**Indian institute of Science**

**Design of Photovoltaic Systems**

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We shall now discuss a very important and very popular topic and that is Grid connection of the PV power, so the PV power is a fluctuating power it various over the day it reaches a pick at known and it is dependent on the insulation. So it is not a fixed power, so therefore you need to use an energy boxer like a battery or like pump ride row or compressor some such energy storage or energy buffering is needed for most of the applications.

Now if you consider grid, the grid power is available and any amount of power can be drawn from it within reasonable limits and it is something like an ideal source where the impedance where the output impedance is almost negligible. Now how do we inter connect such a PV power and the grid together and brings some use out of it. So if the PV power whatever power is available from the pv output whatever power the pv module are capable of capturing in delivering it at the output all that power let us supply it to the grid.

And let the grid appropriately distributed to the various loads, so it acts in the role of a supplementing source. So it is happening from your building let us say that pv modules are on your roof top and from your roof top you have wire in it and in connected it such a way that you are pumping power in to the grid, you will be benefiting in terms of lesser electricity bills to be paid, so therefore grid connection has become very popular and it is supplementing the grid in a very significant way.

So what we need to see is how to we connect the pv modules to the grids what is the sort of electronics that will come in between which will make this possible and that is what we would like to study. But first let us look at thee principle of grid connection.

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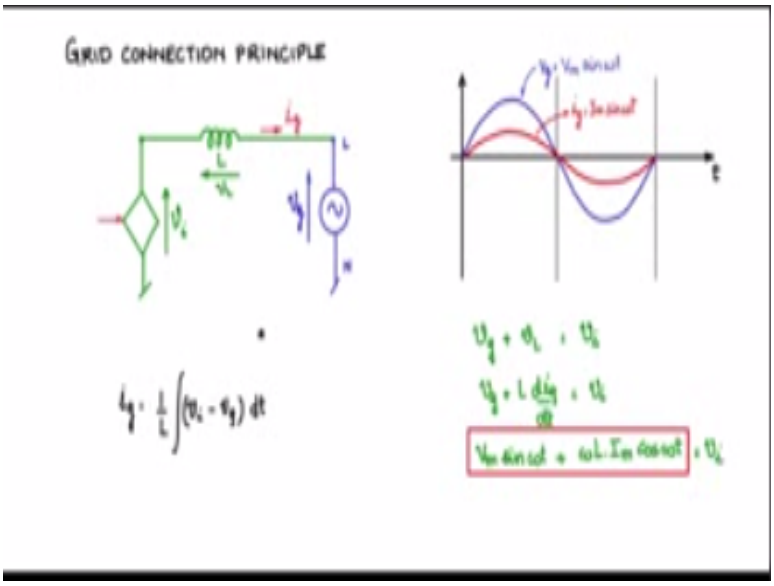


Consider a grid a single phase grid something like this I have line and neutral and in between line and neutral I am representing the grid as a voltage source, so sign way voltage source and let me make the measurement in this passion as shown by the arrow and I will call it as vg, Vg represents grid voltage. Now to this grid you cannot another voltage source and parallel you can definitely connect a current source in parallel like this.

Where the current source here is connected between this common which is the neutral point and this line so the current source is a high output impedance source and therefore it can pump current at a pre set level in to the grid and therefore power is pumped in to the grid. So if you have a current source and this current source deriving power from a pv module you ca definitely connect it like this, however note question very important you cannot connect a voltage source like this in parallel.

Let us say I have a voltage source and I use this symbol vi because most of the time the voltage source that v will be building this is what v will be building, is coming from the output of an inverter. So I will name it as vi inverter output, so this voltage source if you connected in parallel like this there is bound to be huge ig a circulating current between these two either in this direction or in this direction and something is going to blow.

So do not connect these two voltage sources directly like this instead you will have to in propose an impedance L like this in between, so this inductance is a non dissipative energy storing element, so it will act as the impedance and will try to match this voltage source and these two

voltage sources. Alternately you can view it as this voltage source along with the inductance in conjunction with the inductance together they would form a current source and therefore now these two together is current source which I can connect to the grid.

So now let me look at the wave shape of the grid voltage that you have no control it is dissect by the grid and the ig the current you decide to pump in to the grid, so let us have a look at these two voltage wave shapes versus time that is so x axes is time and the y axes is basically the magnitude the voltages in the current.

So let me draw first the magnitude of the voltage vg so it is a 50 hrtz signal here it is having a period of 20ms and this vg in 90 l sense is a pure sinusoid and I will try it as vm sin ω t but in a practical sense vg the grid voltage is not a sinusoid it has lot of harmonics. So there is lot of total harmonic distraction thd present in the grid voltage wave formed, but for now assume that this source is a sinusoidal it is just containing the single fundamental vm sin ω t.

Now how would you like to have the ig that you are going to put in to the grid, we would like to format maximum utilization of the pv panels from which you are drawing power we would like the ig to the fact in to the gird in such a way that maximum active power is put in to the grid. So in under such conditions you would like to put ig in phase with the voltage wave form at unity power factor, at whatever amplitude im as decided by the maximum power point of the pv panels which is driving this voltage controlled source.

So this is ig, it is im sin ω t, so both the voltage and the current have the same phase same wave shape has shown here, what is the power? The power is vm x im / 2 this we know you can intergraded integral of 1/t integral of vg ig dt you will get the power average power is vm im / 2. Now let me consider the voltage across the inductor I will measure the voltage across the inductor in the passion call it as vl, and then let us look this loop and write down the voltage equation.

So vg + vl should be equal to vi, vi is the voltage coming out of the inverter. Now what is vl? Vl as a direct relationship with ig if ig is sinusoidal vl should be co sinusoidal if vl is sinusoidal ig should be co sinusoidal, so we want ig to the sinusoidal so that it is in phase with the vg, therefore you will see that vg + ld ig / dt is vi now if ig is give in this passion im sin ω t dig / dt

will be ω im cos ω t we will replace this equation appropriately, vg is vm sin ω t + ω l im cos ω t out of the differentiation which is equal to vi.

So this is the crucial relationship if I have vi here in this passion, so the voltage across the inductance would be this minus this, and the current through the inductance or the current that is going to be put in to the gird ig is given by 1/l integral of va – vg x dt this is coming from trhe inductor equation. Now vi if I set it equal to this vm sin ω t + ω l im cos ω t – vg which is vm sin ωt the vm sin ω t is will get cancelled and what will be appearing across the inductor will be ω l im cos ω t.

Now that is the cosign wave, now on integrating ig which is the output of the integrator will be a sinusoidal wave and that is what we need and that is what we except, so that it in phase with the voltage. So the take away from here is that this source is a control source we are making it and how would you like to control it? We would like to control it in such a manner that vi is taking this value.

So output of the inverter that we are controlling should how this value which means I should appropriately set the reference such that output vi is coming to this much. So under such conditions then the current that is flowing through ig will be as given by this and it will be sinusoidal and in phase with vg, because vl will be co sinusoidal, so this is the basic underline principle.

So instead of using voltage controlled inverter where I said the reference voltage of the output the inverter to be like this, I could control the current directly of the inductor at the inductor current ig which is also the current that is going to be pumped in to the grid. So if I feed back the current ig and set the reference current ig reference such that I am drawing the peak power from the pv modules then the controller will do the job of appropriately giving the control input such that vi is at a value here such that ig what you desire will flow.

So at current controlled inverter comprising of the inductor and the inverter and the feedback given by measuring the inductor current back and setting the reference current according to the peak power of the photo hold tike module would be a very effective way of connecting the pv modules to the grid. So we will see how we will go about achieving this both in single phase and three phase grids.