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.

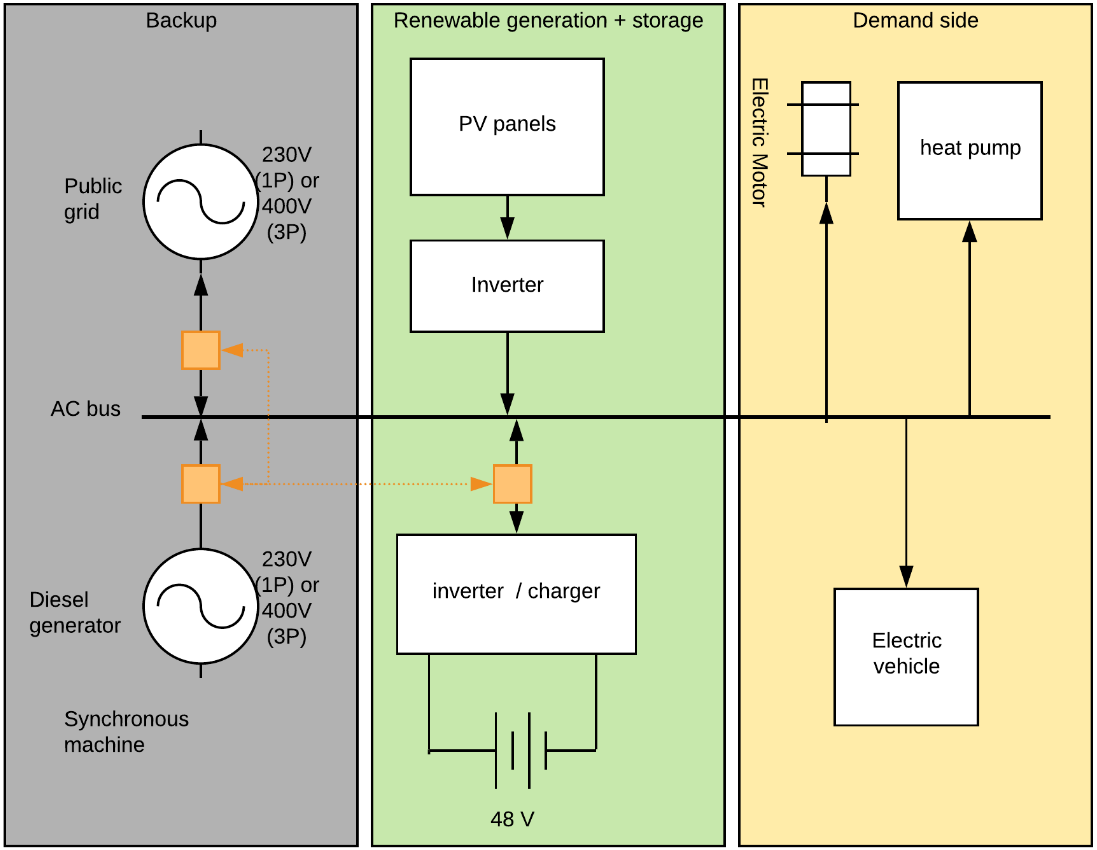
AC grids

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)

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.



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 the reference book for more information.

Power electronics interfaces

Power electronic circuits are interfaces

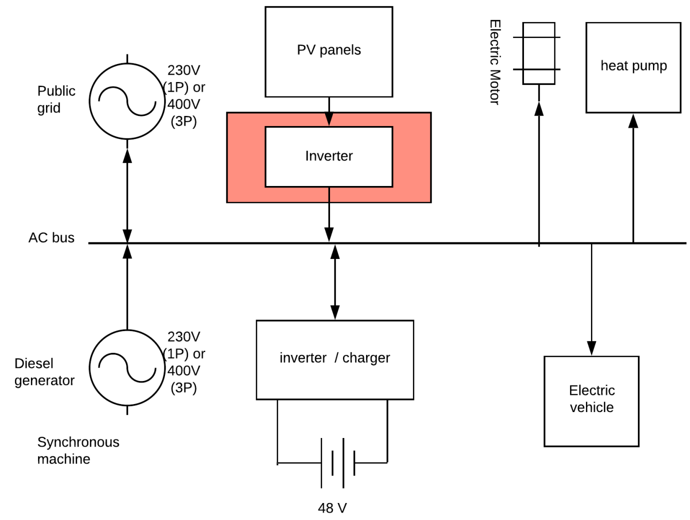
- between devices (DERs and loads) and the power distribution grid
- between the microgrid and the distribution grid (PCC)

Purpose: enable a controllable (bidirectional) flow between devices

- They are either grid-forming or grid-following. In general, there is only one grid-forming device at a time, else some coordination is necessary.

