



— All for dreams

# The role of power conversion systems

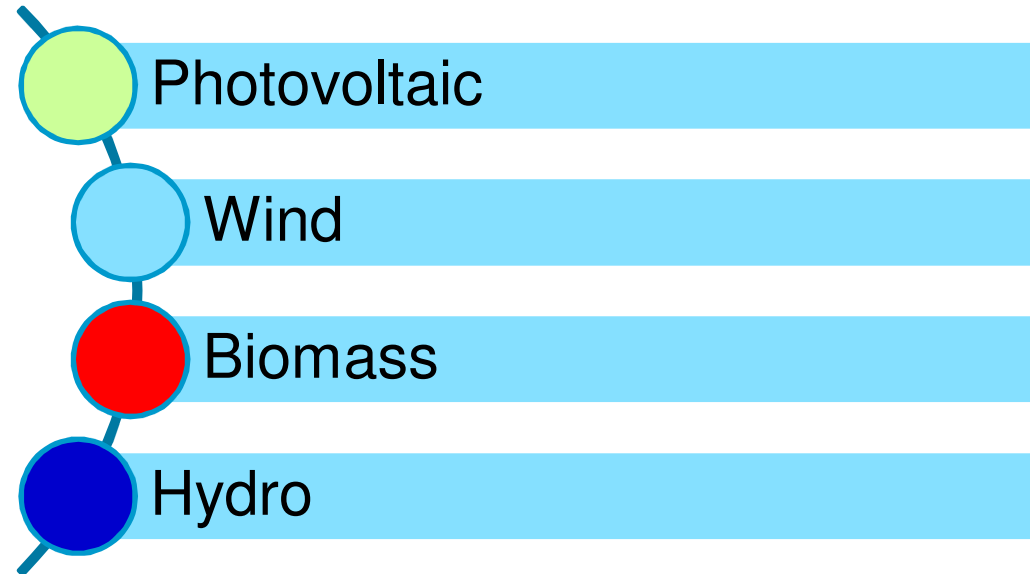
Giordano Torri, Enrico Gatti  
Nidec-ASI - Milano  
[www.nidec-asi.com](http://www.nidec-asi.com)

**Innovative Electrical Networks for a sustainable development in low carbon scenario**  
CIGRE' – Stresa - August, 26-28th 2015

- **Energy is the main topic under discussion all around the world since many years: our ways of life depends on “energy” and mainly on “electric energy”.**
- **Energy calls to mind a lot of questions: how to get secure sources of energy, how to achieve independent provisions of the energy, how to reduce the CO<sub>2</sub> emissions, how to get a cleaner world, how to get lower and controllable costs.**
- **The progressive extensions of the renewable “green” energies, mainly wind and sun, are de facto modifying the transmission and distribution network.**
- **Energy is no longer going to be produced in one big plant but in many “distributed” small-to-medium generating systems.**
- **Unfortunately the “green energy” form wind and sun cannot be dispatched.**
- **Energy cannot be stocked in a large quantity and an electrical network is stable only when production and usage are well balanced at any given point of time.**
- **So, the real question is how to integrate these distributed, random sources (DG) in the users’ system without degrading the quality of the service we are used to up to now.**
- **Many technologies have been developed and the common denominator is the “Power Conversion Systems”.**

## Overview of the Distributed Generation equipment

Among the so-called «green technologies» special attention has been given to the following:



These distributed energy sources can be considered as «non conventional» and the issue is on how to integrate them into a larger power grid. Three factors can help in solving this problem.

- The role of the «Power Electronics».
- The energy storage technology.
- The approach of the «micro grid».

## Distributed Generators

DC source

AC source,  
variable  
frequency

AC source,  
fixed  
frequency

DC/AC or AC/AC  
power converters

Power  
converter for  
reactive  
power control

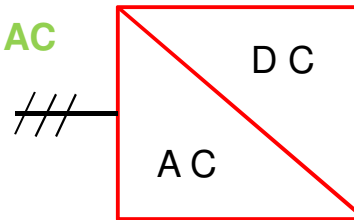
# Power conversion systems: a central role

DC/AC or AC/AC  
power converter

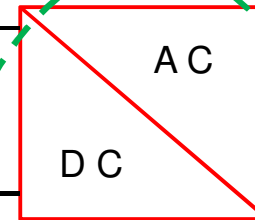
Power factor  
correction

Active Front  
End  
technology

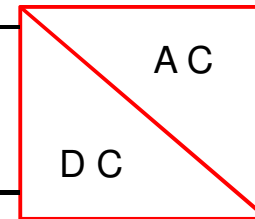
DG source, AC



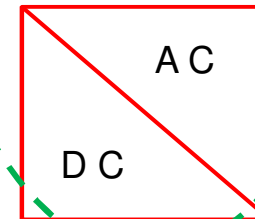
- ☐ DG source, DC
- ☐ Battery



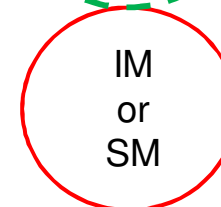
Grid



Grid



Grid



DG source, AC

## Power conversion: the Active Front End (AFE). Voltage and Power Ratings

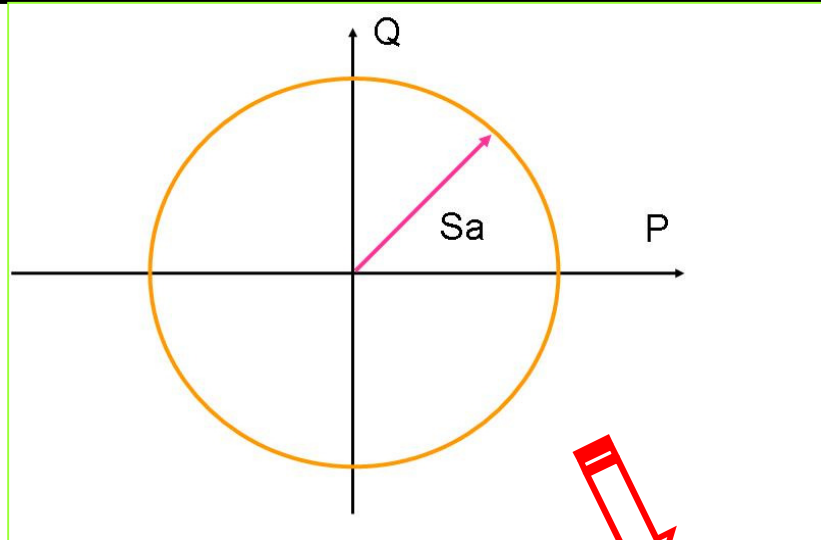
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400 V & 690 V :      2 Levels Inverter Topology

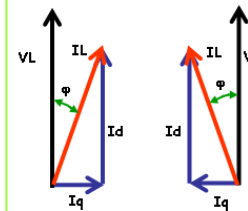
3300 V :              3 Levels Inverter (NPC) Topology

400 V	690 V	3300 V
up to 2080 kVA	up to 6900 kVA	up to 14400 kVA

# Power conversion: the Active Front End (AFE). P-Q capability

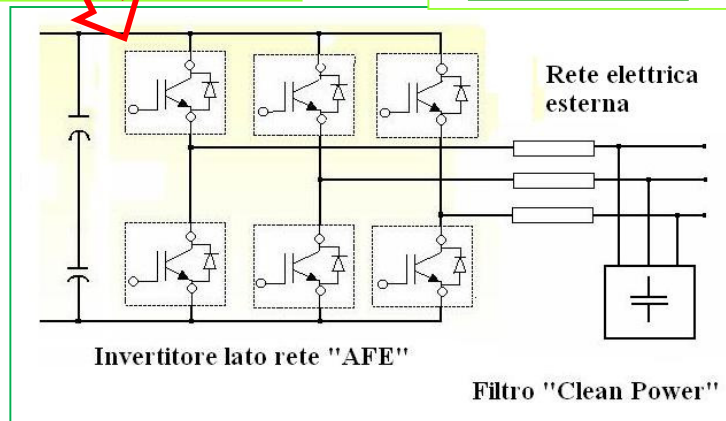
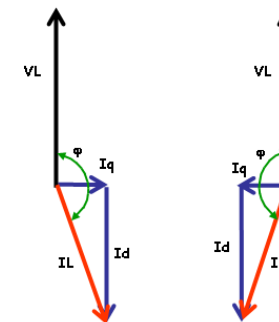


The AFE inverter absorbs energy from the grid with a lagging power factor (left) or leading power factor (right)



