Solar PV Inverters

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Webinar Presenter

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Oriol Good morning and welcome to the international alliance expert training course. This session is going to deal with solar PV inverters. My name is Oriol Gomis Bellmunt. I will be the lecturer for this session. The supporters of this expert training series are the International Solar Alliance, the Clean Energy Solutions Center and the Carbon Trust. About myself I can say that I am a professor in electrical power department of the technical University of Catalonia, UPC where together with other colleagues we are working on UPC research center where we work with grid integration of renewable energy, especially PV and wind. But also in general we are working with power systems, dominated by power electronics. And we are working on trying to understand how the modern power systems will behave with high penetration of power electronics. On this topic we have experience working on different projects where we are studying such _____.

This is the third session of the module four technical integration of solar where we are talking about solar PV inverters after having introduced the module with the third session and having talked about the smart grids and PV integration in the second session. In this session we want to understand what solar PV inverters are, how they behave and what are the main functionalities they need to implement. So we need to go through a broad range of different fundamentals and talk about many different technologies. We will start introducing the basics of electronic converters. We'll later discuss about the electrical circuit fundamentals for AC systems.

We are going to discuss about solar inverter functionalities including the current voltage and power voltage characteristics to justify the need for a maximum power point tracking algorithm in solar PV. We are going to talk about the control principles which are needed to implement the solar included inverters. We will discuss about single and two stage inverters, about galvanic isolation, anti-islanding detection. And finally we will discuss about different inverter technologies which can be employed.

About power electronic converters we know that they are used to change power in a controllable way between two electrical systems which are electrical power source and electrical power sink. So basically we want to change power between the source and the sink and we want to control at every time how much power we are exchanging. The source and the sinks can be of different nature. And basically we can classify them with DC and AC systems. Direct current systems, DC, have the characteristics of maintaining constant voltage for current in a static state conditions. So the voltage and current is only changing when we have _____ in the system. But in a static state condition it remains constant. DC systems can be monopolar or bipolar depending on the number of volts we are using.

The other possibility is to use alternating current systems, AC, where the voltages and currents are not constant but they are _____ functions. So they are alternating all the time. So we have an average value of zero and the voltage is increasing and decreasing all the time. And also the current is increasing and decreasing all the time. And ideally they describe some sort of a waveform. The frequency of this waveform is typically 50 or 60 hertz depending on the part of the world where we are. Different frequencies helping establish that's the standard frequency in different networks in the world.

Another important characteristic comparing AC systems is to use only one phase, two phases or three phases. Three phase systems is the dominant solution we are using in the networks worldwide but some parts of the network like the distribution in low voltage can be done in the single phase or two phases. Comparing AC to DC we have nowadays in the world most of the electricity we are using it is in AC, that transmission distribution network because we have transformers which can easily elevate or reduce the voltage compared to the case of DC where we need power electric converters to do the same function. However, we have more and more DC applications and there is a trend to get more and more DC systems in the network.

The power converters can be AC to DC or DC to AC or DC to DC or AC to AC. So basically all the possible combinations can be done, can be implemented. In all the cases you see in the fillers in this case from DC to AC or DC to DC system. In other cases we have some measurements from the two sides of the converter. We have references from the user which is defining the set point. For example the amount of power we want to exchange between the two systems. And then we have the power converter.

The controller which is in the middle is receiving information from the measurement and applying the modulation which is needed. So we could summarize that the converter controls and measure the relevant voltage use in currents. Also the converter implements the controlled algorithms to track the references which are given through the controller. And finally it applies the appropriate modulation to the converter in order to ensure that the system is tracking the references given by the operator.

Depending on the power flow, AC/DC converters can be classified as follows. We use rectifiers when the power flow goes from the AC side to the DC side. This is the case for example of an electrical vehicle charger which is charging the battery of the vehicle from the AC grid. We have inverters when the power flows from the DC side to the AC side. This is the case of the solar PV inverters we are studying in this session. So the power is flowing from the DC to the AC side.

Also we can have bidirectional converters which can operate on both modes depending on the conditions. This would be the case of a battery converter in a microgrid application where depending on the situation we can use the converter as a battery charger or as an inverter which is injecting power from the battery to the grid. So depending on the needs of the system, the converter can be electrifier or an inverter.