*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.)

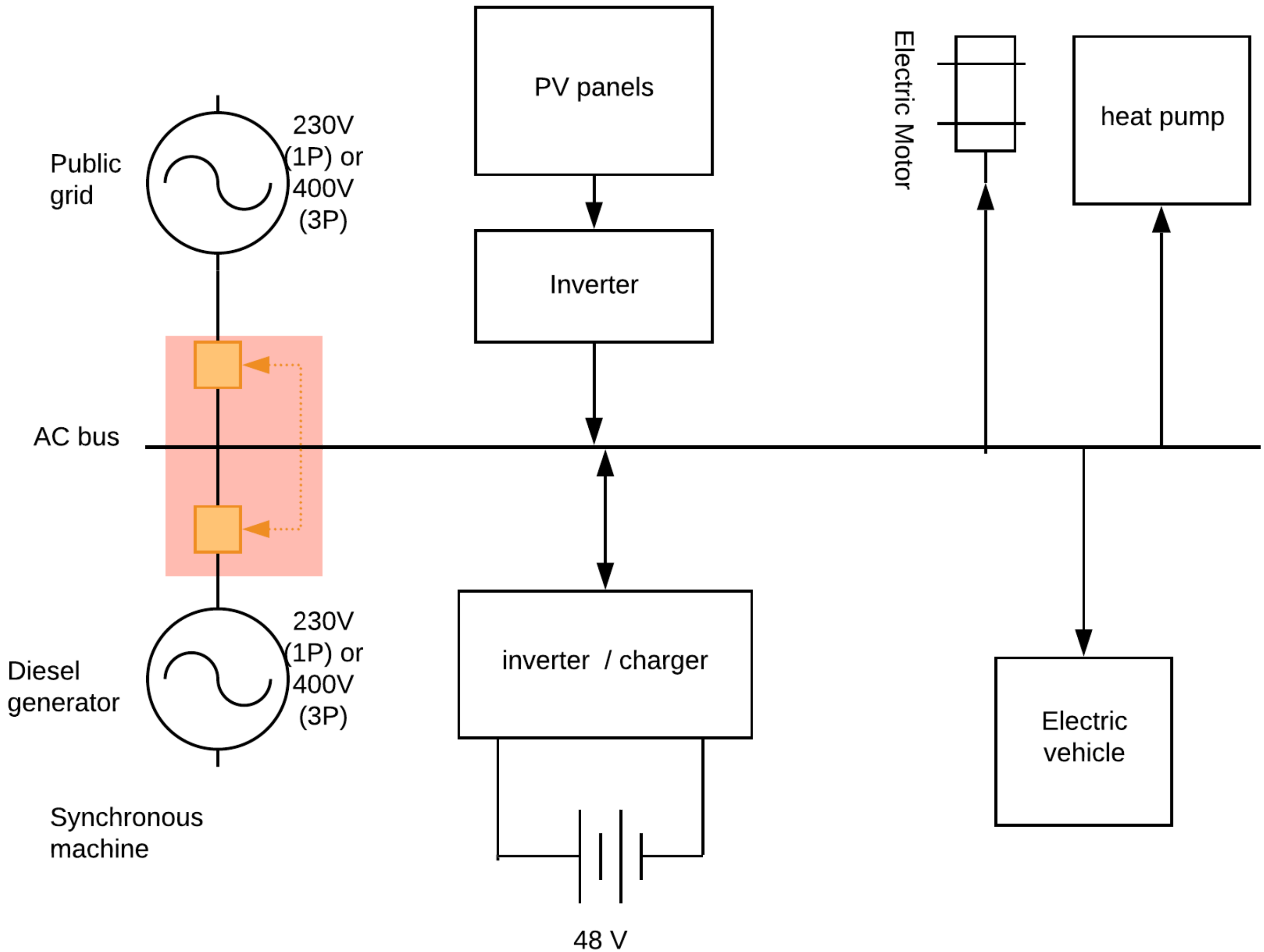
Solar inverter



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

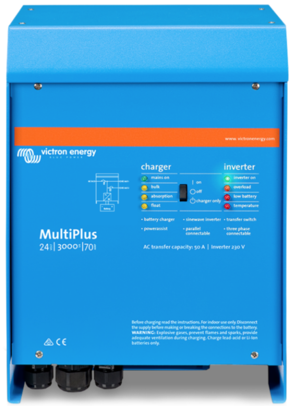
Requires a network signal to work!