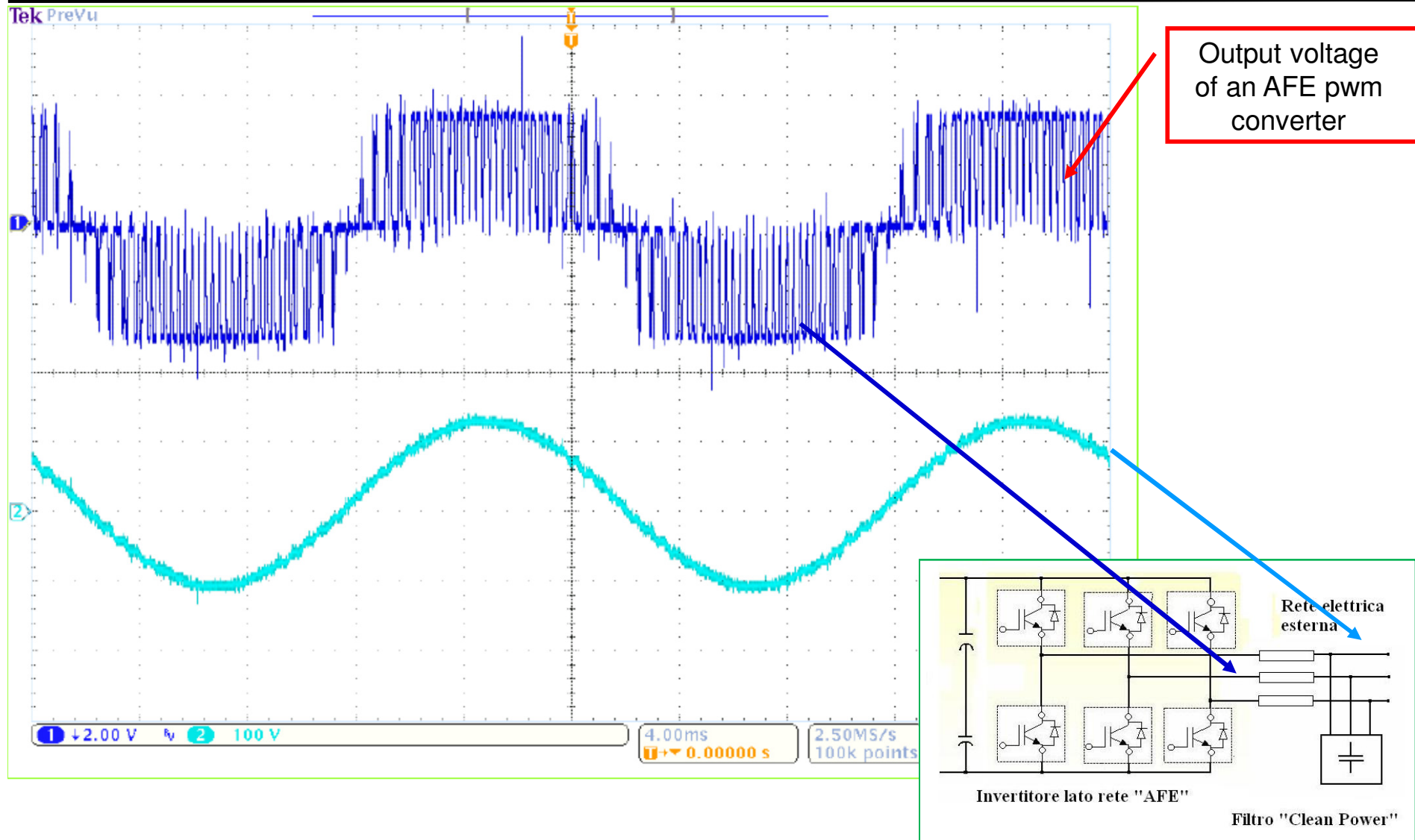
Legend:  
VL = Phase Voltage  
IL = Line Current  
Id = Active Current  
Iq = Reactive Current

The AFE inverter generates energy to the grid with a lagging power factor (left) or leading power factor (right)



AFE converter works on a P-Q plane in a 4 quadrant mode. The limit of operation is established by the circle whose radius is the apparent power  $S_a$ , the max power that the inverter can deliver. Separate and independent control loops are provided either for active or for reactive power.

# Power conversion: the Active Front End (AFE). EMC – Harmonic mitigation.



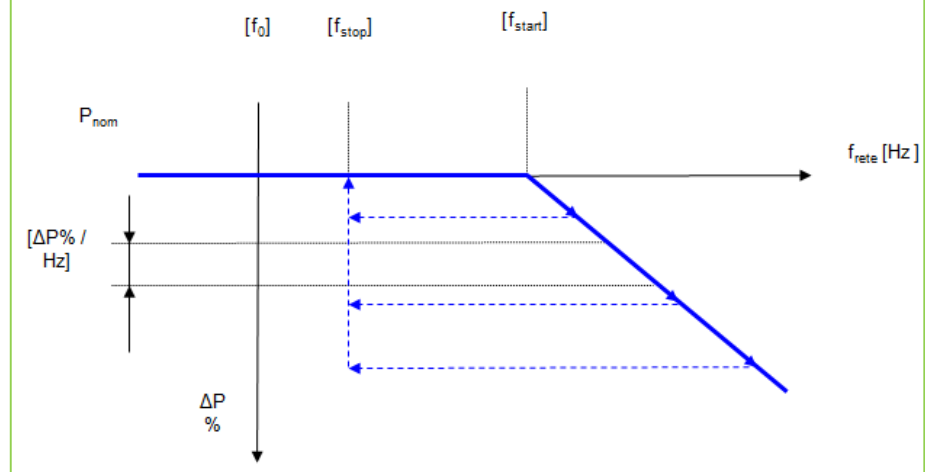


# Power conversion: the Active Front End (AFE). Static and dynamic support to the grid.

## Static support:

ability to participate to the grid regulation.

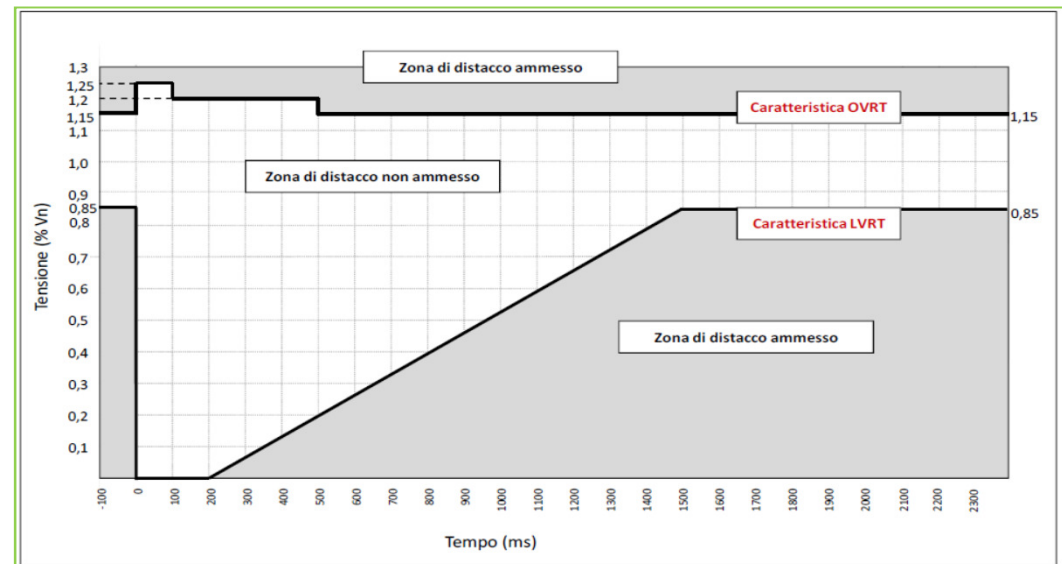
- Disconnection from remote command
- Controlled injection of reactive power to the grid  $[Q, \cos\phi, V]$
- Active power statism on frequency variation



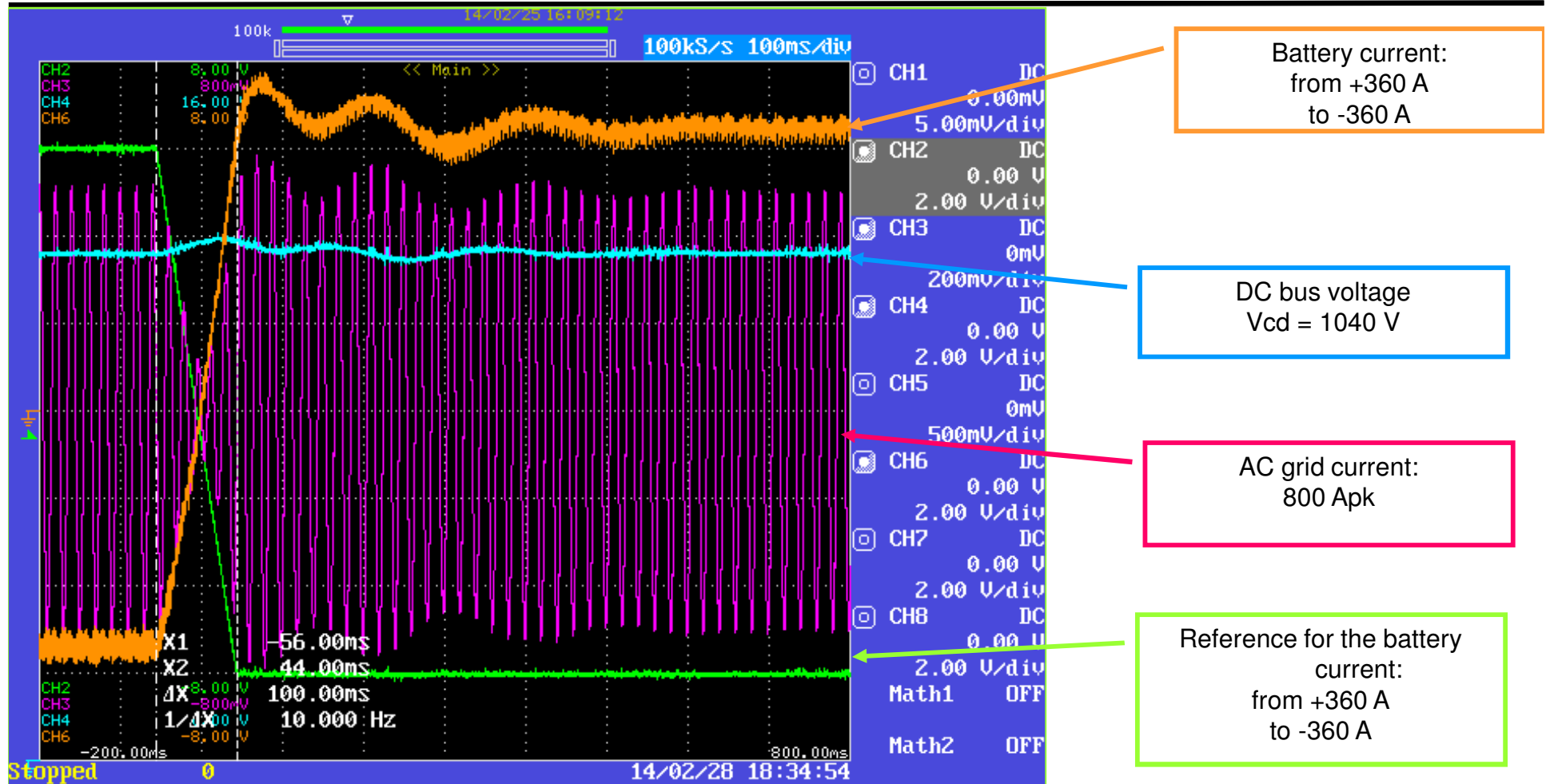
## Dynamic support:

ability to support voltage variations (brownouts) by means of injection of appropriate currents.

