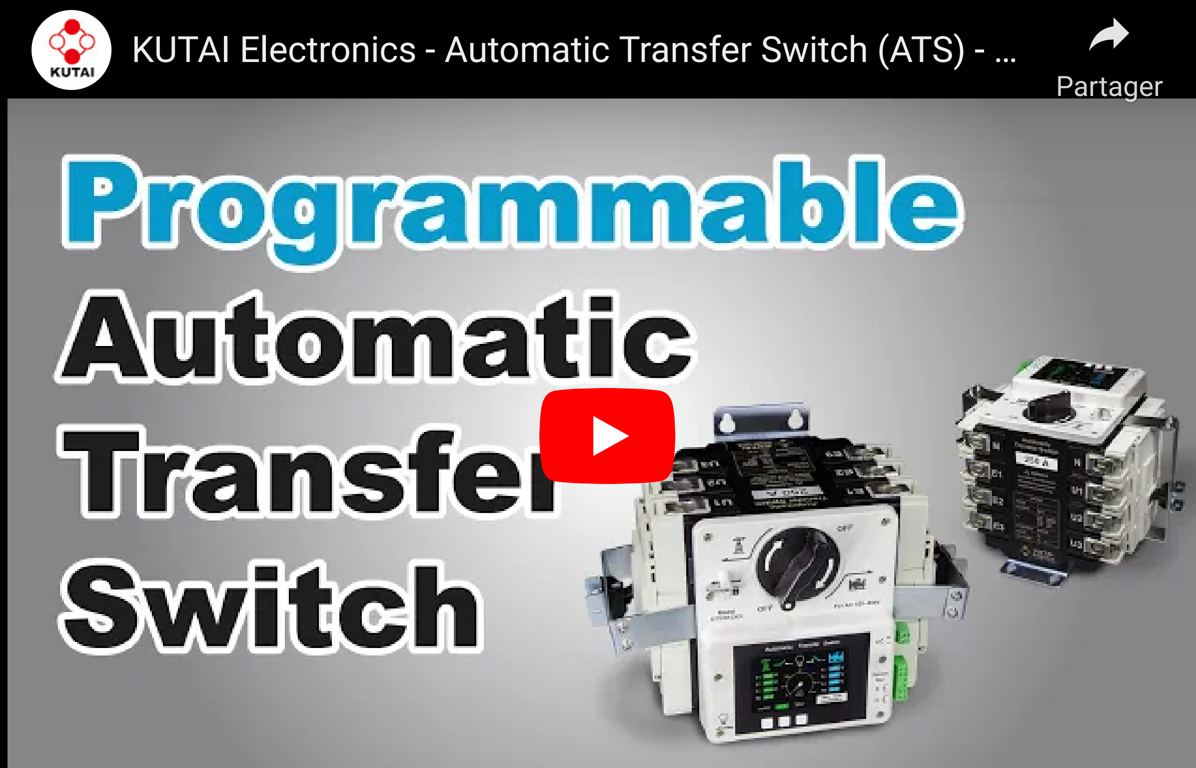
AC coupling example

Let's take the example of a house or a small company that is running at low-voltage (230V or 400V) and has a grid connection plus a backup diesel generator, some PV panels, a battery, and some appliances.



Automatic transfer switches





Automatic transfer switch principle

Power electronics interfaces

Power electronic circuits are interfaces

- between devices (DERs and loads) and the power distribution grid
- between the microgrid and the distribution grid (PCC)

Purpose: enable a controllable (bidirectional) flow between devices

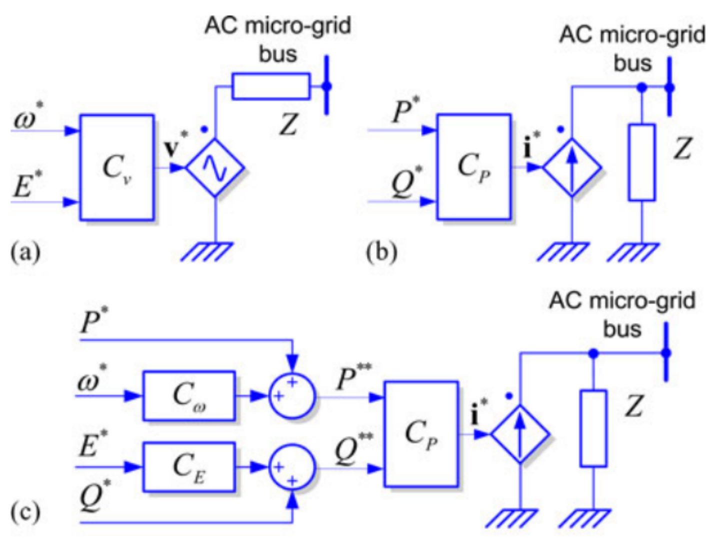
*DER: sources of electric power that are not directly connected to a bulk power transmission system. Distributed energy resources include both generators and energy storage technologies. (T.Ackermann, G.Andersson, and L.Söder, "Distributed Generation: A Definition," Electric Power Systems Research, vol. 57, issue 3, April 2001, pp. 195–204.)