Automatic transfer switches



Automatic transfer switch principle

Automatic transfer switch, grid forming inverter & battery charger

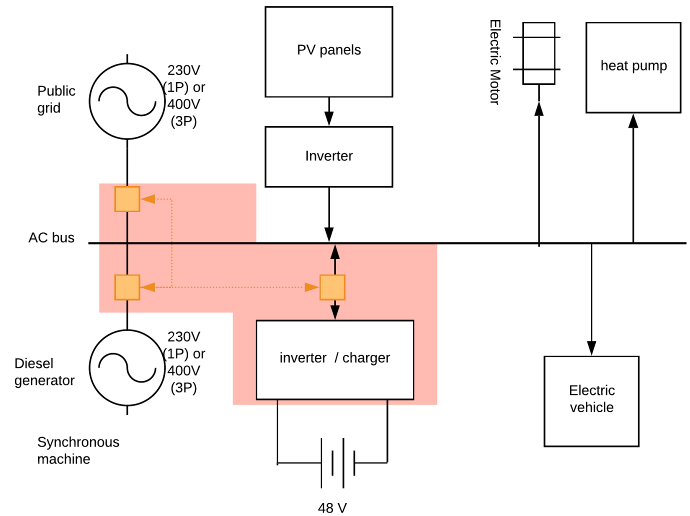


MultiPlus

Multifunctional

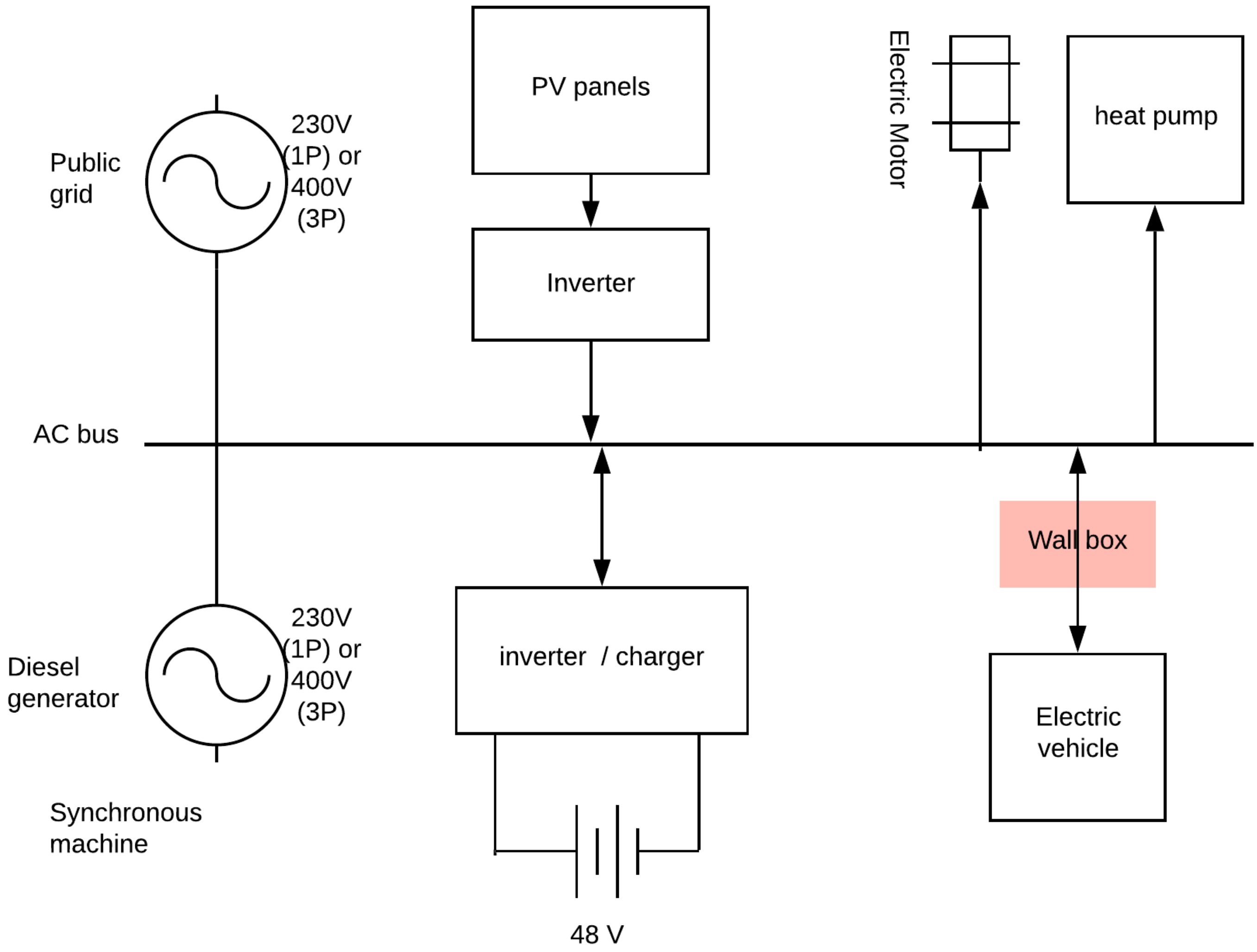
The MultiPlus, as the name suggests, is a combined inverter and charger in one elegant package. Its many features include a true sine wave inverter, adaptive charging, hybrid PowerAssist technology, plus multiple system integration features.