- Fault ride through
- Controlled injection of reactive power during the fault



# Power conversion: the Active Front End (AFE). Active power: fast response time.



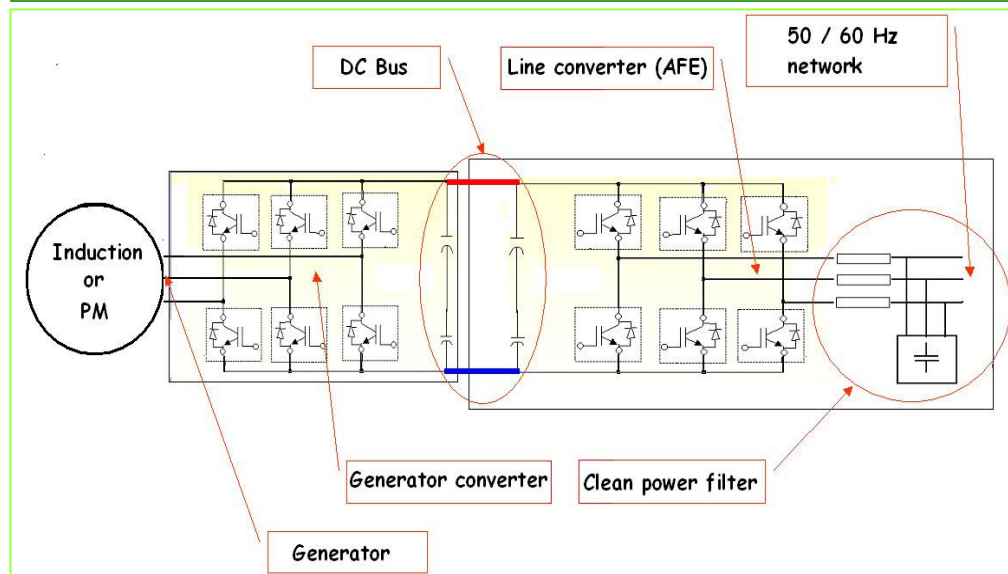
Example: usage of an AFE for a battery system. Power flow inversion from full generation to full charge: about 90ms.

An AFE can provide many functionalities to the grid:

- Frequency regulation: primary, secondary and tertiary.
- Time shifting of the energy
- Spinning reserve
- Black start
- Peak shaving
- LVRT
- Synthetic inertia
- Regulation of the power factors vs. active power
- Regulation of the reactive power vs. the grid voltage
- Anti-islanding
- P, Q control as a response to an external command

## Power conversion: the Active Front End (AFE) in wind systems.

Wind: the energy production is quite unpredictable, either on short or longer time period.



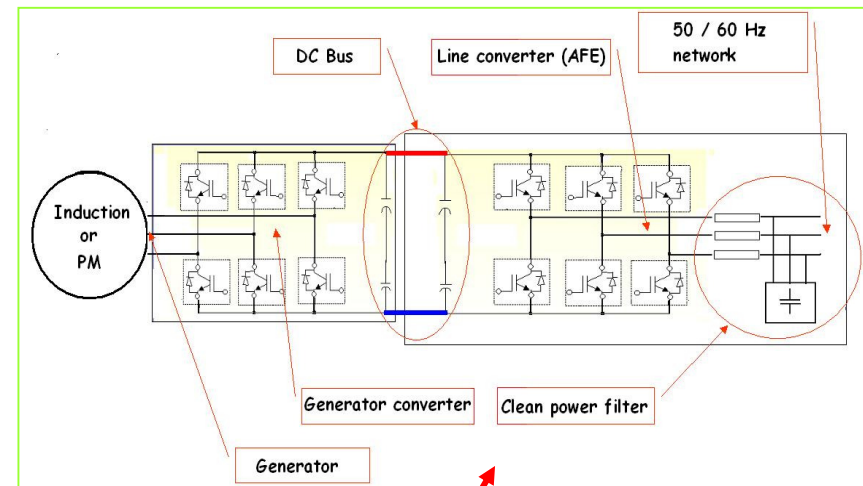
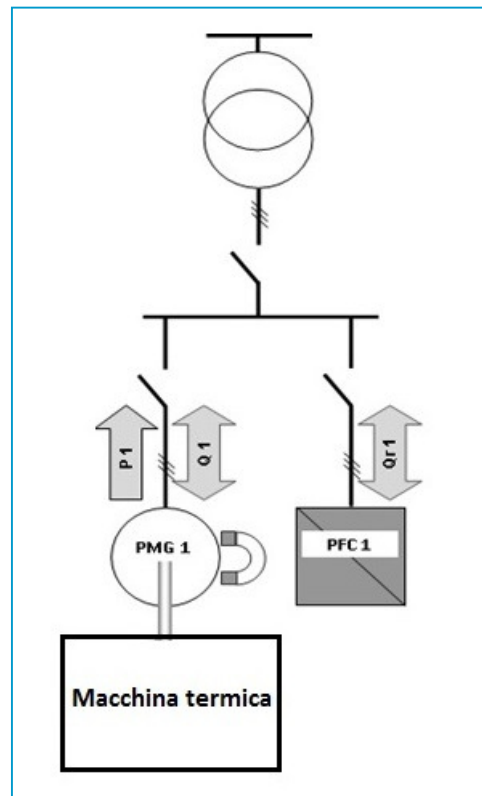
A rotating machine is driven at variable speed and a power converter allows the connection to a fixed frequency grid.

Power conversion equipment are in a wide range, from few kW to several MW.



## Power conversion: the Active Front End (AFE) in bio-mass systems.

Biomass generators. Energy production can be planned.

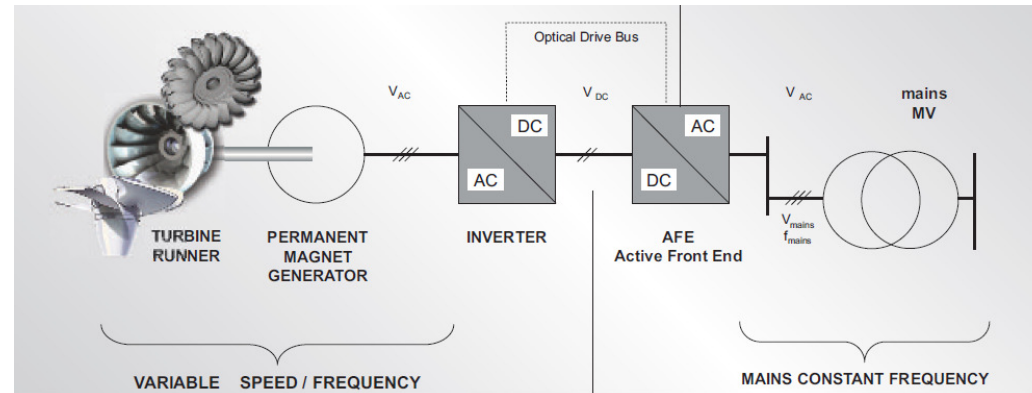
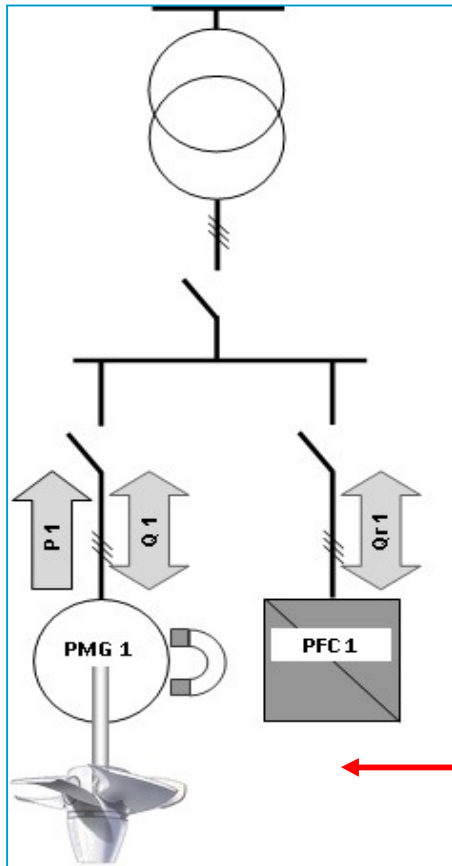


Two solutions can be envisaged:

- Variable speed generator. Connection to the grid by means of a frequency converter.
- Constant speed generator directly connected to the grid. In parallel a power factor correction system is required

Typical power range, from hundreds of kW to several MW.

## Power conversion: the Active Front End (AFE) in mini-hydro systems.



Solution with a rotating PM machine:

At variable speed and frequency converter.

At fixed speed (DOL) with a power factor correction system.

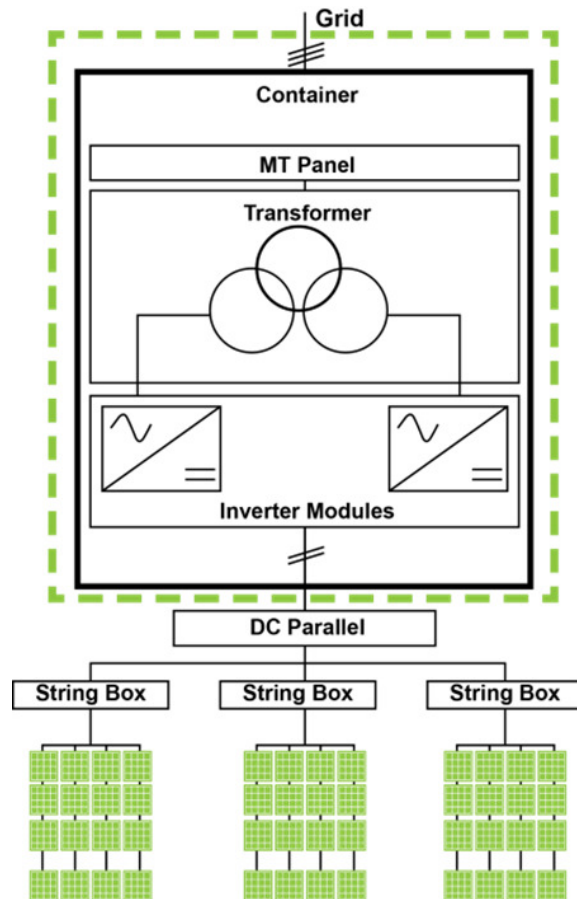


Mini-hydro: energy production can be planned. The water flow can vary during the year.