This last operation mode, bidirectional mode, it is probably what is more needed in the systems. So voltage source converters are using are normally bidirectional converters in nature. We can use them as rectifiers or inverters as we need. Voltage source converters are typically employed in AC/DC converter application. Voltage source converters are bidirectional and can potentially operate as rectifiers or inverters. In some cases we will use them all the time as inverters. [Break in Audio] When they have [Break in Audio] converters [Break in Audio] voltage in the DC side and they use this voltage to modulate an AC voltage at the other end of the converter.

Voltage conductors can have different number of levels and normally for solar PV applications we will use two level or three level inverters. Two level converters can modulate the voltages with two possible levels, positive and negative voltage. So basically the converter switching the semiconductors it has can apply either a positive or a negative voltage to the AC output. These two level converters are used normally for low power applications. To have the good quality on the waveforms, high switching frequency is needed. So the losses increase with the switching frequency. This makes that there is a tradeoff between power quality and the losses.

If we apply a square wave form like the one you can see here in the figure we go not need to apply a very high switching frequency. But you see that the power quality is poor. We do not see a _____ output here. If we include the switching frequency and use _____ modulation, we can obtain very good waveforms also using the convenient filters. But we need to increase the switching frequency. The problem is that when increasing the switching frequency we are switching more times the semiconductors of the converters and the loses of these semiconductors are mainly related to switching. So the higher the switching frequency, the higher the loss is in the converter. As a result as we said we have this tradeoff between power quality and losses. We have to choose if we want good power quality or we want to have low losses.

This can be improved if we use three level converters. In this case the converter can modulate an additional level. We can modulate as before the positive and the negative voltage. But also we have the possibility of modulating the zero voltage. As you can see here it is possible to connect the AC side to the upper side of the converter to a positive voltage or to the lower one. But it's also possible to connect the AC side to the middle point to the _____ of the converter. So three different levels are possible.

This means that we can use this converter for higher power applications. This is because this three level converter technology allows us to reduce the switching frequency and the losses. This happens basically because we can obtain better power quality using the same switching frequency because the waveform has better quality, better power quality.

This can be seen in this slide. If we compare the two and the three level converters we can compare the original waveform we would obtain with one or the other. Here we have like the sine wave that is the ideal waveform we could obtain. B is the square wave. We talked it with two level converter and you'll see that total harmonic distortion of this square wave is up 45 per cent so the power quality is very poor. And this can be improved with the so called modified sine wave which is a three level square wave which you can see here. In this case we have something better because we are adding this level of applying _____ voltage. So the change is not too much from positive to negative. We have also this zero.

But in this case the tier three it is not good but it is much better compared to the previous one. It is 24 per cent so we are improving a lot from 45 per cent to 24 per cent. In the two cases here we have very low switching frequency, the minimum switching frequency. So this tier still can be improved increasing the switching frequency. Like we said before we will be increasing the losses at the same time. So there will be always an advantage using the three levels because we have a much better power quality for the same switching frequency.

Now also we want to introduce some basics about electrical share points. We have agreed that we are using AC systems because we want to connect the solar PV inverters to the AC network. So all the quantities in this AC system are alternating quantities. All the voltages and currents are changing all the time. So the instantaneous value it is not really relevant because it is changing all the time. So how we need to capture the waveform using some mathematical tricks. And what we are using is to use the concept of the phaser to capture the behavior of the waveform.

If we assume that the voltages and currents are defined by the question we have here, so the square root of two times the root of square value of the quantity times the cosine of omega t plus the fixed angle we see here that two important variables are the x which is the [Break in Audio] value of the quantity voltage of current and the phase angle. So we can put these two here in the complex number and we call this a phaser. This phaser captures all the static state behavior of this voltage or current in the system.

Now if we want to study the power in AC systems, we can use the phasers we have briefly defined in the previous slide. Their power is oscillating for a single phase AC system but constant for a three phase balanced system. So if all the voltages and currents are balanced, the power will be constant all the time for three phase systems but not for singe phase system. If we look at the definition using the phasers we have defined we have this apparent complex power S which can be divided into a real part and imaginary part. The real part is the so called active power P and the imaginary part is the so called reactive power Q.

In order to obtain this P and Q from the voltage and current phasers we can use this equation here so that apparent power is equal to the voltage phaser times the _____ of the current phaser. And the real power of this complex number will be the real power and the imaginary power will be the reactive power. The module of the apparent power can be obtained by applying directly without phaser the voltage and the current and then a part of it, this apparent power times the cosine of the phase between voltage and current will be reactive power. And this apparent power times the sine of the phase angle with the ______ current will be the reactive power. This cosine of ______, this cosine between the phase of the voltage and current is also defined as the power factor.

