Indian Institute of Science

Design of Photovoltaic Systems

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NPTEL Online Certification Course

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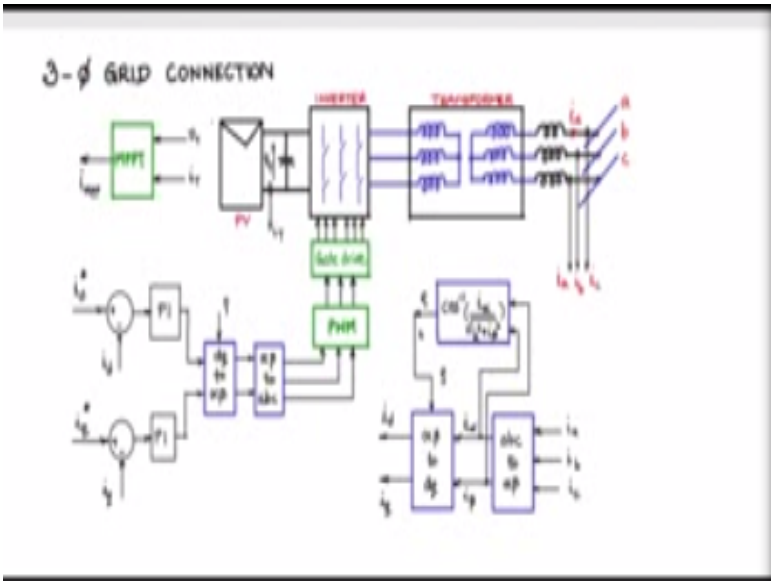

Let me now revisit the three face grid connection to apology that we discussed earlier and see how we can apply the various transformation that we learned into this and we can do a set point controller now let me remove these unwanted lines now, because we need to introduce new blocks we are measuring the currents now I would like to rename this ryd into abc let me do that.

And induced of igr I will just use ibic so let me female that I will mark that ia I have put them as abc softer having done that renaming here also I would like to change, change that later at a proper time now this iaibic are the feedback signals these are AC signals now what you want to do with them let me put a block te inputs are ia ,ib and ic now this ia ,ib,ic which are measured A3 face AC currents .

I would like to convert them into I ∝I β two face AC currents in the ∝ β co-ordinate system so what should I do .i should use a ABC do ∝ β transformation and how would will be I∝ and I β now this ∝ and β I would like to transformed into the DQ co-ordinate reference time it as one

more input and that is rope the angle between ∝ β co-ordinate and the DQ co-ordinate so what should I used here.

I should use ∝ β to DQ transformation the output this block will be ID,IQ now as the DQ co-ordinate system is rotating along these specter the current specter ID and IQ will be C quantities ,ID and IQ are the projection of the current specter on the D axis and the Q axis respectively so these are DC quantities now we will setup the controller here now let me have a current reference +- I will call the current reference as id*.

And what do I feedback I will feedback this id here, I will not draw the line so that it will clutter up the place I will just indicate id. So it means that I have connected this line, now output of the comparator goes to a pi controller so simple pi controller. Now I will do that for iq also, so I will have here iq * and feedback iq which means I will be feeding back this line here, plus and minus and goes to another pi controller block.

Now outputs of these two are suppose to actually generate finally the pwm, which will generate the voltage to appropriately drive the current, so the output of the pi are basically the d and q axes voltages, the voltages in the d and q axes, so let me do at dq to α β the outputs of the two controllers. One of the controllers the d axes portion of the controller is giving you vd let us say q axes portion the controller give vq this will go through a dq at α β transformation and I will get 2 outputs, these two outputs are let us say v α and v β this is the same ρ which I have used here because the dq and α β are having the same different angle. Now α β to a b c I will do one more transformation which will give me the reference va vb vc.

So I will draw these lines so this will be giving me the reference va, vb, vc to the PWM which will have the carrier triangle compare and then generate the necessary PWM signals for the gate drive to go and switch on and off these switches accordingly and supply a voltage here such that ia, ib, ic flows according to this control which we have given such that this error here and here becomes 0.