Typical power range, from few hundreds of kW to several MW.



## Power conversion: the Active Front End (AFE) in PV systems.

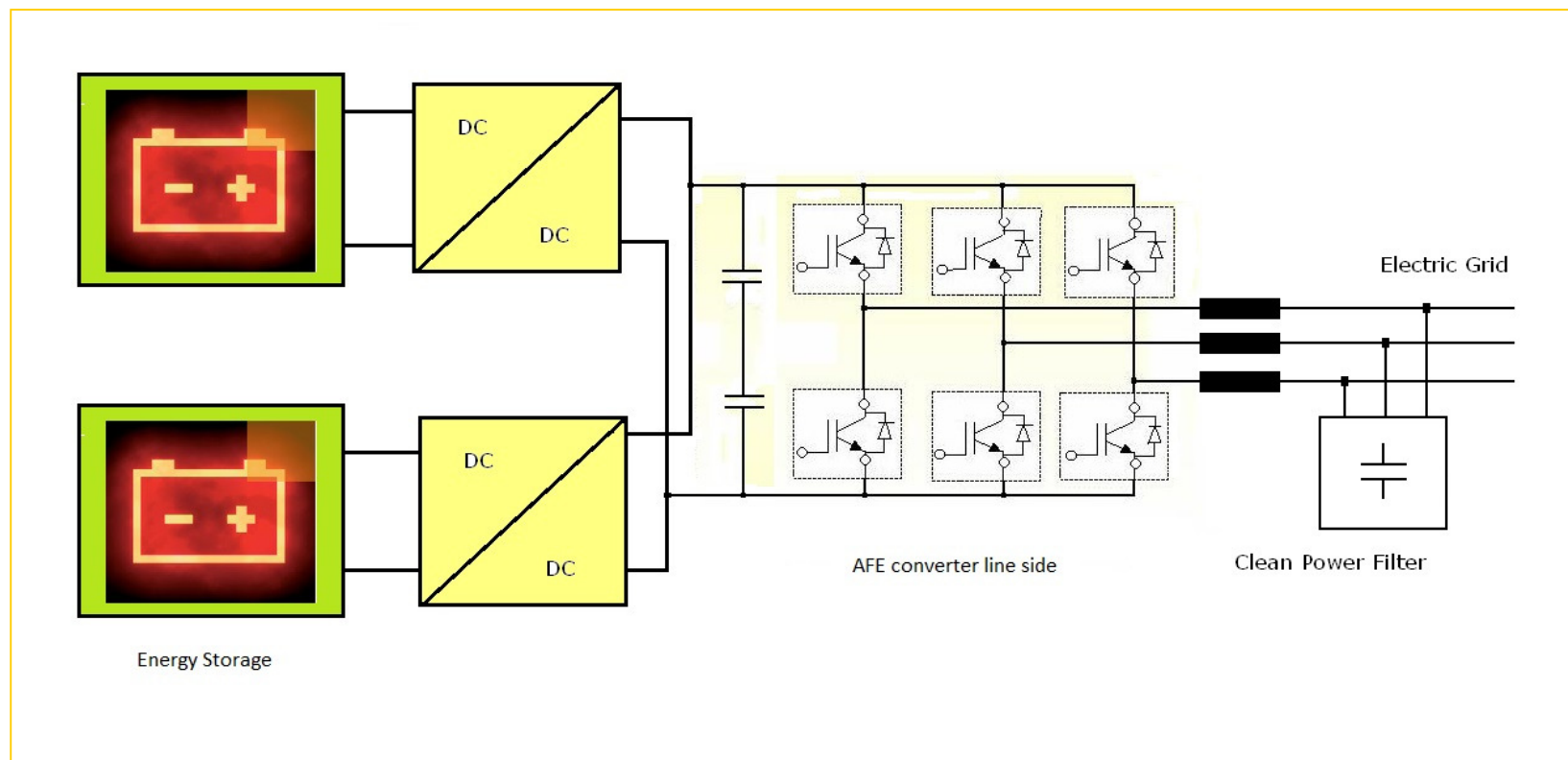


**PV plants: energy production changes during the day and during the seasons. Power range from kW to MW. Power conversion system from DC to AC is required for connecting the plant to a grid.**

## Power conversion: the Active Front End (AFE) in Electrical Energy Storage systems.

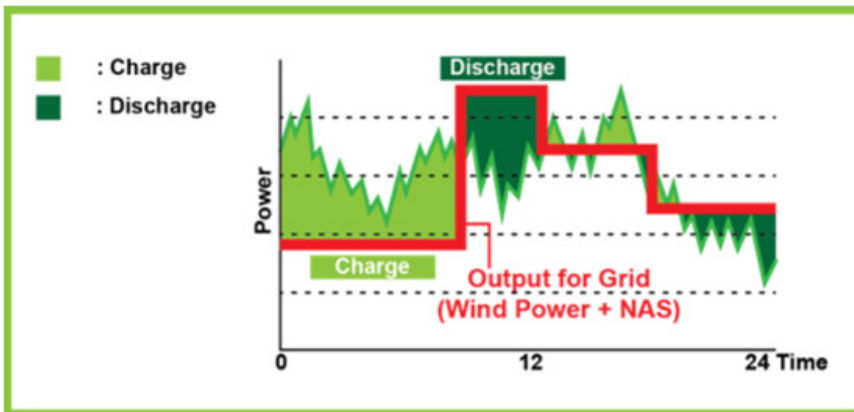
In order to mitigate the drawbacks of the «renewable energy» the challenge of the battery systems offers a solution.

Batteries are DC sources and through a DC to AC power conversion system they can be connected to a grid.



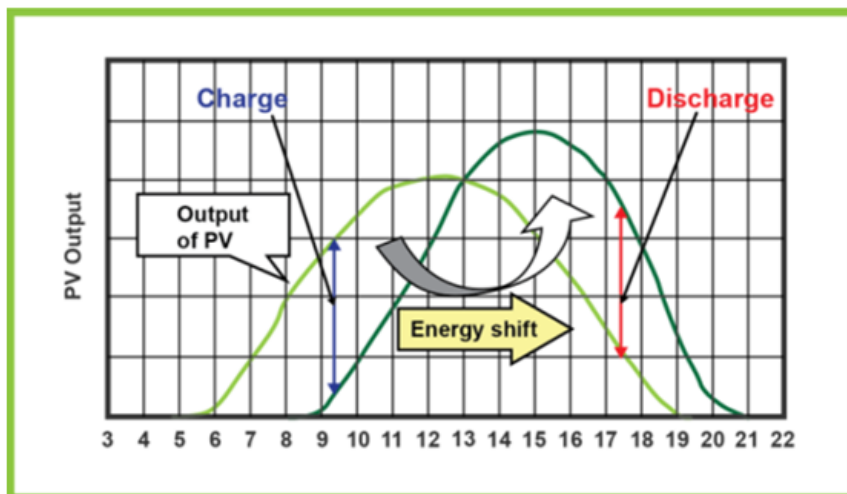


## Power Balancing



Power balancing:  
compensating the random  
production of energy from  
wind and sun in real time

## Time Shifting



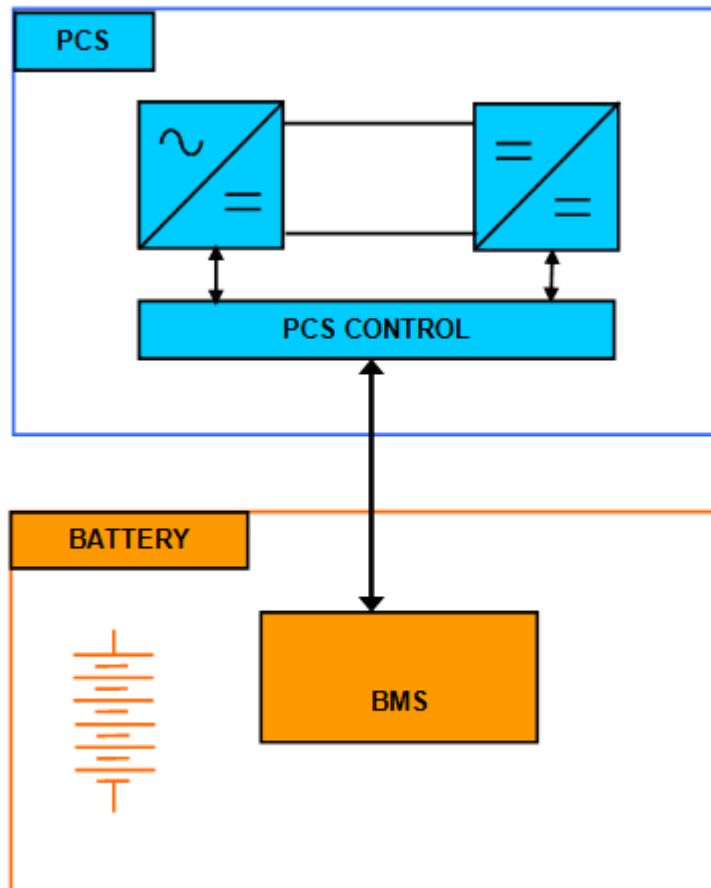
Time shifting / peak  
shaving: the system  
can store the energy  
when the load of the  
grid is weak and it can  
inject energy during  
the peak hours.