Types of power electronics interfaces (from [2])

Grid-following converters (Fig (b)): can be represented as an ideal current source setting the active and reactive power injected into / withdrawn from the grid.

Grid-forming converters (Fig (a)): can be represented as an ideal AC voltage source setting the voltage amplitue and frequency of the local electrical grid.

Grid-supporting converters (Fig (c)): "inbetween the two others", implementing functions to support the grid, e.g. droop control.



All these functions are achieved using several nested control loops.

Grid-following converters (from [2])

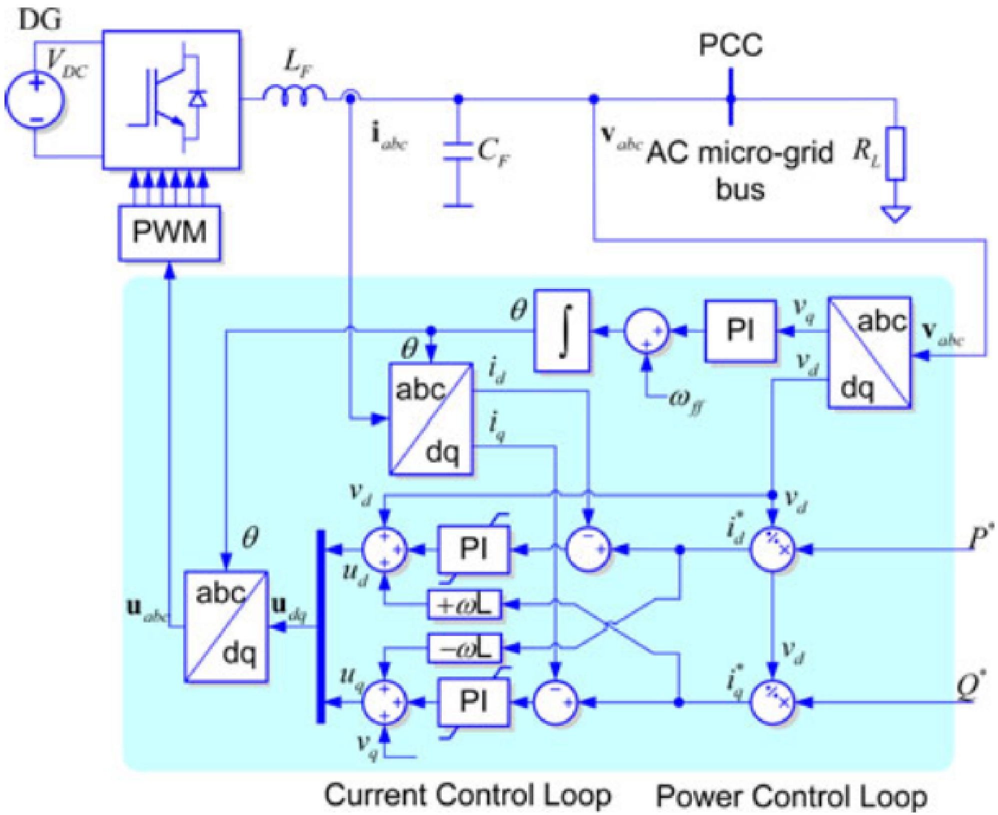


Fig. 3. Basic control structure in a three-phase grid-feeding power converter.

Closed-loop control of $P^\star$ and $Q^\star$

Grid-following converters: principle

A grid-following unit is based on a power converter whose injected currents are controlled with a specific phase displacement with respect to the grid voltage at the PCC.

As a consequence, the knowledge of the fundamental frequency phasor of the grid voltage at the PCC (PLL) is needed at any time for the correct calculation of the converter reference currents (DQ transform).

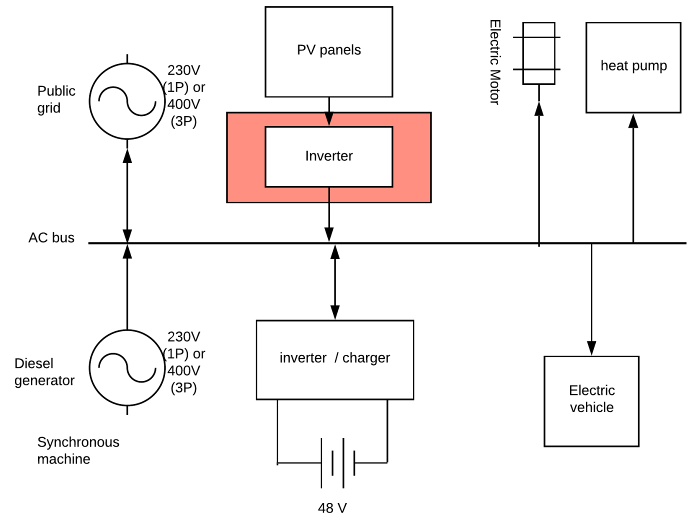
The currents amplitude and angle with respect to the grid voltage phasor are properly modified by outer control loops so as to inject the required amount of active and reactive power or control the RMS.

