FACT SHEETS ABOUT PHOTOVOLTAICS

European Technology & Innovation Platform PV

Smart inverter: the grid enabler for a high PV system integration

Introduction

The global installed photovoltaic capacity in 2020 has a significant growth reaching about 707 GW. Europe drives the penetration of PV technology in many countries, first with Germany which achieved the 9% of PV penetration based on the data at the end of 2019. According to the International Energy Agency Photovoltaic Power Systems (IEA PVPS) Trends, currently, the PV supplies around 3.3% of the world's global electricity demand.

This is still an intermediate step because in December 2018, the recast Renewable Energy Directive (RED II) set the ambitious targets of 40% of renewable energy and 55% of emission reduction by 2030 in Europe. Despite the pandemic situation in 2020 the EU member states installed 18.2 GW of solar power capacity with an 11% increase over the 16.2 GW of the previous year, which represents the second-best year ever for solar in EU after the 2011. The energy transition will be primarily driven by PV generation and this will lead to a growing penetration mainly at the grid level.

The amount of PV that can be installed in a power system is defined by the so-called hosting capacity, which indicates the limits for the installation of a PV system into a grid, without negatively affecting the grid operability and reliability. A high PV penetration could create some issues like cause further frequency reduction by being disconnected during big frequency drops, or voltage collapse if disconnected during faults or other steady state issues, related to voltage deviation, power quality or reverse power flows and thus can lead grid operators to limit the PV power installation or adapt curtailment options. However, today the PV systems, thanks to the presence of the intelligent inverter, when properly used, could not only reduce the aforementioned potential problems, but also support the whole grid in voltage, frequency, and dynamic control.

PV inverter: from power converter to smart device

Currently, the inverter is not only a power electronic device able to feed the generated PV power into the grid, but it has an active and dynamic role to properly support the grid in a resilient, reliable, and efficient operation. To accomplish this task, the most recent inverters have an embedded intelligence that can support advanced functionalities for different actors. Figure 1 summarizes some of these specific actions grouped by the context of operation and if they are common or future practices. In the following the grid support functionalities will be described.

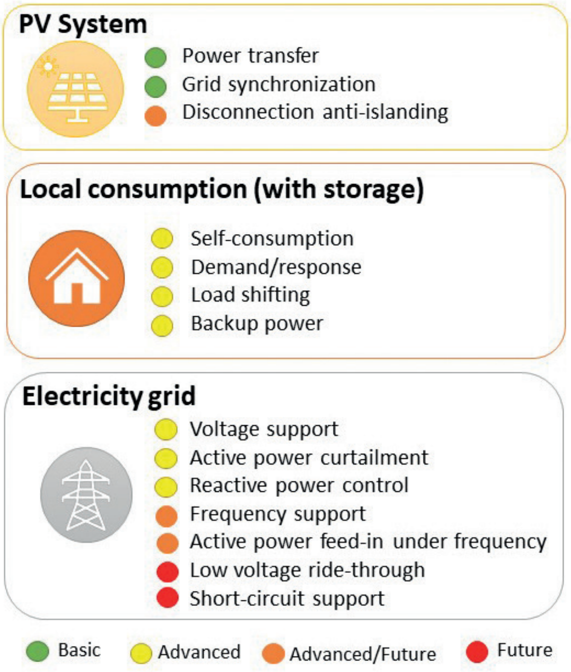
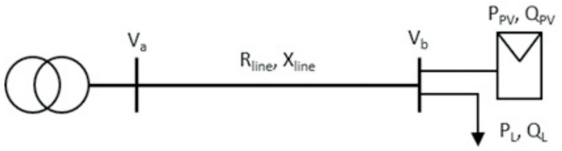


Figure 1- PV inverter functionalities grouped by action domanain (PV system, local consumption, grid) and type of implementation (basic, advanced, future)

Grid-support functionalities

Voltage support

High penetration of PV generation can cause distribution grid voltage to rise at certain buses. Generally, distribution systems exhibit a high resistance/reactance ratio which leads to diminishing the voltage along the line. Considering Figure 2, at the point of common coupling (PCC), indicating with V the nominal voltage of the system, the relation between the voltage and the PV power can be written as:



$$V_b = V_a + \frac{R_{line}(P_L - P_{PV}) + X_{line}(Q_L \pm Q_{PV})}{V}$$

Figure 2 - Simplified distribution lines with connected a PV system and a load

When P_L=Q_L=0, and taking into account the fact that the value of R_line on the distribution system is high, the magnitude of V_b can cause overvoltage, which can limit not only the PV hosting capacity but also the voltage regulation in the distribution grid. However, properly active and reactive power controls actuated by a smart inverter can mitigate these effects.