## **PCS-BMS INTERFACE**

In Energy Storage Systems, Battery is equipped with a Battery Management System (BMS) that has the main scope to guarantee the correct operation of the Battery connected to the Power Conversion System (PCS).

Once correctly interfaced with the PCS control, the BMS is able to guarantee the proper operation of the system Power Converter-Battery.

## Power conversion: the Active Front End (AFE) in Electrical Energy Storage systems.

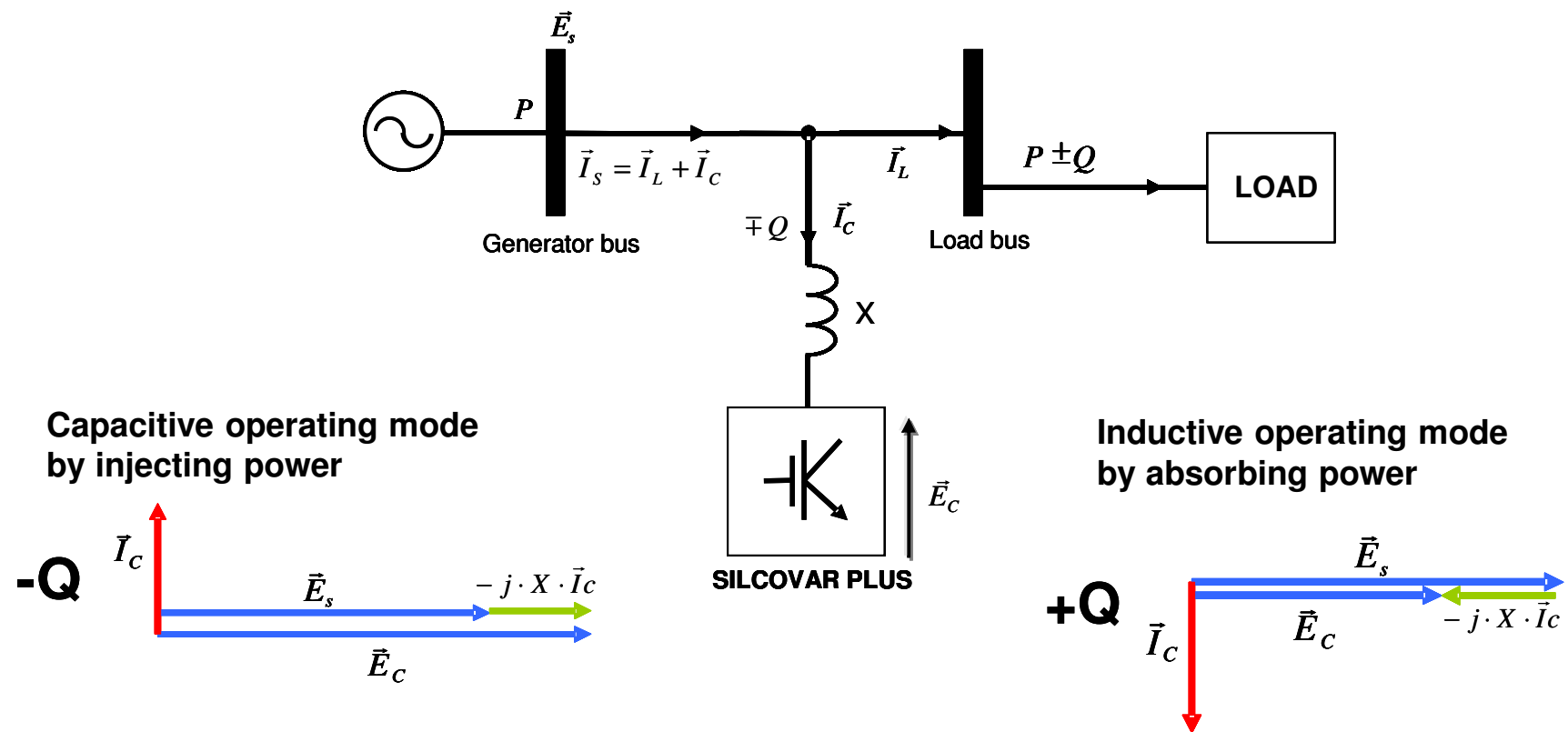


The main groups of variables exchanged between BMS and the control of the PCS are:

- Battery status
- PCS status
- Voltage, current and power references
- Voltage, current and power feedbacks
- Commands from Battery to PCS
- Commands from PCS to Battery
- Battery alarms and protections
- PCS alarms and protections

# Power conversion: the Active Front End (AFE) in Power Quality (Statcom) systems.

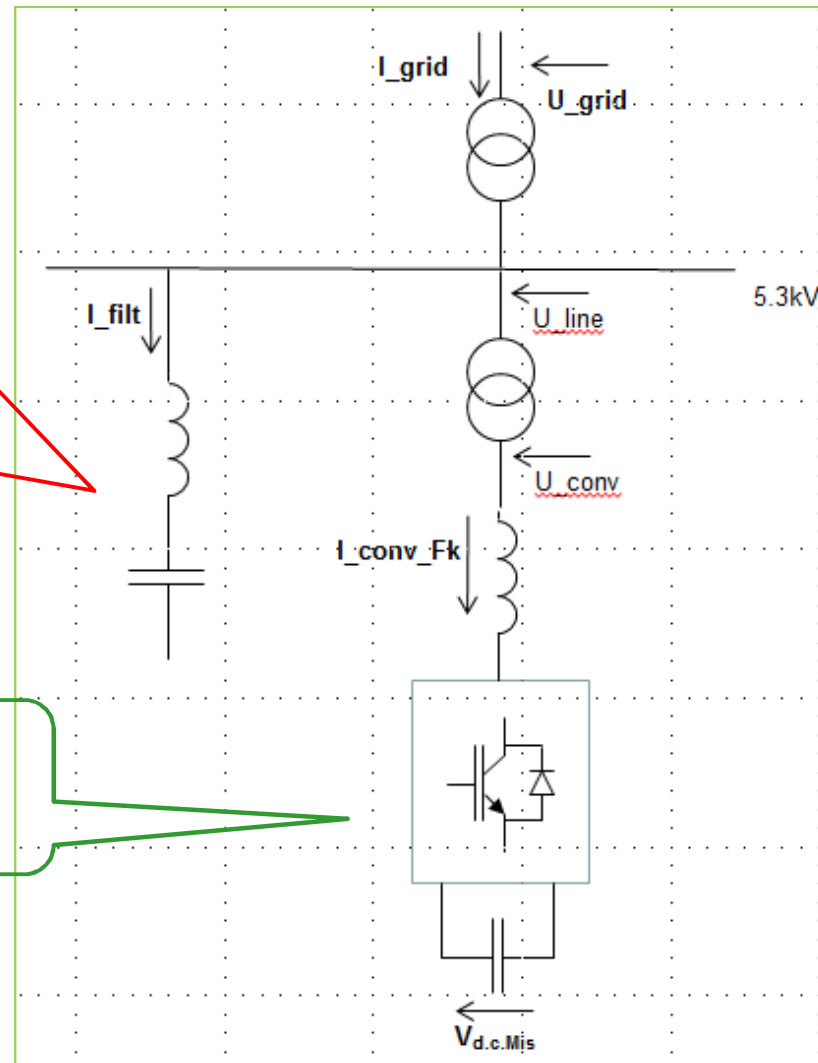
**STATCOM** by injecting or absorbing reactive power enhances power flow and stability in the electrical line