Source: Paolone, M., et al. (2020). Fundamentals of power systems modelling in the presence of converter-interfaced generation. Electric Power Systems Research, 189(April), 106811.

Grid-following converters: comments

- If connected to a battery, means that the battery is controllable, i.e. can absorb or deliver power depending on a setpoint.
- the setpoint is fixed by a higher level controller
- Several grid-following converters can work in parallel in a system
- But they require another device to regulate the imbalances, the grid frequency and the grid voltage (e.g. grid-forming inverter).

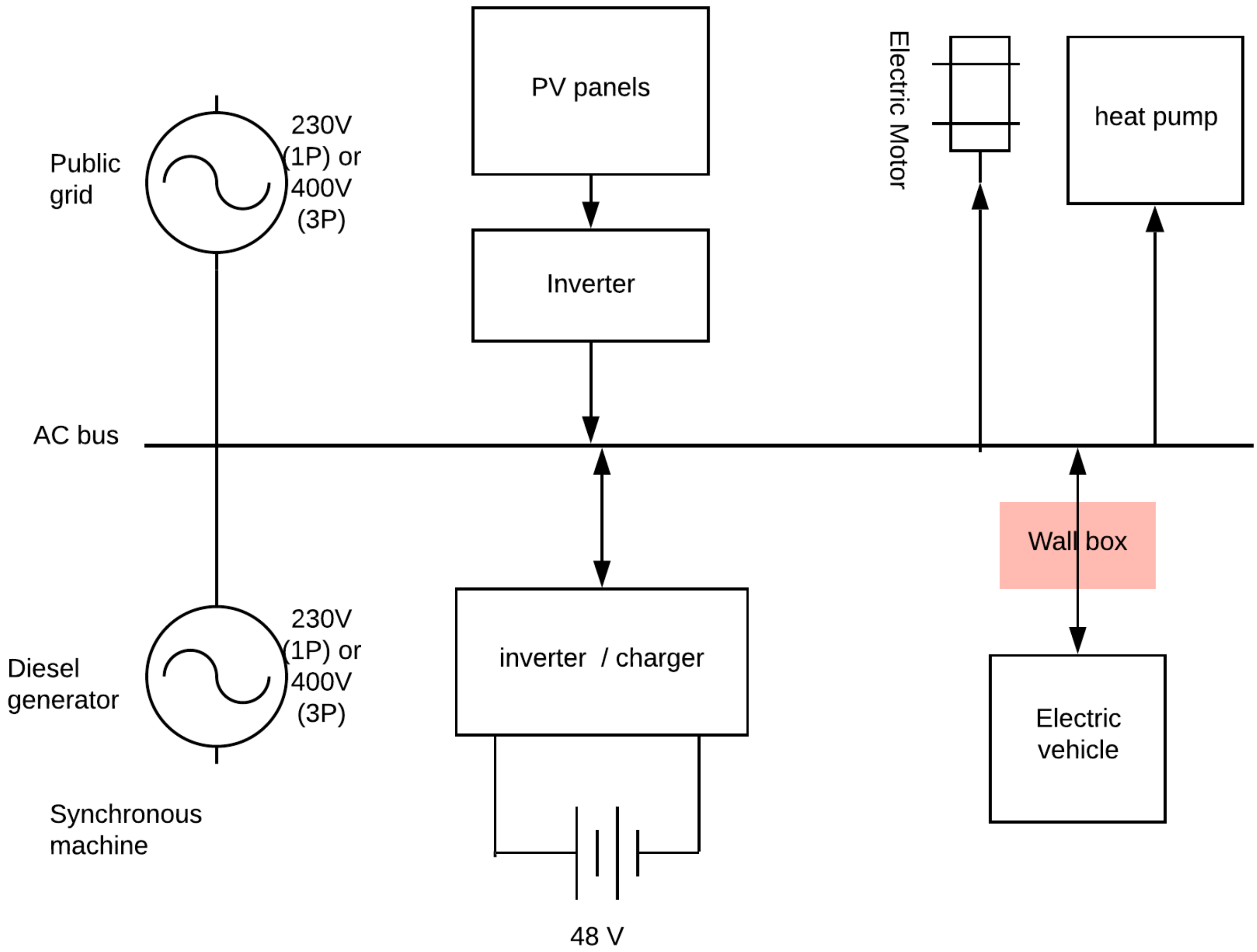
Example: solar inverter

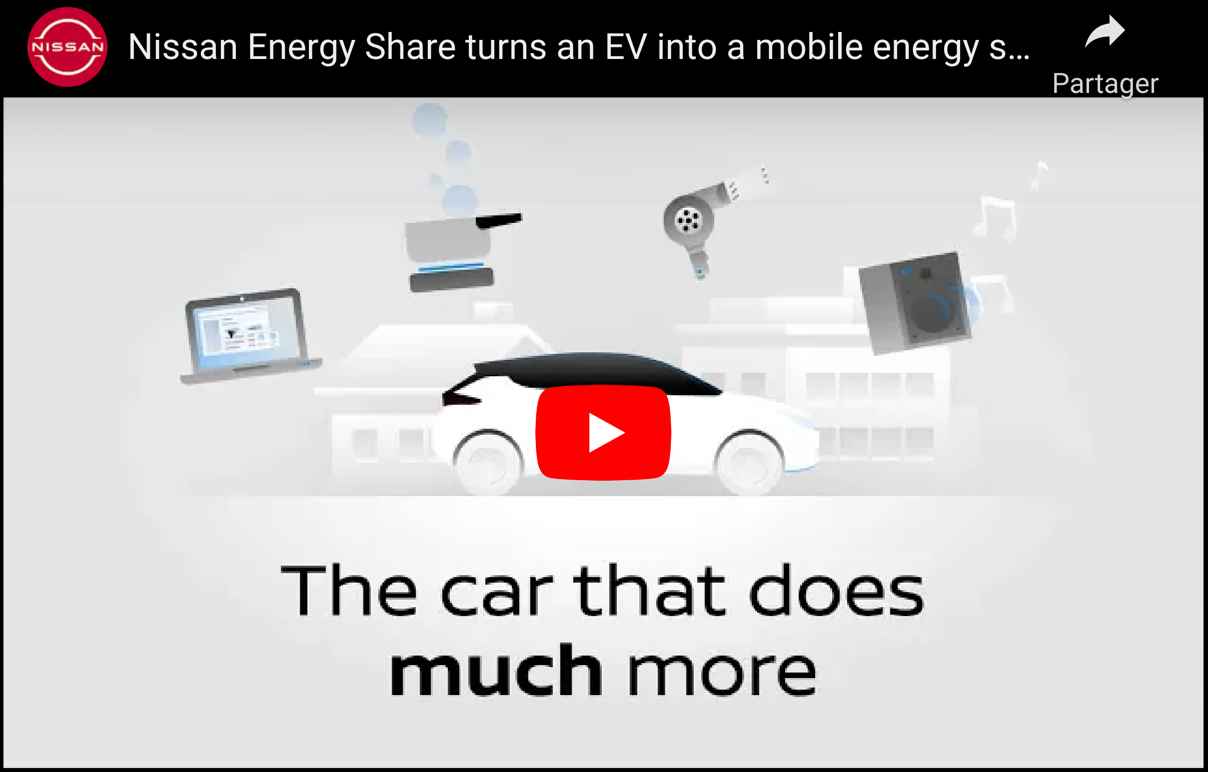


Here it is a three-phase inverter from SMA. Source: website of SMA

Requires a network signal to work!

Example: Vehicle to grid




Nissan Energy Share turns an EV into a mobile energy s...
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Grid-forming converters (from [2])