So this is the control principle that we use, now I will remove those three quantities and output of the MPP I will use a single output of the MPP to indicate to represent iMPP I at maximum power point and let me see what I have to do with that ultimately I have to give it as a references to id* I will discuss that a bit later but right now the MPP will taking vd and id and use the power

calculated to and the MPPT algorithm to give out an output which we will call it as iMPP which represents the current at maximum power.

Now what is remaining is how to obtain and give the value of row to these two blocks this is and defined as z, so row we said was the angle between the αβ axis, co-ordinate axis and the dq axis and we know that we want that the dq axis to be rotating along the space vector current space vector so if the dq co-ordinate system is also rotating along the current space vector then the current space vector and the dq axis are sink annoyed and rotating together and therefore the idea iq will be dc.

Therefore what we will do, we will take iα iβ and generate ρ so the angle of the current space vector will be ρ let us say. So let me say $\cos^{-1}$ iα $\sqrt{i\alpha^2+i\beta^2}$ is the block will give me ρ, so what should be the input I will take the input from iα and iβ as indicator the output will be ρ and that output I will use here and the same output I will also use here, so I have ρ. So in this case the id will get aligned along the current space vector iq will be 0 because id is aligned along the current space vector itself there will not be any quadrature component so this can be 0 and the only the id controller will exist.

However, this is one way of obtaining ρ but we would like to see that the currents which are flowing air or in phase with the voltage, so it is it would be appropriate to taking the voltage wave shapes, wave forms va, vb, vc and use the voltage wave forms to obtain ρ then id and iq will be such that it will be with the respect to the voltage space vector as the d axis, what is the advantage we will see and I will discuss that shortly. Let me now focus on this aspect on this generation of ρ.

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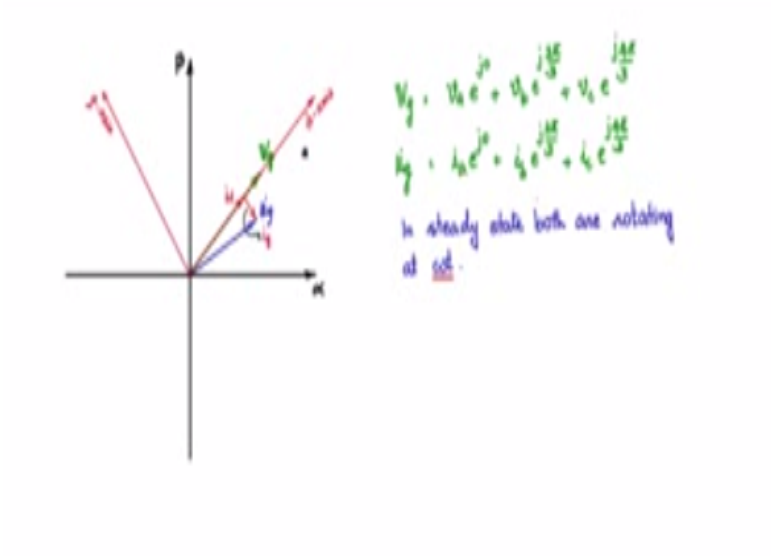

Consider the special co-ordinates αβ because αβ co-ordinate system and in that co-ordinate system let me have a voltage space vector shown like that, that is a resultant voltage space vector and this voltage is the grid voltage and likewise I will also have another space vector the grid current, this is the resultant meaning that it is composed of V_A V_B V_C and this is composed of I_A I_B I_C and resulting in this space vector in fact you can write down the Vg vector is given by $V_A e^0 + V_B e^{j2\pi/3} + V_C e^{j4\pi/3}$ we know how to do this you will land up with bα + j bß likewise I can also get the current space vector $I_A e^0 + I_B e^{j2\pi/3} + I_C e^{j4\pi/3}$ in this study state both the voltage space vector.