## Power conversion: the Active Front End (AFE) in Power Quality (Statcom) systems.

Additional line filters, made by MSR and/or MSC, controlled by the AFE control

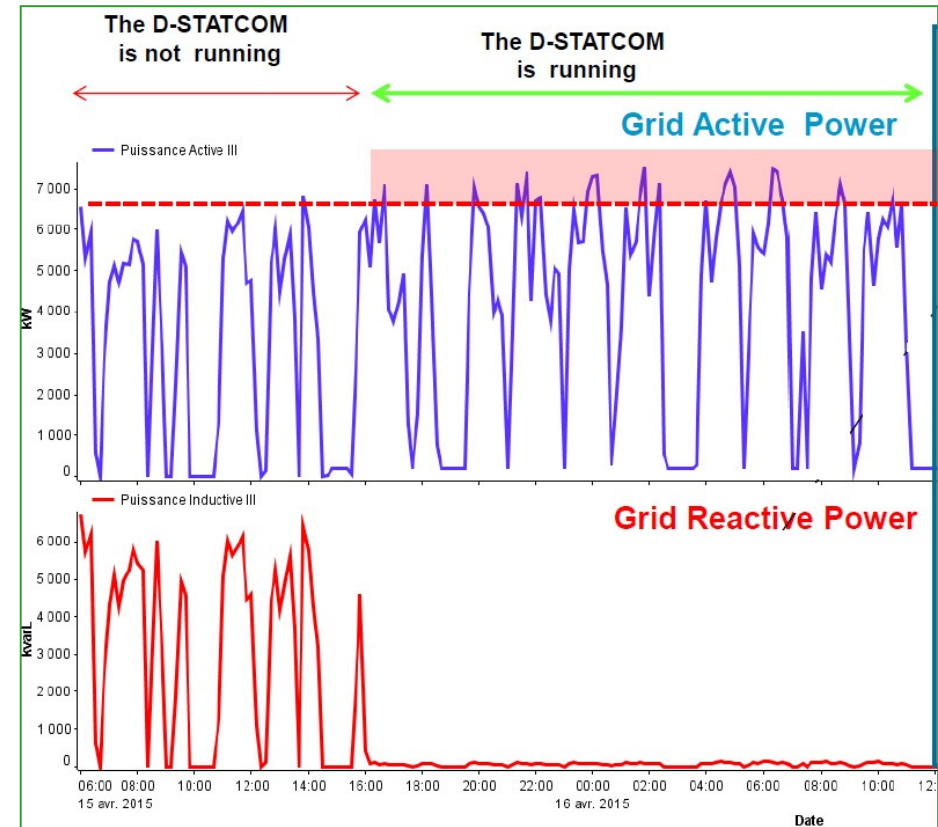
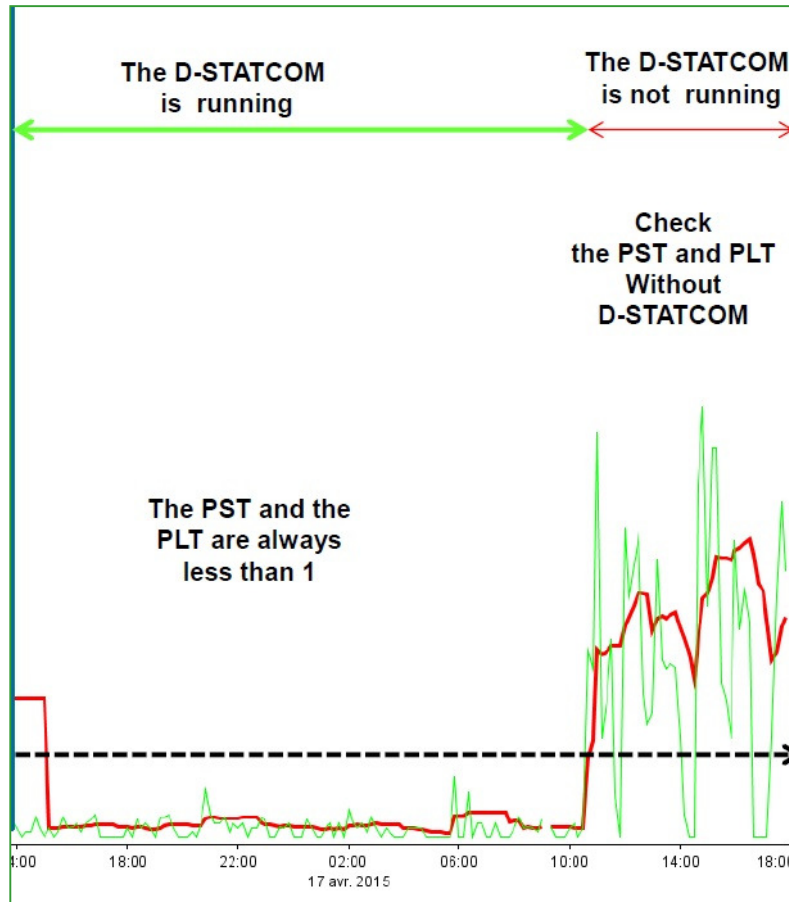
Voltage source converter (AFE)



Main features of a Statcom:

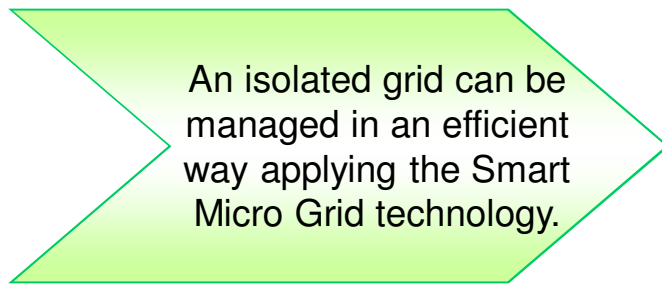
- Flicker mitigation
- Voltage support
- Harmonic cancellation
- Power factor control

## Power conversion: the Active Front End (AFE) in Power Quality (Statcom) systems.



Behavior of a Statcom in a furnace application. Left: Flicker mitigation. Right: reactive power compensation.

## Power conversion in the Smart Micro Grid.



A Smart Micro Grid has two main features:

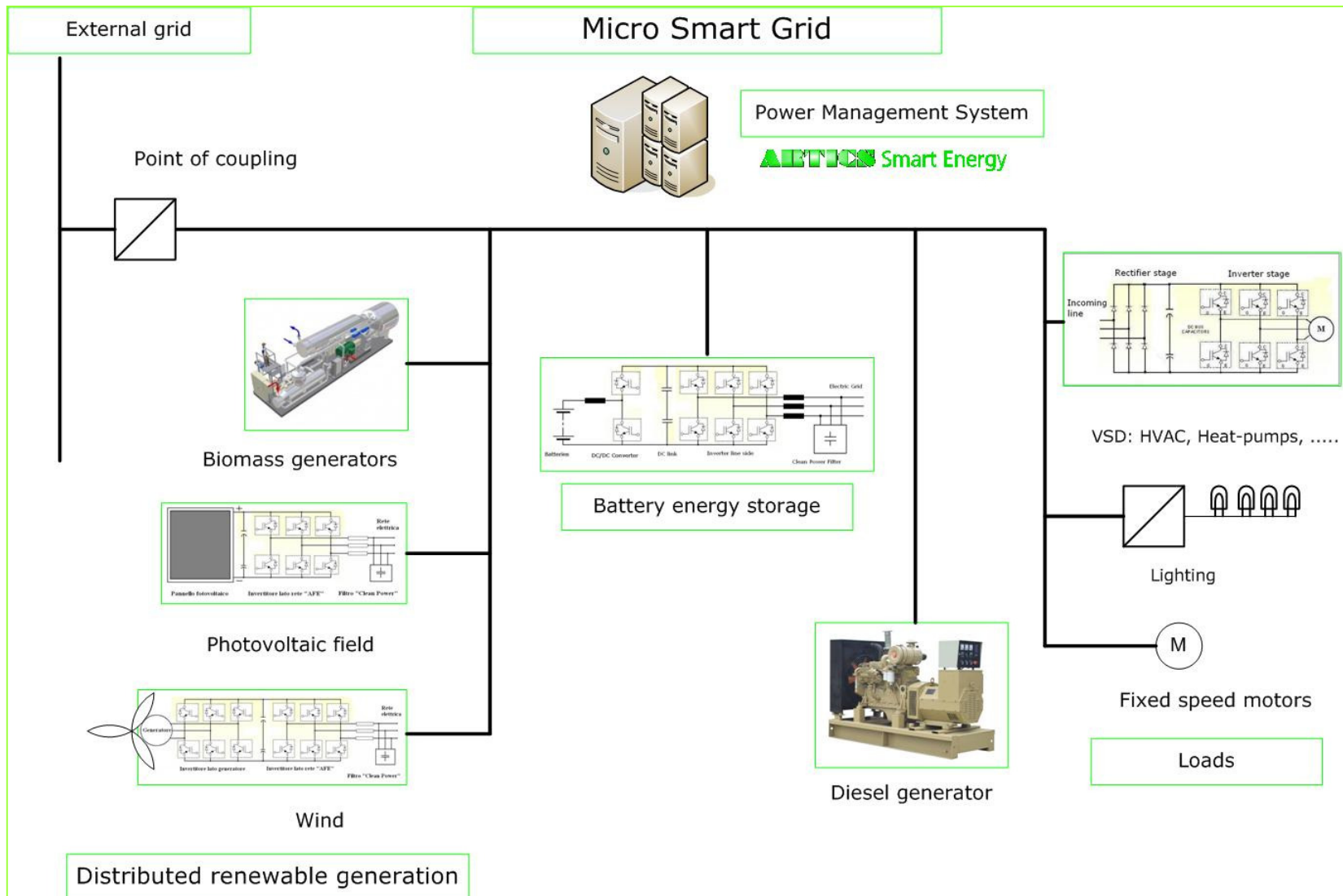
- It must have enough energy production compared to its loads, mainly from renewable sources.
- It must have a Power Management System – PMS in order to control either the production or the usage of the energy.

**Solution for small communities, far away from the transmission lines.**

**Fuel saving.**

**Efficient exploitation of the renewable sources.**

# The Smart Micro Grid: simple schematic.





## The Smart Micro Grid: some basic principles of operation.

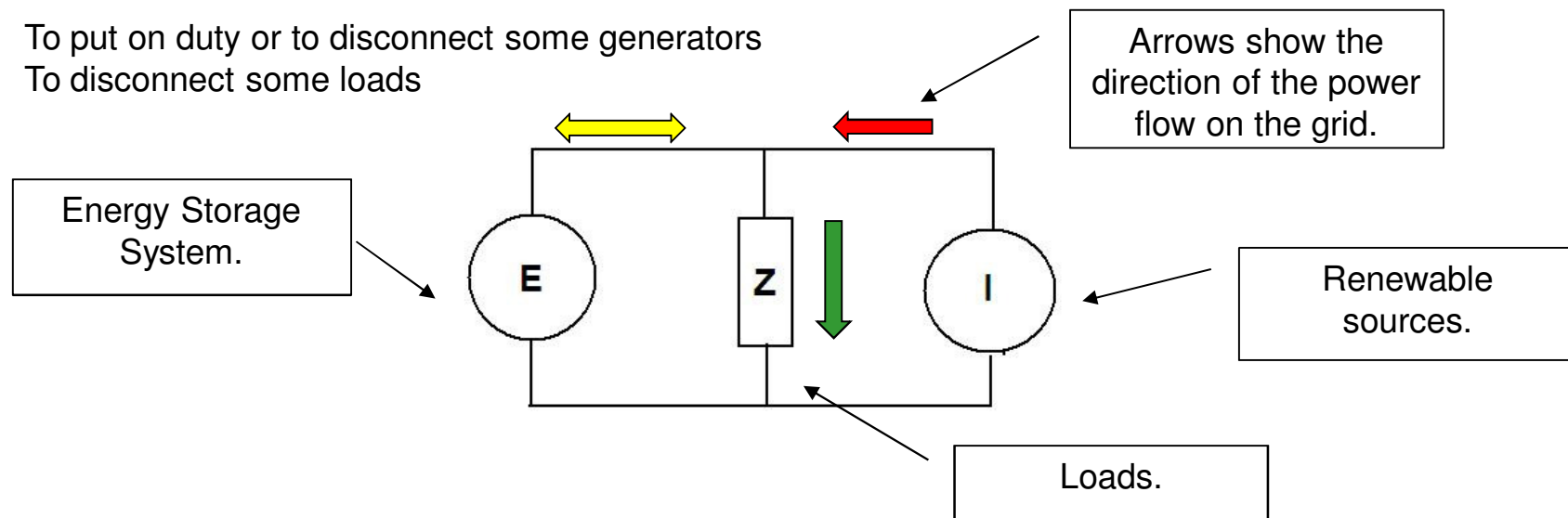
The simplest case: an isolated grid whose energy production is provided either by renewable sources or by conventional generators.