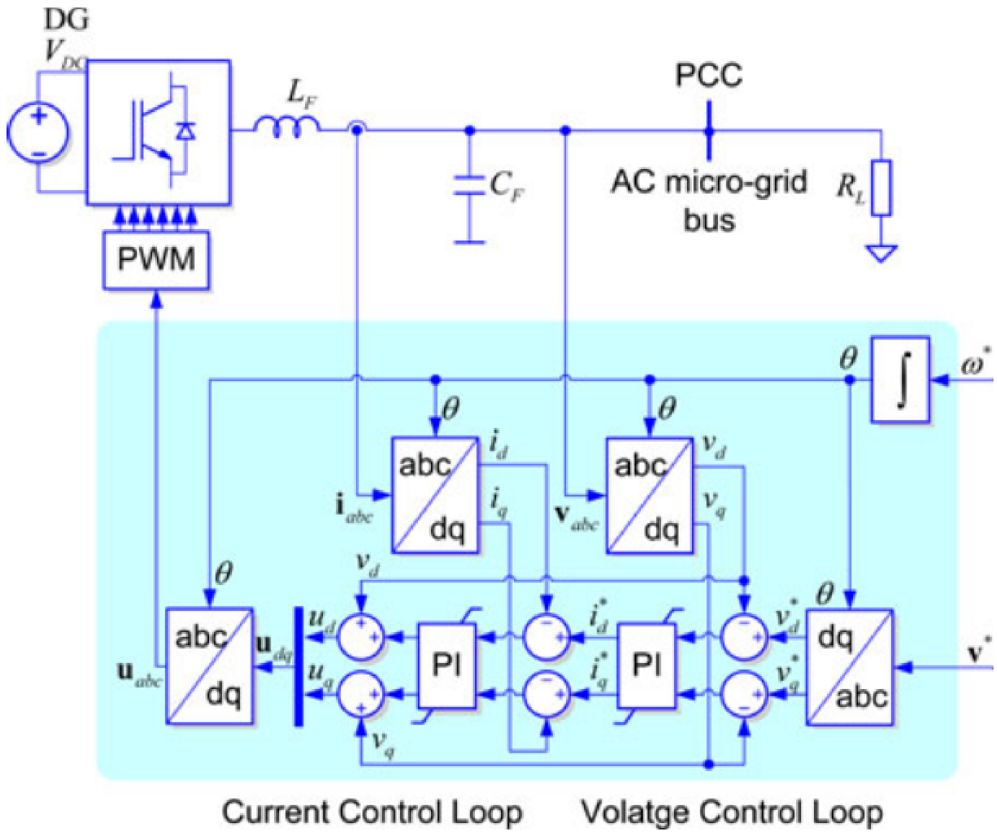


Fig. 2. Basic control structure in a three-phase grid-forming voltage source inverter generating a sinusoidal voltage determined by a nominal voltage amplitude v^* and reference frequency ω^*.

Closed-loop control of $v^\star$ and $\omega^\star$

Grid-forming converters: comments

- In general, there is only one grid-forming device at a time, else some coordination is necessary:

" As voltage sources, they present a low-output impedance, so they need an extremely accurate synchronization system to operate in parallel with other grid-forming converters. Power sharing among grid-forming converters connected in parallel is a function of the value of their output impedances." [2]

- If connected e.g. to a battery, means that the battery follows the residual between generation and demand.

"A practical example of a grid-forming power converter can be a standby UPS. This system remains disconnected from the main grid when the operating conditions are within certain limits. In the case of a grid failure, the power converter of the UPS forms the grid voltage." [2].

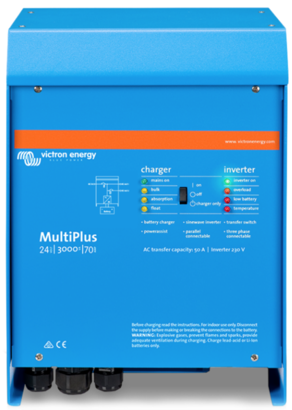
"In a microgrid, the AC voltage generated by the grid-forming power converter will be used as a reference for the rest of grid-feeding power converters connected to it." [2].

Grid-forming inverter will likely be more and more present in bulk power systems

"Grid-forming inverters are able to operate AC grids with or without rotating machines. In the past, they have been successfully deployed in inverter dominated island grids or in uninterruptable power supply (UPS) systems. It is expected that with increasing shares of inverter-based electrical power generation, grid-forming inverters will also become relevant for interconnected power systems. In contrast to conventional current-controlled inverters, grid-forming inverters do not immediately follow the grid voltage. They form voltage phasors that have an inertial behavior. In consequence, they can inherently deliver momentary reserve and increase power grid resilience."

Source: Unruh, P., Nuschke, M., Strauß, P., & Welck, F. (2020). Overview on grid-forming inverter control methods. Energies, 13(10)

Example: Automatic transfer switch, grid forming inverter & battery charger

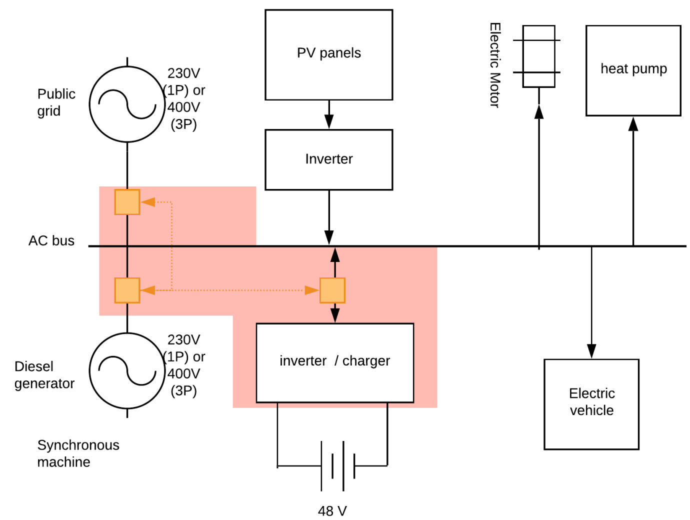


MultiPlus

Multifunctional

The MultiPlus, as the name suggests, is a combined inverter and charger in one elegant package. Its many features include a true sine wave inverter, adaptive charging, hybrid PowerAssist technology, plus multiple system integration features.