And the current space vector or rotating at ωd angle now let me position the q axis write the position that d axis so I am positioning that d axis which is aligned along the voltage space vector Vg so this is our d axis and the q axis is orthogonal to the d axis and that is the q axis and if you do this you will see that because the d_q axis is aligned along the V_g space vector and it is rotating along with the V_g space vector there is no quadrature component of the voltage space vector only V_d is there.

Because there is no projection on to the quadrature axis so V_g magnitude will be V_d that is the dc valve now Ig is let us say lacking V_g by some angle it is having two components and the projection of I_g on to the d axis and the orthogonal component, so this portion is projection will be Id the direct component and that would be the quadrature component I_q so the current space

vector can be resolved into Id and I_q now let us say we put the requirement that the current that is pumped into the grade I_g should be in case with V_g.

Then Ig and V_g should be aligned so what does it mean from the control point of view it means that Iq should be 0, so I go and set the Iq star send point to 0 then in the steady state Iq will be 0 so Id will be same as Ig and it will be in line with V_g and then you will see that the current is pumped into the grid in unity power factor, so this is the advantage you would get if you aligned d axis along Vg so now let us do this updation in the three phase grid connected block diagram grid connected in.

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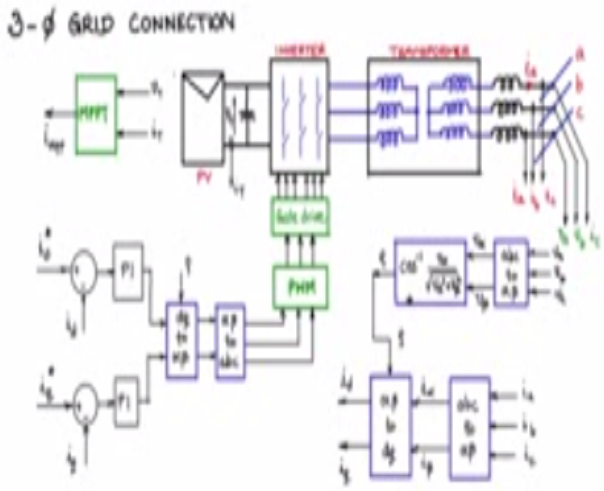

As we discussed is now let me make the update for the row generation block instead of align aligning it along the current space vector I will align it along the voltage space vector for the modification is as follows let me first remove the current inputs I will shift that out of bit make some space and then I will measure the phase voltages V_A V_B and V_C I will have block here I am going to take an input V_A V_B V_C and have a abc to α ß transformation just like this and output how the VBC to α ß will give me V_α $V_ß$ and I will use V_α / square root of $V\alpha^2 + Vß^2$ to generate ρ.

So now this ρ is giving the space vector position of the voltage V_A V_B V_C composed into I will now update this ρ generation block instead of ρ being the current space phaser angle I would like to replace it with the voltage space spacer angle, so for that let me remove this let me move this up to clear up some space and then let me taken the voltage measurements these are the phase

voltages V_A V_B and V_C and I will have a block here and this block will take an inputs V_A V_B V_C and I will use a abc to α ß transformation.

I will get at the output of this block B_α and $V_ß$ I will use V_α $V_ß$ to determine the ρ which will be the angle of the voltage space phaser V_α / √ of $V\alpha^2 + V ß^2$ will give you the angle ρ this angle ρ will give the displacement of the voltage space vector from the α ß from the α axis.

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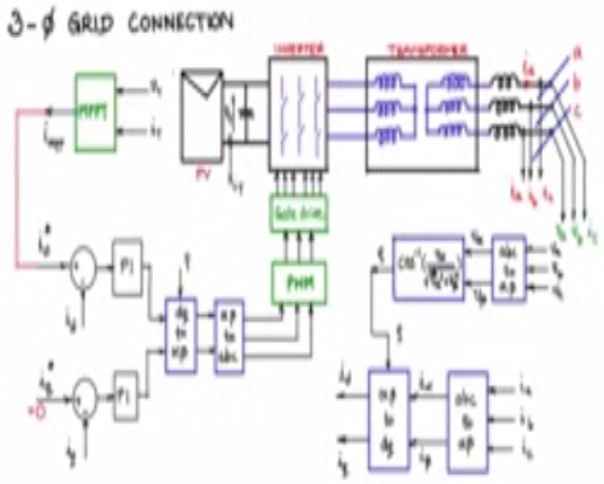