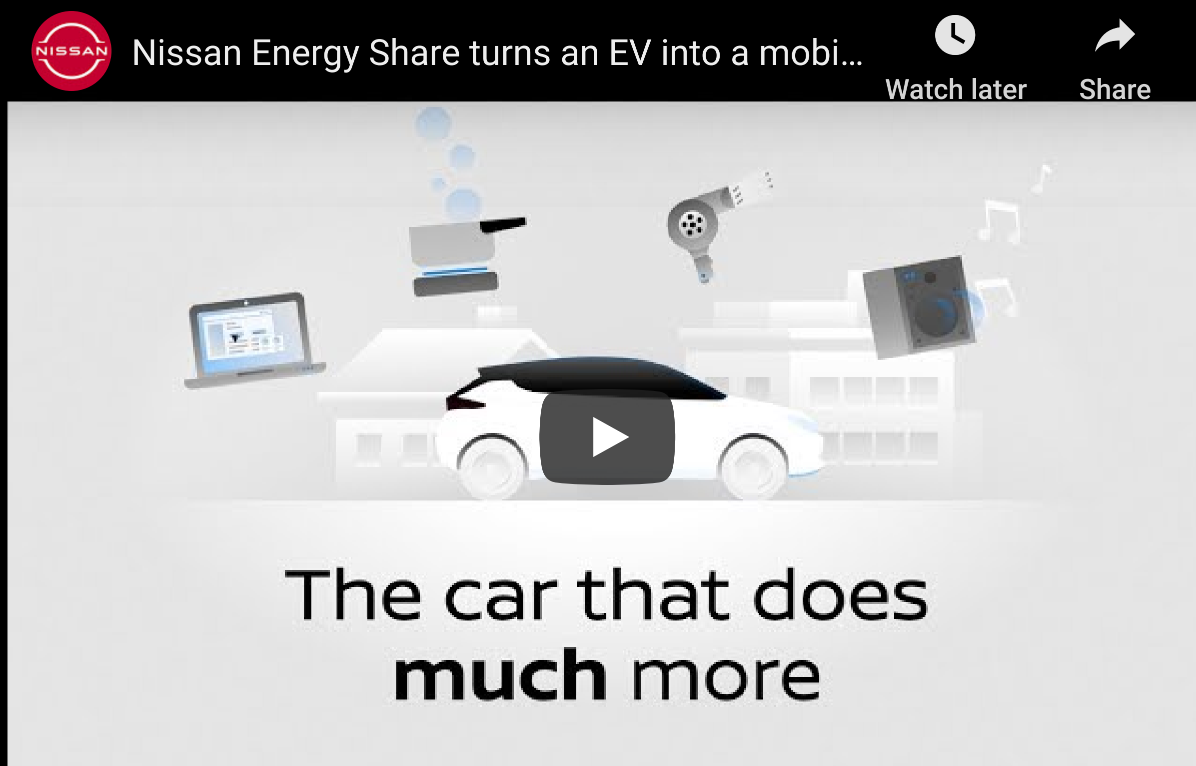
Models:
800VA, 1200VA, 1600VA, 2000VA, 3000VA, 5000VA



Source: website of Victron.