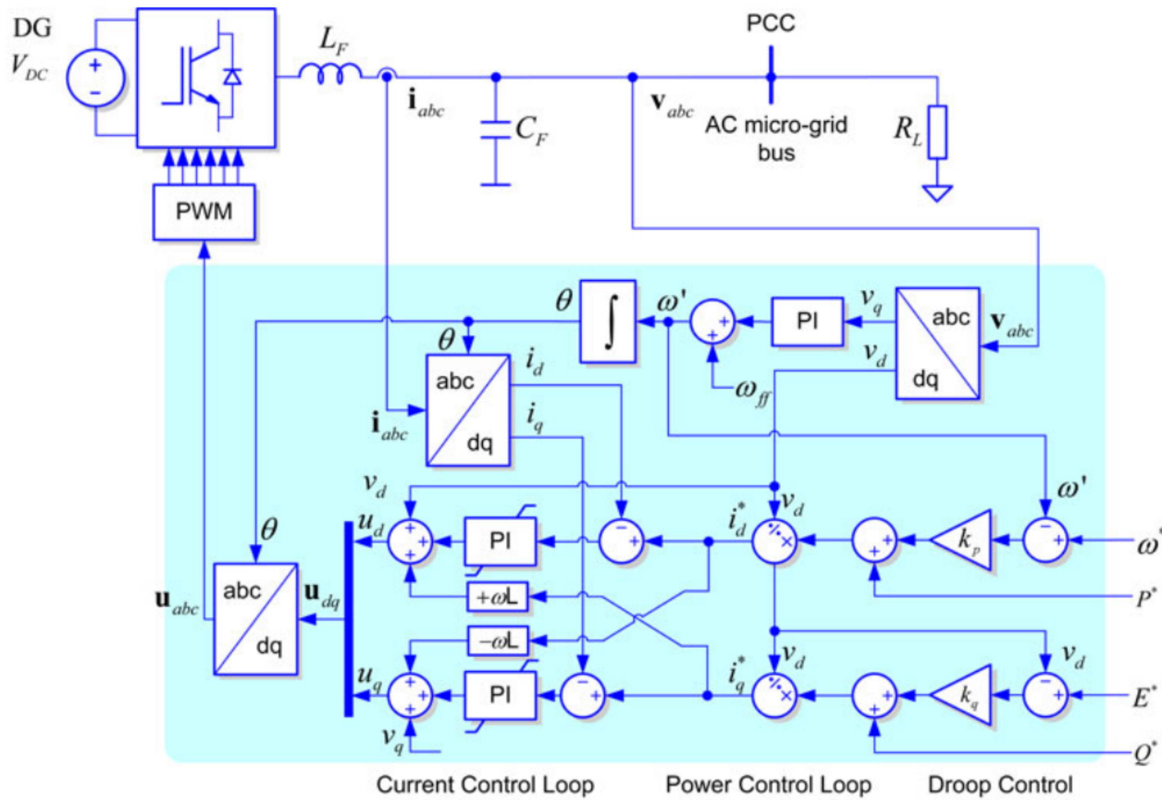
Models:
800VA, 1200VA, 1600VA, 2000VA, 3000VA, 5000VA



Source: website of Victron.

grid-supporting converters

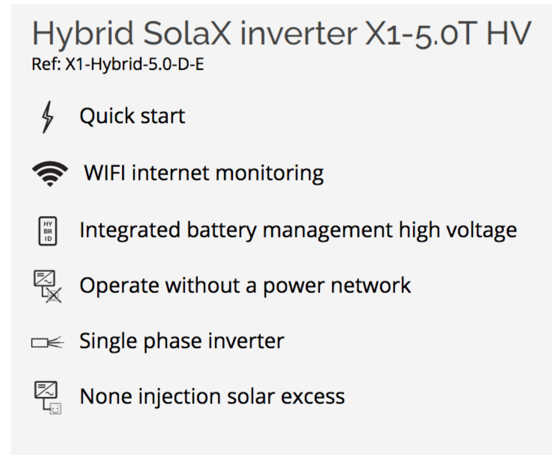
Can be seen as a grid-following converter with additional control loops to support the grid -> frequency and voltage regulation.



(a)

Characterizing power distribution architectures based on how power conversion is performed

- Centralized: power conversion is performed at a single power electronic interface. Example:



- Distributed: power conversion functions are spread among converters
    - may lead to parallel or cascade structures

Source:https://www.alma-solarshop.com/solax-power-inverter/982-hybrid-solax-inverter-x1-50t-hv.html

Rules for connecting DER to the grid (Belgian case, C10/11)

Synergrid

Synergrid is the federation of electricity and gas network operators in Belgium. Synergrid establishes prescriptions for a series of topics related to distribution systems.