Active power curtailment

The limitation/curtailment of the PV plant active power generated by the inverter reduces the possible overvoltage at the point of common coupling (PCC). This functionality enables the avoidance of the inverter disconnection because when the voltage is close to the limits suggested by the Standard EN50160 (i.e. the 10% deviation of the voltage nominal value) the active power injected into the grid is reduced. This solution that can be seen apparently as a limitation, in reality, increases the productivity of the PV plant because the system is not disconnected from the grid. An example of how active power curtailment behaves is shown here:

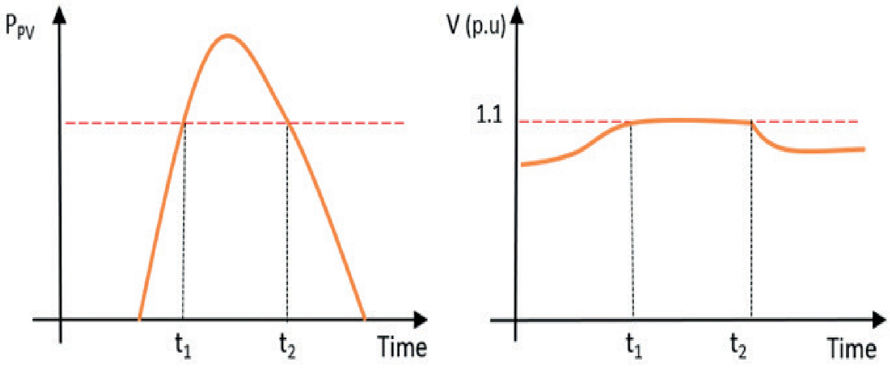


Figure 3 – Example on how active power converter functions behaves

Reactive power control

Smart inverters have reactive power support capabilities, which can influence the voltage at PCC without active power losses. The voltage of the grid can rise by delivering reactive power while on the other hand, it can diminish by consuming reactive power. Reactive power control can be exploited with **static control** such as *fixed reactive power setpoint (Q= const.)* and *constant power factor (cosφ=const.)* or **dynamic control** as reported in Figure 4 and Figure 5 :

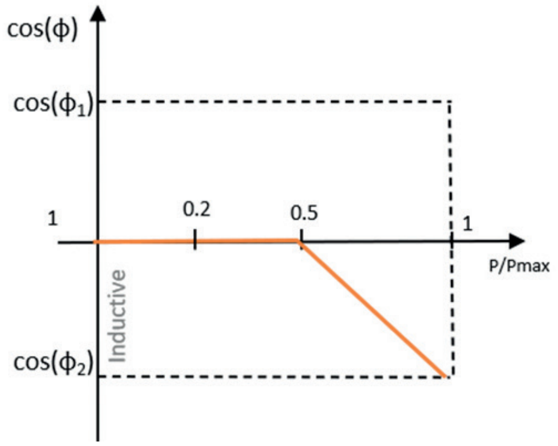


Figure 4 – Power factor as function of active power cosφ=f(P) reactive power as a function of voltage (Q(V) – volt-var)

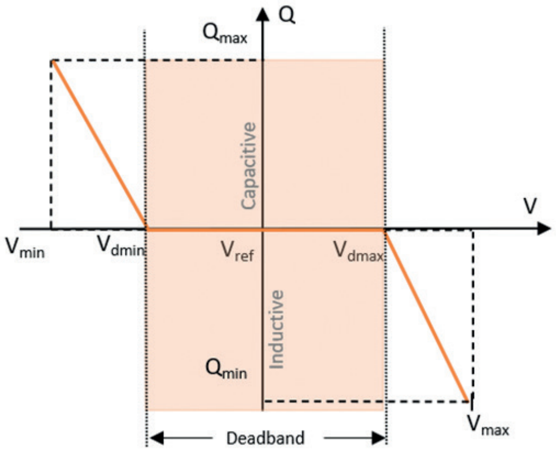


Figure 5 – Ractive power as a funcion of voltage Q(V) – volt-var control

Frequency support

A crucial problem characterizing 2030 energy scenarios will be the lack of rotational inertia due to variable renewable energy sources (vRES) connection to the main AC grid by electronic Inertia Free Converters (IFC). Static converters are not intrinsically able to face frequency instability problems without adequate control. In this scenario, smart inverters will be called upon to provide their own contribution implementing appropriate strategies to active power injection/absorption in/from the main AC grid to mitigate the Rate of Change of frequency (ROCOF) criticalities.

In future contexts, smart inverters will be involved in virtual or, as they are called, synthetic inertia logics in case of grid underfrequency or overfrequency operating conditions.