Now when you have to look at this voltage space vector so now the b axis is aligned along the voltage space vector Vg because we have taken this ρ and we see that the current has now to be controlled in such a way that Iq is made 0, so that the current space vector also aligned itself so we can now go to the block diagram make this set point 0, if you make this set point then the state is state you will see that Iq will reach 0 that p_i controller will see in to that the error here is 0 which means Iq will become 0.

Iq is 0 then with means the currents that are being fed in will be in phase and ID is representing the current space vector because Iq is 0 now in that case the output can directly dictate the set point for Id are Id so now Id's are actually the set point which defines dictates the current that are being pumped into the grid.

It dictates the total overall space current space vector that is fed into the grid as the grid voltage is fixed by the grid the current actually will dictate how much amount of power is being put into

the grid therefore if Id is actually representing the peak power point of the pv panel then the maximum power is put into the grid.

So let us say this block which is taking the terminal voltage of the pv modular and the pv current into it and the power calculated based on Vt it is used for determining the maximum power point the output of torque is now connected to Id like this say and Id is representing the value to which is indicating the maximum power point so this Id is used as a set point and why do you tried to match it on the in such a way.

That maximum current can be fed into grid and the grid can be the voltage which needs that maximum power is being into the grid so in this way also integrated iteratively within the inverter control the computation of this row by this method here is algebraic it is also open loop so it is not resilient to harmonics which are there in the remains voltage is formed it is not resilient to surges to spikes, noise, and due to various many uncertainties which may cause the ρ value to drift, so to make it more robust a close loop modification is suggested it is also call the pll, let us see how it works.

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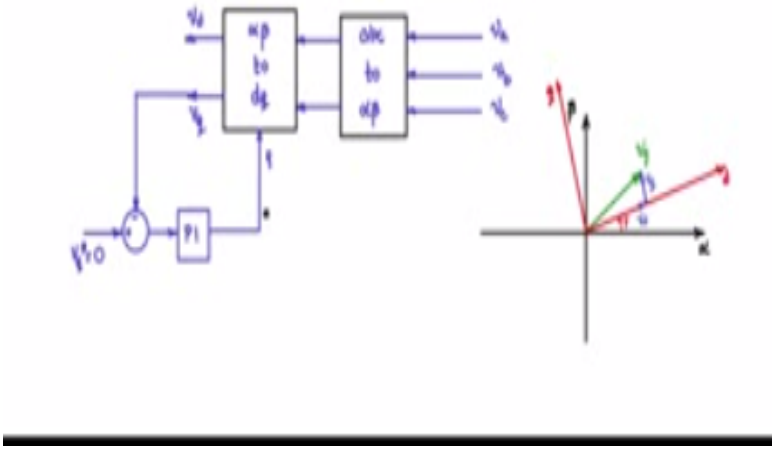

Consider the phase voltages va vb vc I will pass it through a b c to α β transformation I will get v α v β, and I will pass that to α β to deuce transformation and I will get vd vq, now there is ρ requirement here how will like you this ρ by the following method so let me built a small

controller here, I will set vq star I will say this is the set point vq * = 0 and then I will feedback the vq which is coming out of this α β to dq block.

And the error I pass it through a pi controller and deviate as ρ how does this work? This is like a pll it is also call pll in many literature, let me visualize the coordinate system and I have α β coordinate system and let me have a voltage space vector like this vg of the grid voltage. Now let us say that the d axes is miss align like this it is not aligned along the vg space vector, it is missed aligned by some angle and as a consequence the projections on the d axes will give the vd and vq, so there is a VQ component also if it had been aligned along vg if d axes had been aligned along vg then vq component would have been 0, now this is ρ, ρ is nothing but the angle between the α β coordinate and the dq coordinate.