If we look at three basic elements we can have in circuits like resistances, ______ and capacitors we can see how they behave and how the power can be understood. Here you can see that the voltage is a bold line and then we have a dashed line for the current. If we have resistance we know that the voltage will be always proportional to the current. So if we want to apply voltage times current, the result will be always positive which is logical because we know that the resistance is always absorbing power from the grid. If we look at the resistance in one phase circuit we see that the power is changing all the time. And then there's an average power value which is this average we see here in the figure which is the average power and it is what we define as active power in the system.

In this case we see that we do not have any reactive power because the angle between voltage and current is zero so reactive power will be zero. If we take the example of an inductance we see that the behavior changes a lot. In this case we see that sometimes the product of voltage and current is positive. And then the power is going from the grid to the inductance and during sometimes the power is negative and then the power is going back to the grid from the inductance. What is really happening here is that during sometimes we are using the grid to let's say charge the inductance and create a magnetic field storing some kinetic energy. And then this power is injected again to the grid.

If we take the average of this power, we see that it is zero. So in fact we are not exchanging any power, any active power and if we were using a meter the result would be zero. We would not take any power from the grid as an average. But we can see that the reactive power will exist because the [Break in Audio] between the voltage and the current is 90 degrees. So here all the power is reactive power.

As it happens with a capacitor, in this case the angle is the same. It's 90 degrees but now it is the current which is leaving in respect to the voltage. And the current is advanced 90 degrees. What is happening again is that the capacitor is being charged, taking energy from the grid, converting it into electrical field, store it in the capacitor and then this energy is sent back to the grid again in the next cycle. Again the average of the power is zero and we have only reactive power here.

So if we need to give a definition for reactive power we can use this previous figures we were discussing. In AC systems there can be currents with associated average power of zero like the two cases we discussed before concerning ______ or capacitors. The current flows but no active power is exchanged. There is instantaneous power but not an average. In average it's a power of zero. There is power coming back and forth from the grid at double the grid frequency. But the average of this power is zero.

Reactive power helps us to quantify this phenomenon. It is mathematical inversion which is useful to describe what's happening in this case. Reactive power leads to additional losses in the system associated to the so called reactive currents and also requires oversizing of equipment. So compensation equipment will be used in many applications. If you think about the previous example it is clear if you connect the inductance to the network you are not, although you are not consuming real power. The average of this power is zero all the time. But the current needs to flow to the inductance. So this will require some oversizing of the distribution network.

Ok. So it just needs to be compensated. In addition, reactive power is used for voltage control in transmission and distribution systems. We can use reactive power to adapt the voltage. And this will be discussed also in the next slide and in the next sections in this module.

Now we will see how we can apply all the concepts we discussed about in the voltage source converter operation. In our case in the solar PV inverter application. We have a converter, we have some references from the user which is giving us some active and reactive power at set points. If we look at the system, we can use this scheme below. Right? We have the DC system. We have the AC system. But we have a voltage Ug. This is the voltage of the grid. It is not a voltage we can control. And we have the voltage Uc at the AC side of the converter which is the voltage we can control. Basically this is the voltage we are controlling with the converter.

Between the two systems there is a coupling inductance and a current Ic flowing into this conductance. This current Ic can be controlled by controlling the voltage Uc. If we want to exchange an even amount of active and reactive power P and Q using these equations here we can calculate what current we need to inject in order to insure we are exchanging this amount of power P and Q. Basically using this equation we can isolate Iz and obtain Iz using this simple equation here.

Now if we know the current Iz we want to have flowing in the inductance using _____ loss we can calculate the voltage we have to apply in the converter. Basically we know the voltage at ______ and we know the voltage of the inductance which is this J omega L Iz we can assume these two voltages and the resulting voltage is the voltage we need to apply in the converter. So basically if we apply this voltage we will have the desired AC current. And if we have the desired AC current we will have the desired active and reactive power. So the converter will be doing what we want it to do.

This can be seen as well looking at the phasers in the system. In this case we are using Ug as a reference so it is this blue vector here is the reference phaser showing the grid in the AC system. If we want to have zero reactive power and the current aligned with the voltage then we will this voltage from the inductance and Uc will be in the resulting voltage we have to apply with the converter. If Iz is not in phase with Ug then we will have non-zero reactive power. So we will have a source of a sink of reactive power. If the voltage is leaving the current like in this example then we will have the resulting voltage stopping the inductance in that 90 degrees from the current.