In the "Technical Prescription C10/11 of Synergrid, edition 2.1 (01.09.2019) (English translation)", you can find the rules that apply to a new installation.

"This document C10/11 lays down the technical requirements relating to the connection of power generating plants capable to operate in parallel to the distribution network. The objectives of this document are the following:

- ensuring proper operation of the distribution networks;
- improving the safety of staff active in these networks;
- protecting the distribution network's infrastructure;
- and contributing to the general system stability. "

Application domain of C10/11

Applies to:

- Plants < 25MW connected to the distribution grid
- Any energy source
- Without limitation regarding the possibility of actually injecting energy to the distribution network; this means, for example, that it is also applicable to power-generating plants equipped with a zero export relay. (...)
- ...

But not to:

- Off-grid systems
- Backup systems (not actually able to feed in the grid)
- ... (elevators)

Special cases

A power backup system (as specified in § 4.1.9) will only operate in parallel with the distribution network for a short time in the following sporadic cases:

- During tests
- In case of islanding / reconnection after a network faults ("make-before-break")
- ...

There are maximum durations depending on the cases.

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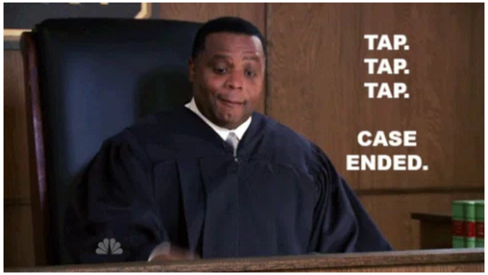
There are maximum durations depending on the cases.

In case of infringment, either:

- all rules of C10/11 apply to the backup system
- or parallel operation made impossible



Maximum power limits for a small power-generating plant

	Connection to the low-voltage distribution network		Connection to the high-voltage distribution network
	Single phase connection to the distribution network	Three-phase connection to the distribution network	
Sum of the power of the power-generating units other than the possible energy storage systems	≤ 5 kVA[9]	≤ 10 kVA	≤ 10 kVA
Sum of the power of the energy storage systems	≤ 5 kVA[10]	≤ 10 kVA	≤ 10 kVA

- Each power-generating unit must be equipped with an automatic separation system
- If the power-generating plant includes an energy storage system,
  - an EnFluRi sensor must be provided to control the power injected on the distribution network.
  - the EnFluRi sensor is a directional power sensor having a communication link with the energy storage system.
  - the power injected into the distribution network is limited to the maximum power of the other means of power-generation.

Settings of the automatic separation system (Annex C)

Function	Trip setting
Overvoltage 10 min mean	230 V + 10 % no delay*
Overvoltage	230 V +15 % no delay*
Undervoltage	230 V -20 % no delay*
Overfrequency	51,5 Hz no delay*
Underfrequency	47,5 Hz no delay*
LoM	according to EN 62116
**« No delay » means that no time delay is added to the intrinsic technical duration required to initiate the disconnection. The operate time may not exceed 200ms.*	

Syncrocheck

The power-generating units which synchronize with the voltage on the distribution network (such as synchronous machines, island equipment ...), have to be equipped with a synchrocheck relay (equipped with a synchroscope) of a type homologated by Synergrid.

The synchrocheck is set as follows unless determined otherwise by the DSO:

- Voltage difference < 5 %
- Phase difference < 5°
- Observation time = 0,5 seconds

Technical basic requirements regarding the power generating units (Annex D)

E.g. Specific for a small power-generating plant (D.7.1.1)

By default, the power generation unit must operate according to the following rules:

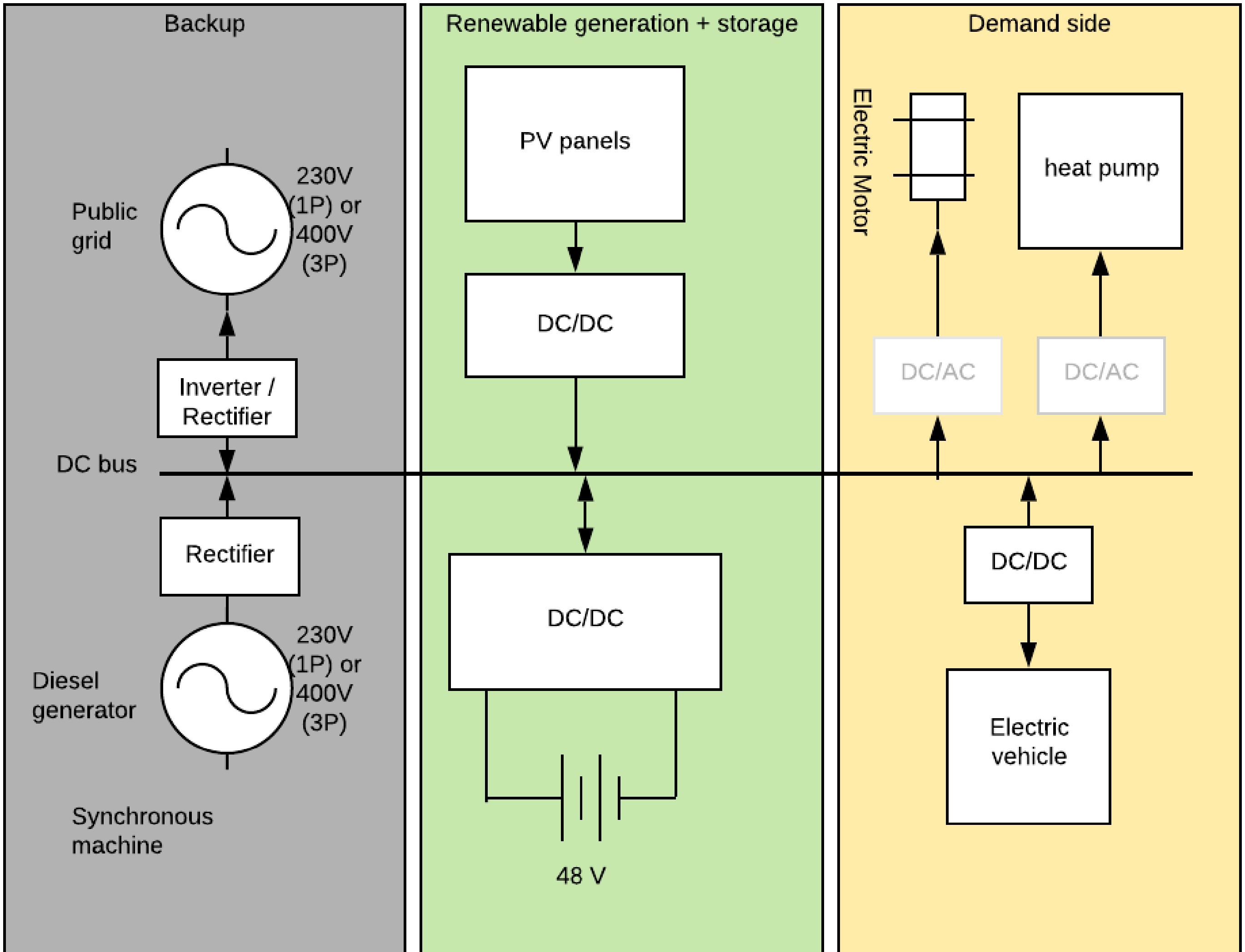
- When the voltage $\leq 105\% U_n$: $\cos\phi = 1 (Q = 0)$
- When the voltage $> 105\% U_n$: free operation with $1 \geq \cos\phi > 0.9$ under-excited. (no overexcited operation allowed)

DC microgrids

DC microgrids

- The distribution system is DC
  - Requires DC to DC converters to adapt voltage to devices
  - DC to AC to power AC loads, or to inject in the public grid
  - AC to DC to convert AC generation to DC (e.g. from public grid to microgrid)
- DC microgrids are not widespread but gain some interest

DC microgrid example



DC vs AC: pros

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- DC systems enable a simpler integration of distributed energy resources (DERs*), since many of them are either DC by nature or require a DC interface anyway
- Parallel distributed architectures are simpler to realize in DC:
  - unnecessary frequency control and phase synchronization
- Frequency control is not necessary in DC systems
  - unwanted harmonic content may by easier to filter too

:(

- Autonomous distributed control harder in DC than in AC because no information carried through the signal (frequency, phase)
- There are stability issues due to DC-DC conversion stages
- It is more difficult to clear fault currents: the signal “does not go through zero”. Hence protections are more costly and harder to set up.

A first microgrid demonstration

Lab visit

Assignment

By teams of 2, write a little report and draw an electrical diagram of the demonstration board:

- wiring diagram
- protections
- equipment ratings (voltage, current, power)
- types of controllers and regulations
- cable sections
- try to get some datasheets to understand how components work, can do and cannot do

References

[1] Kwasinski, Alexis, Wayne Weaver, and Robert S. Balog. Microgrids and other local area power and energy systems. Cambridge University Press, 2016.

[2] Rocabert, J., Luna, A., Blaabjerg, F., & Rodríguez, P. (2012). Control of power converters in AC microgrids. *IEEE Transactions on Power Electronics*, *27*(11), 4734–4749. https://doi.org/10.1109/TPEL.2012.2199334

The end.