Now let us see how this works, now let us say due to some reason due to many uncertainties the dq axes is miss aligned with respect to the voltage space vector which means vq is not 0 then this compares with the vq it goes negative the pi controller will become active it will initiate a ρ change in to initiate a ρ change in such a direction that the input to the pi controller which is the error will 10 to 0.

If this tends to 0 then vq here will 10 to vq 8 8 that is the command value or the represent value, we are said vq start v = 0 therefore vq will ten to 0 so the pi controller will see to it that vq will tend to 0 which means the ρ will keep adjusting it will adjust such that it will aligned the d axes along the voltage space vector, and such a value of ρ will come up out because of the control action such that vq here will become 0.

Under such condition the ρ value here is the correct value of ρ which will give you the value of the difference between the d q axes coordinates system and the α β coordinate system such a way that d axes is aligned along the voltage space vector, which is what we would like to have. This is a very robes mechanism because it is close loop and then there is a pi component there is history in it which will filtering effect on harmonings, surges, spikes and such than uncertainties. So if we incorporate this modification in to our entire 3 phase grid connected inverter block diagram then it will be a complete workable solution, let us do that.

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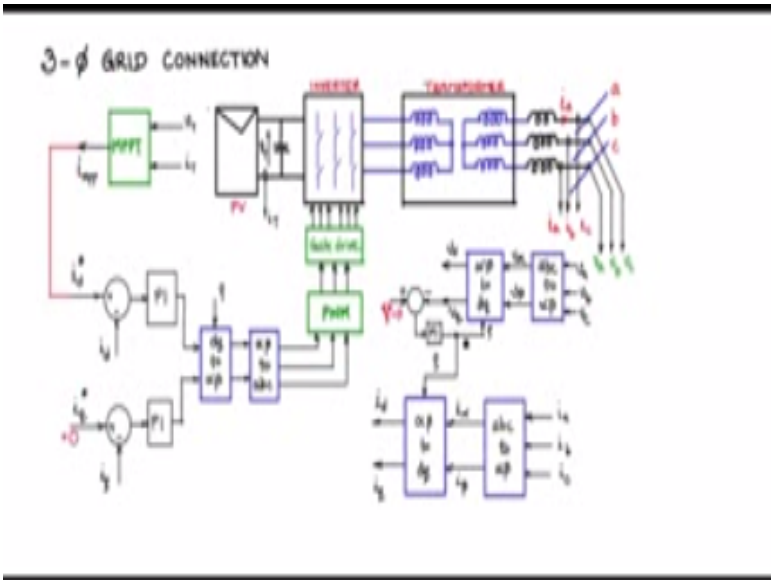

Let us now modify this ρ generation which is open loop and not very robust and is also algebraic we will replace this with the close loop pll based type of technique that we just discussed let me do that let me erase out this blocks let me clear, now let me first start with the a b c va vb vc which are the phase voltages I will do a a b c to α β conversion transformation which will give me d α and d β, and I will pass it through an α β to dq transformation which will give me vd and vq I will not do anything with vd.

I will now introduce a control mechanism this is the reference plus minus vq is given as the feedback to the control mechanism. The error is given to a vi controller which will generate the ρ for the dq block it will generate Sin such a way that vq will go and take the value set by this reference. Now this ρ value I can take it up and then connected here, now this vq start set point for this control mechanism will set pq start to 0 as I discussed so that eventually vq will reach vq*.

So vq will become 0 in which case vd will be aligned along the voltage space vector and because you are going to use this ρ for all your αβ to dq conversion that dq axes will be taking this value of ρ and therefore will be aligned ali0ong the voltage space vector. So we have now here the complete block diagram of the three phase grid connected inverter topology and which take sin to account all issues.

And this is an implementable block it contains dq transformation it contains the dq axes theory principles frame transformations from the 3 phase to two phase AC to dq and having set point controller the number of controllers are only two as against three in the AC control tracking

control, we now have MPPT integrated in to the inverter and the power block is simple it has just only one power stage and then we have a robust pll based ρ determination algorithm.