So the resulting voltage which has to be applied by the converter will be much larger. If the current is leaving the leaving respect to the voltage we will have again reactive power but the voltage stopping inductance will reduce to, will lead to reducing the voltage in the converter. So we see that depending on reactive power we will need to apply different modules of voltage in the converter.

Now we will talk about the solar PV inverters which is at the end the main objective of this section. Solar PV inverters convert the DC output of photovoltaic solar panels or strings into an AC current which is injected to the grid or to the load. The solar PV inverters have the following functions. DC AC conversion and voltage adaptation like all the other voltage converters, maximum power point tracking. We will discuss this point later. Anti-islanding protection so we will have to detect if there is an island and disconnect if it's the case. Also they are responsible for the synchronization with the main AC system where they are connected. And they have to support the grid where the PV system is connected.

The PV inverters market is a very mature one. There are many different manufacturers worldwide supplying inverters. So here you see a long list of manufacturers. And you see that the largest group is all others. So probably we would have an endless list of manufacturers of PV inverters which is of course a good thing, not bad.

We can talk a bit about the characteristics, voltage current and power voltage which are not characteristics of the solar PV inverter but are characteristics of the PV panels. These characteristics change for different radiations and temperatures. And we can look at them briefly to understand how they change. Here in the figure we have the bold line which is the power to voltage characteristic and the dashed lines with the current to voltage. Usually the bold one, power to voltage is obtained multiplying the voltage times current. So that was the ______ connected.

What we see here is that for different radiations from 500 watts per square meter to 1,000 watts per square meter, when the radiation changes basically it increases the maximum current in the current voltage characteristic. And of course also it increases proportionately the power to voltage characteristic. We see that if we have always a maximum power. But if maximum power is obtained always at similar voltages. Obviously if the voltage is different from the optimum voltage then we will generate much less. So we will need to be sure that we are operating at a voltage which is providing the maximum power which is maximum power point.

But we see that when the temperature changes, everything changes in a completely different way. The voltage to current characteristic changes and the power to voltage characteristic change in a way that when the temperature increases we need to reduce the voltage in order to track the maximum power. Because if we are not doing that then we will lose maximum power. We know that when the temperature increases basically the panels generate less. But we need to have the voltage to make sure that they generate the maximum they can. Ok. So if we are at zero degrees and we are at this point and the temperature rises to 20 degrees we will need to reduce the voltage accordingly.

So how we can do that? In order to do this we need what we define as the maximum power point tracking. The converter can modify the DC voltage to attract the maximum all the times. Ok. So when something changes we need to ensure that this voltage is the optimal one and that we are capturing the maximum amount of power which is possible. There are different algorithms which can be used in order to do that. All of them are maximum power point tracking algorithms. The first one is very simple, to have constant voltage. Ok. So we keep the voltage constant and we take what we can. Ok. Obviously this will not be optimal because when the temperature changes we have seen that the operation point should change and the voltage will change. So this method will not behave very good. But it is a possibility.

Another option is to inject a short pulse of current, observe how the voltage is changing in the capacitor and in the converter. And then we can map basically this voltage current characteristic and identify the optimum point and then operate at that point. Ok. So every given amount of time we can run one of these tests and then operate at the optimum point. Another option is to use perturb and observe method. Basically here the idea is to do small increments to see how the system is changing and then to keep changing the system in the right way.

For example if we increase the voltage and we see that the power is increasing we keep increasing the voltage until we see that the power is not increasing anymore. In this case we assume we are at the maximum and we keep operating there. The problem is that we can keep operating at some local maximums in some cases. And while there are other methods which are possible like the incremental conductance method, temperature method and open voltage method and many other methods.

In order to implement the functionalities we are discussing we need to have a controller in the converter. Here we have the main principles of this controller. Basically what we have said is that the converter can basically control the active and reactive current which is related to active and reactive power. Active current is used to control active power to curtail the maximum power available in the panels or to control the DC voltage to do the MPPT. What this means is that normally we will be controlling the DC voltage. So basically adapting the power needed to control the DC voltage in order to do the MPPT.

But at some times we can need to curtail the power because that power cannot be injected into the power system. In this case we will not be operating at the MPPT anymore and we will be operating in a suboptimal point. In this case, we need to control the active power instead of the DC voltage to maximize the production. The active current can be adjusted to the desired reference considering the converter limits which are the capability curves. We will see in other sessions how we or how this will be required from the power system. But it's of the inverters in a power plant can be required to provide reactive power. We see in the figure that there are some limitations in reactive power so depending on the active power we are injecting and the voltage conditions in the AC systems we have some limitations. And these limitations need to be taken into account when assessing the reference for the reactive power.