A central role is played by the Energy Storage System (EES), whose behavior is like a «Voltage source at constant frequency». The other generators can be assumed as «current sources».

Under normal conditions the exchange of active power between renewable generators, the EES and the loads is automatic.

When some limits of the EES are met (e.g., battery fully charged/discharged) the PMS may activate some actions, like:

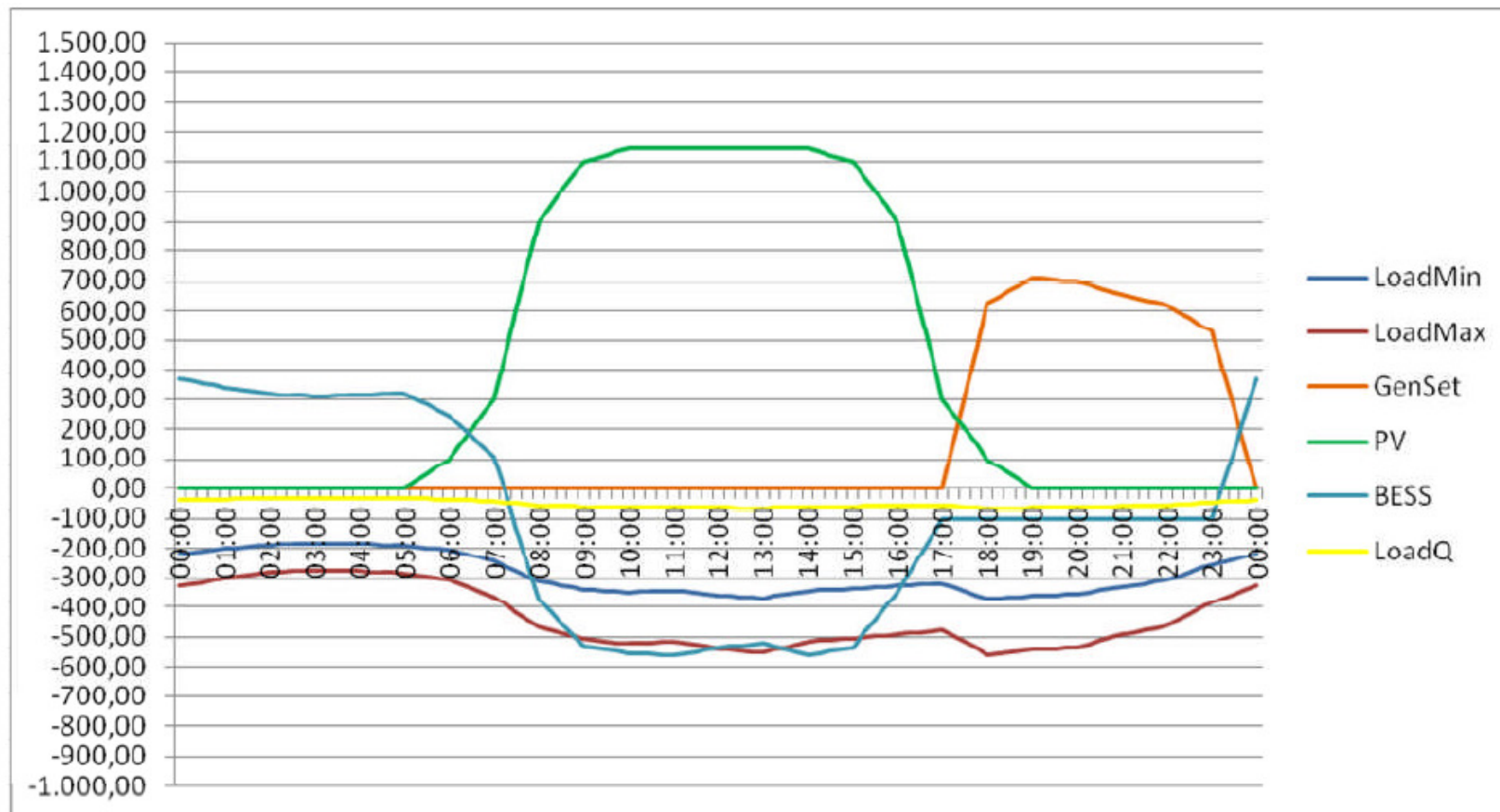
- To put on duty or to disconnect some generators
- To disconnect some loads



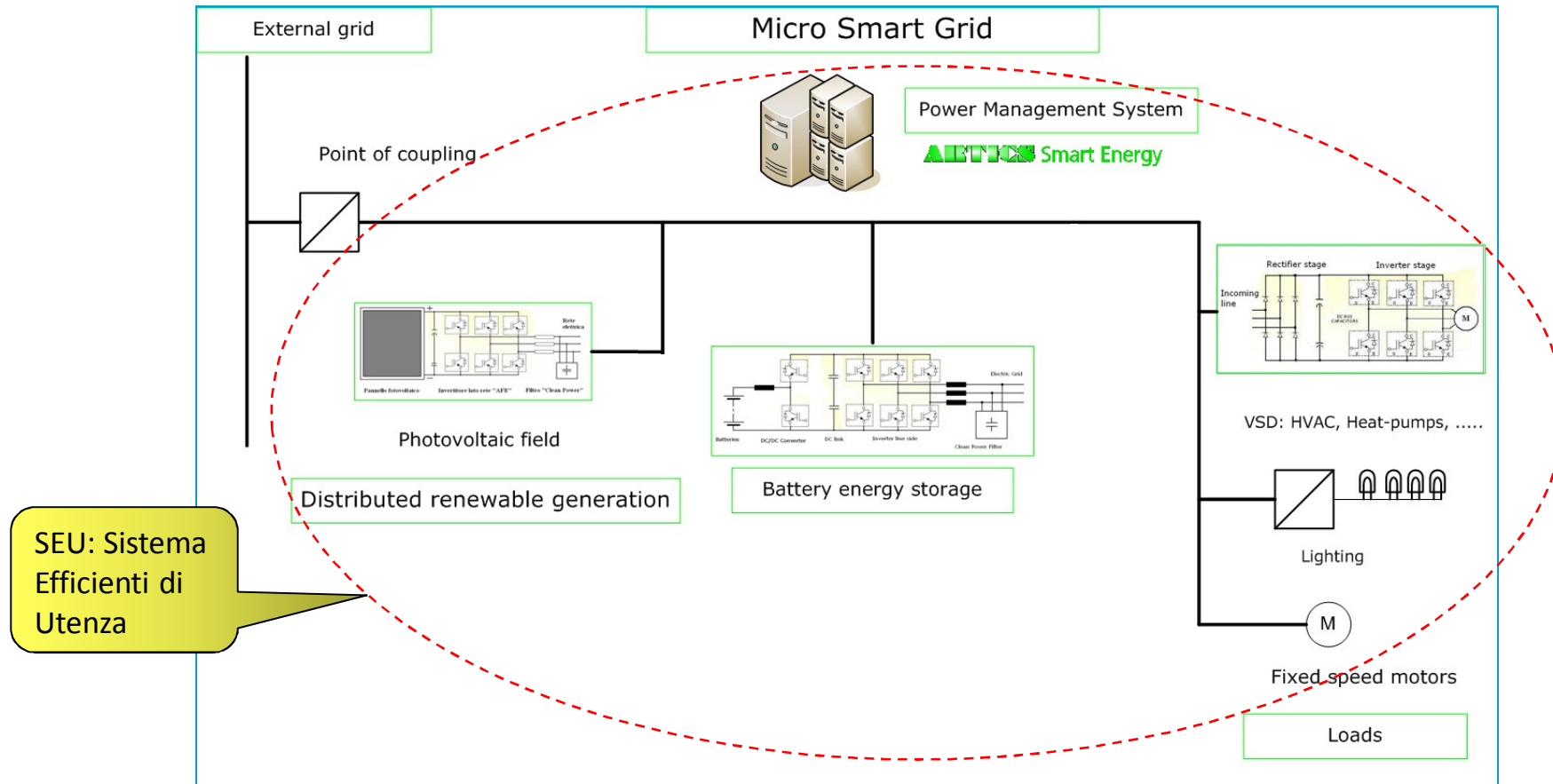
## The Smart Micro Grid: planning.

The size of each generators is evaluated taking into consideration the various loads during the 24-H.

Here an example of how a grid behaves during a typical day. The system is composed by an EES, a PV and a diesel generator.