Reduction of active power at over frequency

Grid disturbances characterized by frequency values exceeding 50.2 Hz determine Distributed Generation reduction. It consists of active power injection decrease according to frequency deviation. Regulation documents define active power reduction graphs (Figure 6) which have to be suitably implemented by static converters controllers.

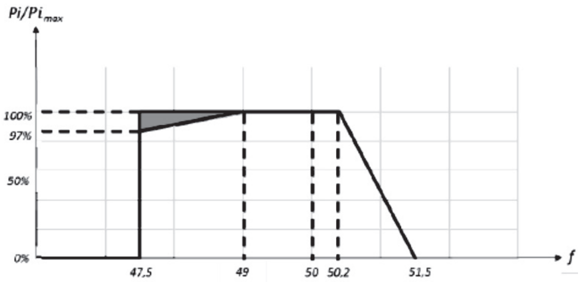


Figure 6 – Active power reduction graph according to the Italian regulation (CEI 0-21: Reference technical rules for the connection of active and passive users to the LV electrical Utilities in Italy.)

It should be noted that the active power has to be suitably controlled also at overfrequency events in order to avoid a subsequent excessive frequency decrease able to make the grid unstable again.

Active power feed-in at under frequency

Different control strategies can be implemented for PV inverters participation in active power provision to the main AC grid in case of under frequency conditions.

In detail, PV inertia control, PV governor control and Automatic Generation Control (AGC) logics can be applied. The following briefly reports their main characteristics. The PV inertia control can contribute to frequency drop nadir decreasing immediately after the disturbance event. PV governor control is developed to provide an active power feed-in proportional to frequency deviation so facing both frequency drop nadir reduction and long-term frequency deviation.

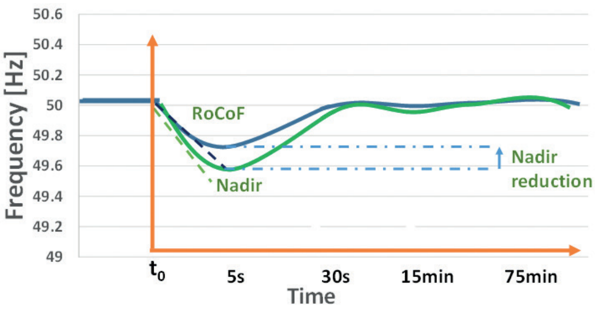


Figure 7 - Under frequency events

High performances can be obtained by a smart inverter implementing both PV inertia and PV governor logics. Furthermore, the AGC represents a promising solution since it is able to manage PV generation in a very fast manner so rapidly contributing to under frequency events mitigation taking also care of the power availability to do it.

Dynamic grid support

Low Voltage Ride Through

The major paradigm shift during faults and especially unbalanced grid faults, for smart inverters in recent standards, is from disconnect and let the traditional means to do their job, to “stay connected and support voltage and frequency”. Smart inverters with dynamic grid support functions act within milliseconds during temporary drops in grid voltage, preventing the grid failure spreading further. The actual applied trip settings shall be specified by the grid operator and must be field adjustable even via communication. The dynamic grid support ensures that the smart inverter will be ready to feed energy into the grid immediately after a grid voltage drop and is referred to as Voltage Ride Through. During temporary voltage disturbances, we usually take the applicable voltage on the phase that has the least voltage magnitude and check if it is within the operation region, the smart inverter shall maintain synchronism with the grid, continue to exchange current with the grid and not trip. The requirement also holds for ride-through for multiple consecutive voltage disturbances as long as they are within the operating region, for which the voltage range and the cumulative durations are specified.The application in this case is to stay connected for separate faults that might occur in a severe storm, or dynamic voltage swings that cyclically transition in and out of the continuous operation region. It should be noted that maximum ride-through disturbance sets also apply.

Smart inverter requirements for ride-through need to be coordinated with unintentional islanding detection features. That is to allow enough voltage shift to occur for unintentional islanding to be detected before compensating for the change.

Contribution to short-circuit current

Smart inverter behaviour related to contribution to short-circuit current might be not to reduce its apparent current during the disturbance period below say 80% of the pre-disturbance value or of the current level. Exceptions from this requirement may be cases with big oscillations and are also subject to the available active power. The setting selection should be based on grid local conditions and fault levels. The condition that is complementary to the above is the so called “cease to energise” condition that limits the fault current if the operator requires so, that means stop exporting current but not necessarily trip. Such condition may also apply for cases with open phase conditions that may occur directly at the connection point. Smart inverters should behave intelligently once the applicable voltage enters back to the continuous operation region; the idea is to to provide to the grid with enough reactive power to support voltage up to a few seconds giving priority to reactive current and then restore output of active current to at least 80% of pre-disturbance active current level or to the available active current until conditions permit functionality for normal operation.