If we look at the control scheme diagram for a solar PV inverter we see everything combined as it is shown in the slide. On the left side you see the PV panel, the voltage and the current. So if we use a measurement for the voltage and the current, this can go to the so called MPPT control, the maximum power point tracking control. Basically we will have the algorithm also with some estimations of the variation in temperature which will calculate what is the optimal voltage we can define as a set point for the converter control.

This voltage together with the measured voltage will be implemented in an outer controller which receives also the references from the operator and also measurement of the voltages and power exchange in the grid side. This controller is basically defining the set point for the current controller as we discussed before. So basically we want to have this active and reactive power. For doing this we need this current which is compared to the actual measured current. And with this controller we calculate what it is the voltage we have to apply in the converter. And then we apply the voltage in order to have this current and to have the power we want it to have. This is a brief initial description of how that control is implemented inside solar PV inverter.

The inverters can be designed with one or two stages. In one stage converters [Break in Audio] when they are doing MPP tracking there can be limitations in the AC voltage because basically the converter needs to adapt the DC voltage in order to track the maximum power. But if the DC voltage needs to be produced it means that also the maximum AC voltage we can potentially apply it is reduced as well. And this implies a limitation in the reactive power capability of the converter. This does not happen in two stage converters which convert the DC output from the panels to a constant DC voltage an intermediate point of the converter and then in the second stage they converted this voltage to AC voltage. In this case we do not have the problem related to the MPPT. But we need to convert all the power two times, first DC to DC and then DC to AC.

For the operation of PV power plants and for the integration of PV in the system it is also interesting to think about how to combine PV with historic systems. Historic systems can be used and connected both to the AC side or to the DC side. The two solutions are possible. PV inverters with two stages allow a better integration of the energy storage system especially for small systems which in some cases can be directly connected to the DC bus. This is especially relevant as I said for low power systems. In larger power systems normally the option of connecting it in parallel as in the diagram will be much better.

Another important functionality of the system is galvanic isolation. Galvanic isolation is a protection principle in electrical systems based on ensuring that there is no direct electrical connection between two subsystems which are electrically isolated. In this case, power can be exchanged with magnetic fluxes ensuring no electrical connection. Galvanic isolation between the panels and the grid is typically needed. It can be provided by transformers used at different points of the system. One option is to use the typical 50 or 60 hertz transformer connected at the grid side. So we achieve isolation using a standard transformer. Here we can see a solution in this figure which is using this approach. So we have in this case two inverters connected, two _____ of the transformer and the isolation is provided with this transformer. So there is Galvanic isolation between the medium voltage system and the backups.

Another option is using a medium or high frequency transformer in the DC DC converter in the first stage of a two stage system. We will see later some examples of this. But basically the idea is to have the isolation inside the converter. So we have faster switching to reduce the size of the transformer and we have the isolation inside the converter. This solution is better in terms of volume and weight but it can add cost to the overall system.

Another important functionality is the anti-islanding detection system. When the AC grid is lost for any reason, the inverter has to detect it, block the inverter and ensure the grid is not energized by the inverter. This is very important for safety purposes. The detection is done by monitoring the voltage and frequency and actuating when an anomaly is detected. This problem can be challenging in some specific conditions when resonance occurs exactly at the grid frequency. This is unlikely but it can happen in some cases so it needs to be considered. In this case, anti-islanding detection techniques are used and by active islanding detection we mean that we are injecting so much more current and different frequencies. We are observing how we approach the grid and we can detect if the grid is isolated or not depending on the response to these injections. So we'll see the system. When the AC system is disconnected, the backup needs to detect it.

There are multiple different power electronic solutions for the PV solar inverter. Here we show only some important ones. And some of them have been already discussed before. So for example this one stage conversion with isolation of low frequency is shown here. Here we have the transformer at the frequency of the grid and then single stage inverter. We can go to two stages without isolation. So we have here the first stage, DC to DC converter and then an inverter directly connected to the grid. So in this case we have two stages but we do not have isolation.