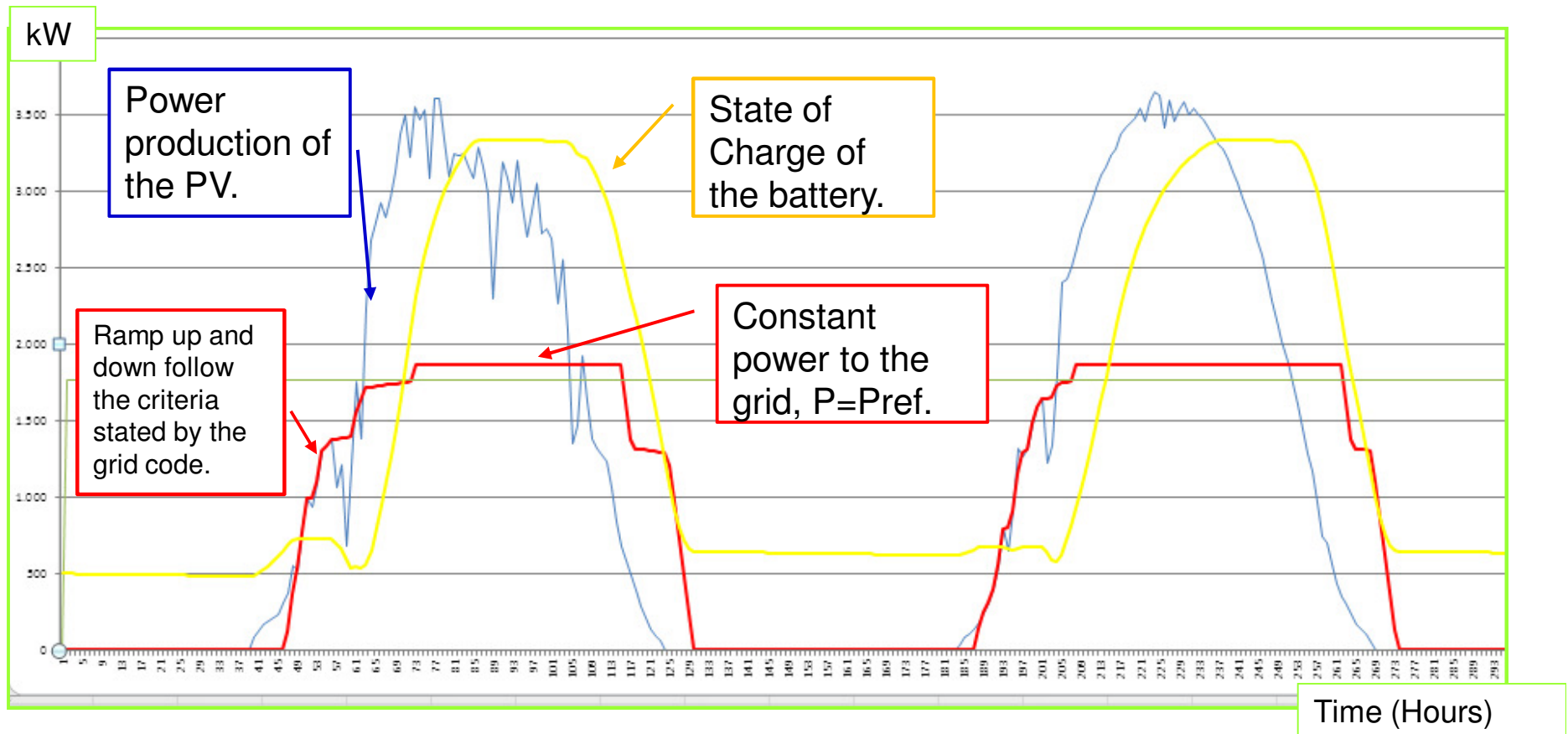
# The Smart Micro Grid: The combination of PV and Battery.



When a PV field is associated with an EES, the generating unit becomes «programmable» and it can sustain a grid.

## The Smart Micro Grid:

The combination of PV and Battery. Constant power operation.

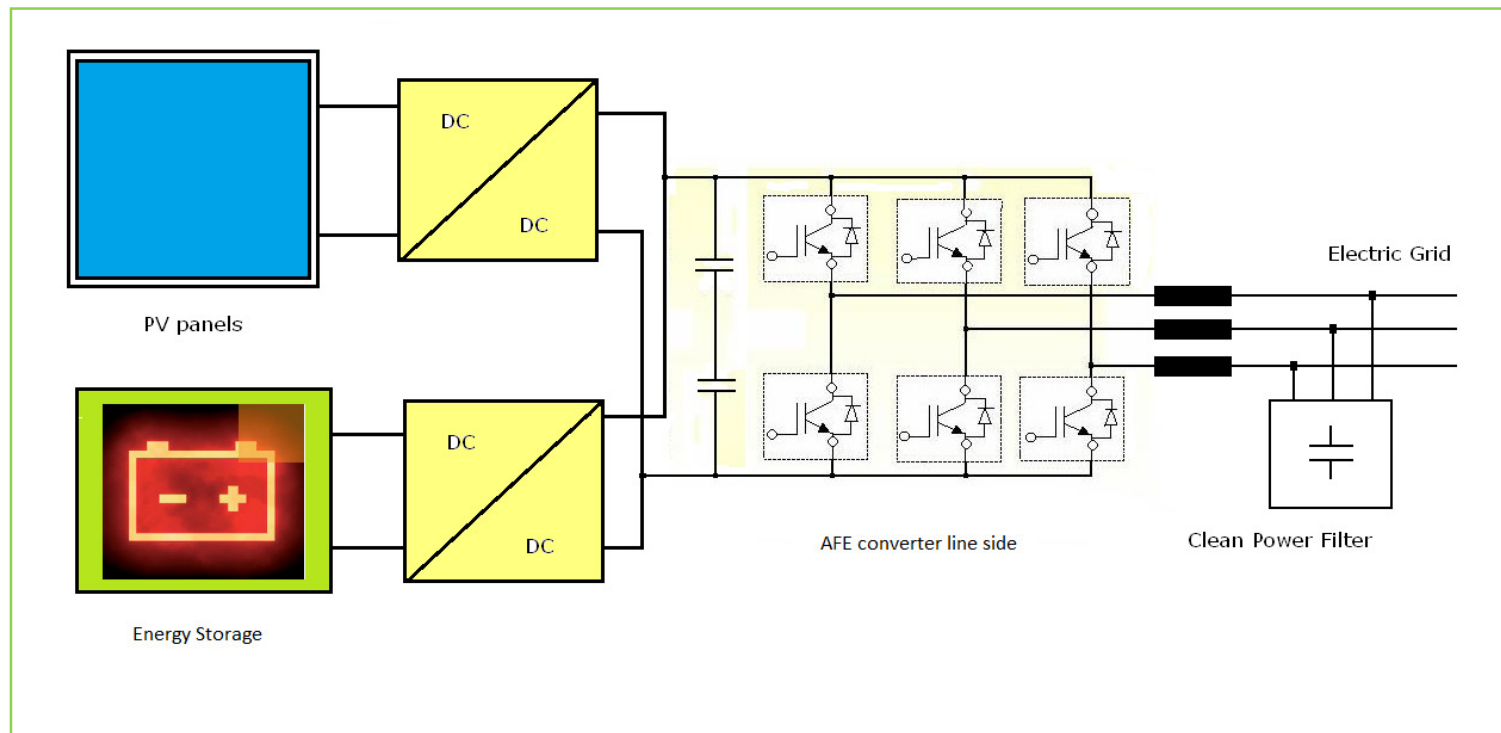


The diagram shows how the system can also be programmed in terms of «constant power» profile, that can be provided on a forecast basis for the «day after».

# Power converters can integrate in a single unit the EES and the PV.

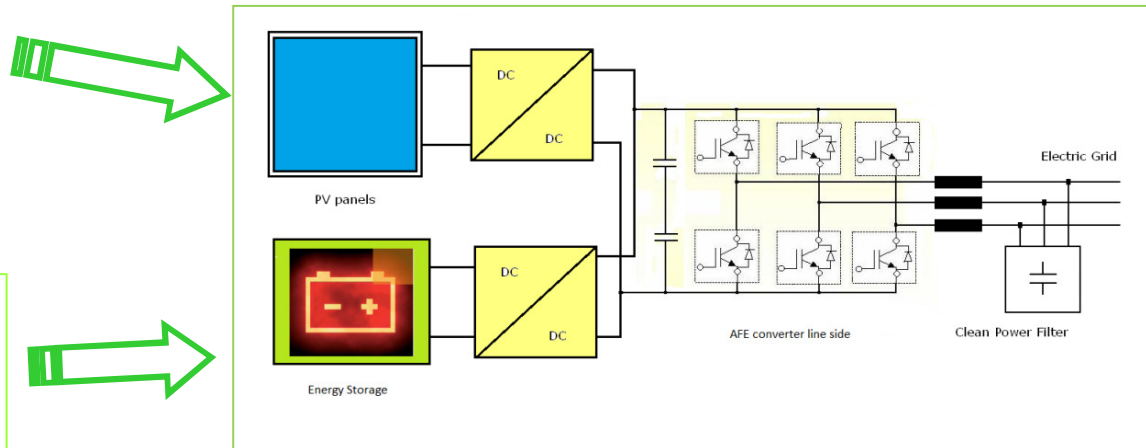
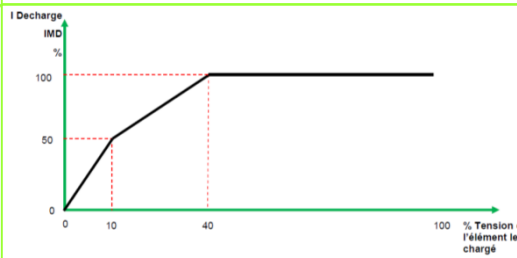
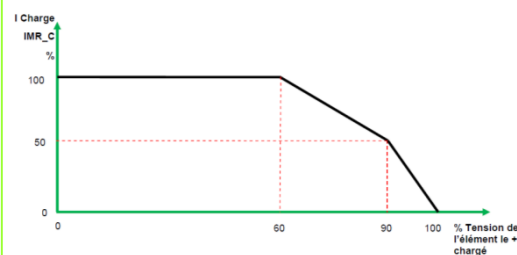
In order to increase the efficiency the power conversion system can include an integrated management either of the battery or of the PV.

The AFE solution is fed on its dc bus by some dc/dc converters, dedicated to the batteries and to the PV.



# Power converters can integrate in a single unit the EES and the PV.

MPPT



The dc/dc converters for the PV field have the MPPT functionality inside.

The dc/dc converters for the batteries have the role of controlling the charge/discharge process of the batteries, in terms of max current and SOC.

## Conclusion.

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The power conversion systems based on the AFE technology is well consolidated.

Its proven reliability and the versatile usage, make the solution suitable for solving the connection to any grid of the distributed generators.

In a low carbon scenario the power electronic has a central role for the development of the renewable energy sources.

***Thank you for your kind attention***