Vehicle to grid

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Characterizing power distribution architectures based on how power conversion is performed

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

Hybrid SolaX inverter X1-5.0T HV
Ref: X1-Hybrid-5.0-D-E

- Quick start
- WIFI internet monitoring
- Integrated battery management high voltage
- Operate without a power network
- Single phase inverter
- None injection solar excess

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

Grid-following inverter

- If connected to a battery, means that the battery is controllable, i.e. can absorb or deliver power depending on a setpoint.
- Of course also depending on the availability of generation / demand and of another device to regulate the imbalances.

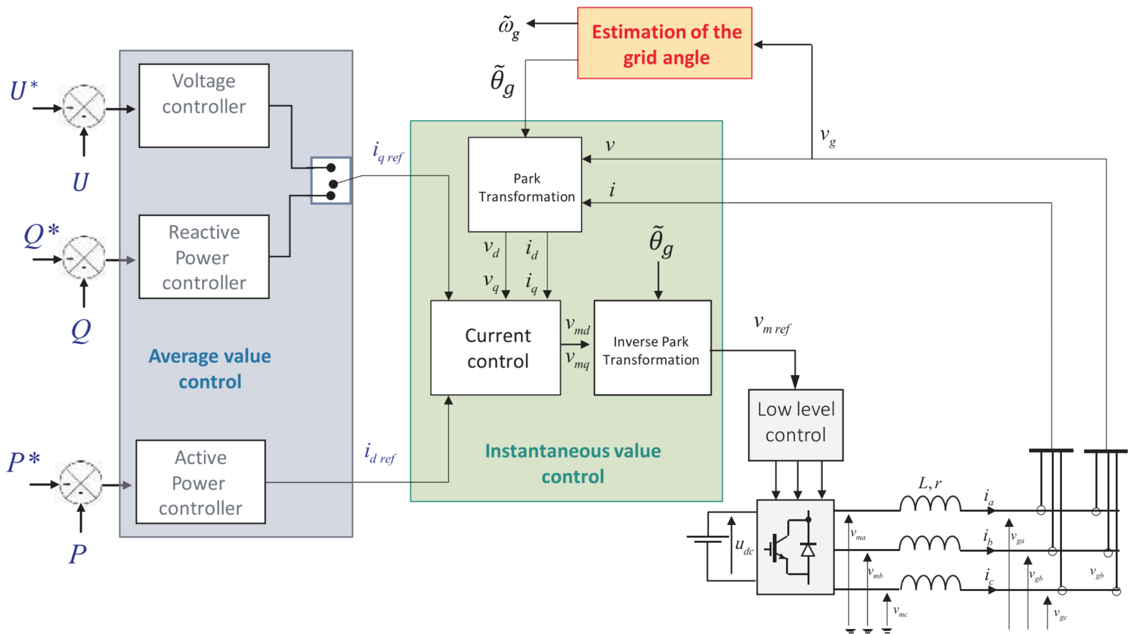

Fig. 24. Main scheme of a grid-following control.

Grid-forming inverter

- Frequency and voltage control
- Synchronisation (PLL)
- If connected to a battery, means that the battery follows the residual between generation and demand.

"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."

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

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.