If we want to have isolation at higher frequency inside the converter then we need to create a higher frequency wafer inside the converter. So here we have a DC to DC converter. But basically we have an inverter here at high frequency undulating this voltage. Here we can have a compact and light transformer at this high frequency. Then we are rectifying the voltage we obtain of the output of the transformer. And then we have here the output DC and then the conventional inverter to take this power to the grid. So in this case we have two stages with isolation included in the design. Another option is to use this scheme where basically we are replacing this capacitor by an inductance. So we have a similar concept with a ______.

A very important quantity in general engineering and also in solar PV inverters is efficiency. The efficiency is not constant for all the different operating points of the inverter. So it is not—it is important not only to consider the maximum efficiency and the rated operation point but also it is good to consider the efficiency at different operating points because in the end the power will be changing all the time depending on the radiation and the temperature. In order to deal with this there are different weighted functions to calculate the weighted efficiency like the ones defined and used in Europe and in the US. The one defined in California by the California Energy Commission.

Here in the _____ we have the equations we are using to weight the efficiency of different operation points. And while depending on the country and the standard use we can use one or the other equation. But the most important here is to understand that the efficiency is not a constant number. It depends on the operating point. In fact it depends not only on the operating point on the power but also changes depending on the voltage we have on the DC side of the converter as we can see in this figure here. So for different voltages the same inverter is showing different efficiencies at the same operating point and the same output power.

We will see now some data sheets of manufacturers as examples to see important quantities which are important in solar PV inverters. Here we see the example of a single phase solar PV inverter from _____. We see the nominal power in the DC side, maximum power, also the DC range of voltage which ranges from 335 to 800 volts, changing a lot for the reasons we mentioned before of that in ______. We have a maximum voltage of 900 and also this nominal voltage. In this case we can include up to four different parallel connections without strengths during the DC side.

In the AC we can arrive to this nominal output power with this nominal current at the nominal voltage. Ok. Again we have different possible ranges here for voltages and frequencies. But in this case the ranges change depending on the grid conditions, not on the conditions of the solar plant. It depends on external factors as the external electrical power system. And as we said before we see there is different efficiencies we can use like the maximum and the _____ efficiency.

Some information about the power consumption and environmental limits. And also it is important to look at protection systems which can exist or not. These protection systems include the ground fault monitoring and the islanding detection, current detection. Also we can have, we should have DC power switches, DC _____ fuses, detection of DC reverse polarity. Also capability of running in basically short circuits overload and over temperature detection, surge protection devices and overloaded protections.

All this information is also seen here for different types of converters for different nominal powers but basically we are seeing the same information we discussed about before. And we can see again similar information in this case for three phase inverters, for larger inverters. We see them normally for larger inverters we will operate at higher DC voltages, higher powers. So everything will be of more power. But basically the different parameters we can look at in the _____ are fundamentally the same.

If we look at possible schemes for the implementation we see here an example of a single phase converter. We have the four different possible connections to external extremes in the positive and in the negatives poles. We have the surge protections at DC suite which can connect the panels to the inverter or disconnect them. We have filters in the DC side and the inverter doing the conversion from DC to AC. Then an LCL filter, AC disconnectors and output filters in the AC side. As this is a single phase system we have only one line and the neutral connection for the output power in the AC side.

If we look at the three phase example we see that basically we have the same thing, the different strings connected in parallel. This is with the inverter filter transformers and then the connection to the power system. In this case in the three phases and then in the ______ with the three phases.

As a summary of this session we can summarize the main important messages we have given. The objective of the session was to introduce solar PV inverters because they are going to be used in many of the following sessions. They are like the building blocks which gives us controllability in the system so we can use the solar PV inverters to control active and reactive power injected by any of the inverters in the system. And as a whole they can provide the integration of the solar power plant. So they are very important building blocks for us in the system.

So we can say that solar PV inverters employ voltage source converters to interconnect the DC output to the AC network. They will have always a DC side. With the panels we have an external AC system. And basically if we employ this voltage source converters to do this interconnection. PV inverters can control the AC voltage and exchange power both active and reactive power. Ok. So they can be used for active and reactive power control applying the _____ voltage in the AC side of the converter. These converters perform the maximum power point tracking and ensure anti-islanding protection in the AC system.

So they will ensure that we generate the maximum amount of power all the time. And also if there is any problem in the AC system they will detect it and activate accordingly. We have seen that different conductor solutions are possible depending on the number of stages and the galvanic isolation we need. Depending on this different versions are possible and we need to choose the most appropriate solution for each specific case. And well, here finishes the session on solar PV inverters which as I said are going to be used in the next session related to integration of solar PV inverters. Thanks for your attention.