Special cases

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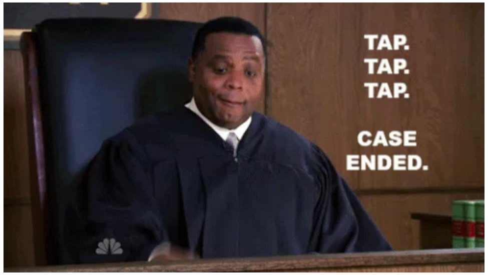
In case of infringment, either:

- 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:

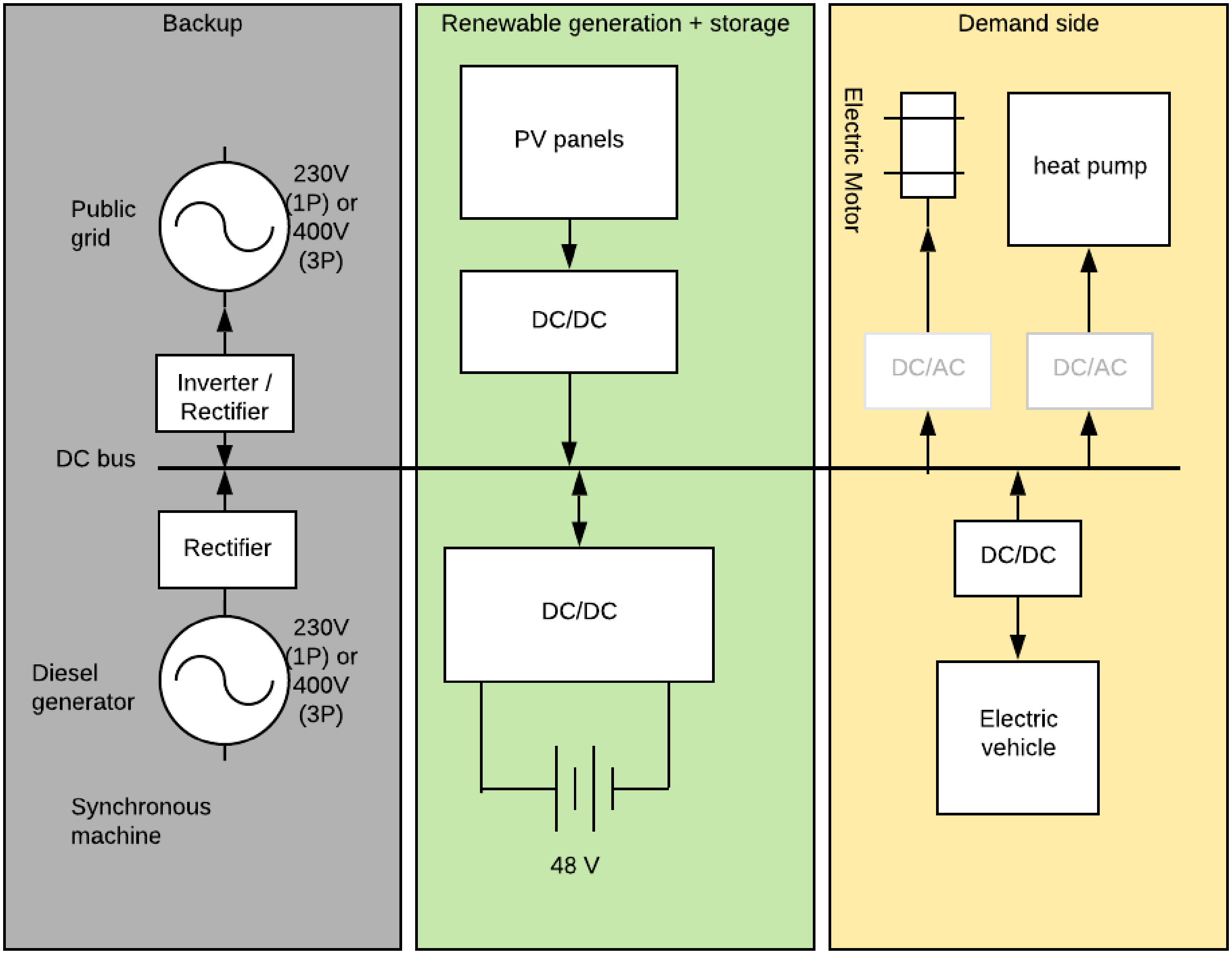
- When the voltage $\leq 105\% U_n$: $\cos\phi = 1 (Q = 0)$
- When the voltage $> 105\% U_n$: free operation with $1 \geq \cos\phi > 0.9$ under-excited. (no overexcited operation allowed)

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

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- 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

Off-grid case design

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)
- cable sections
- try to get some datasheets to understand how components work, can do and cannot do

References

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

The end.