High Voltage DC Transmission

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Module No # 02

Lecture No. # 11

Converter Charts

So, let us start the lecture number 11 of this module two. In the previous lectures, we analyzed the converter circuit and especially, we saw the six pulse converter both inverter as well as the rectifier operation and also we saw this 2, 3 valve conduction 3, 4 conduction modes.

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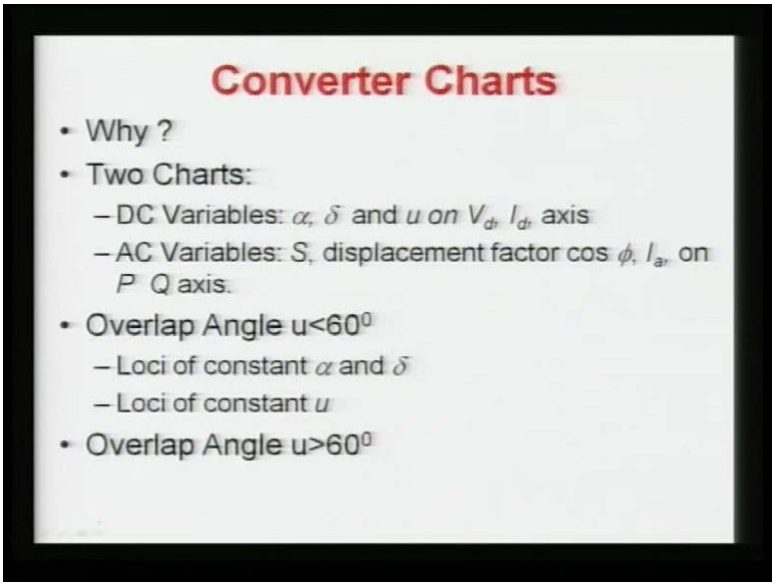

Now, I will explain based on the derive equations how we can draw the converter chart. The question arise, why converter chart? By the help of converter chart, we can identify for a given set of voltage on this converter, and the current what will be the required quantities or you are knowing any quantity then you can go for the voltage and current corresponding.

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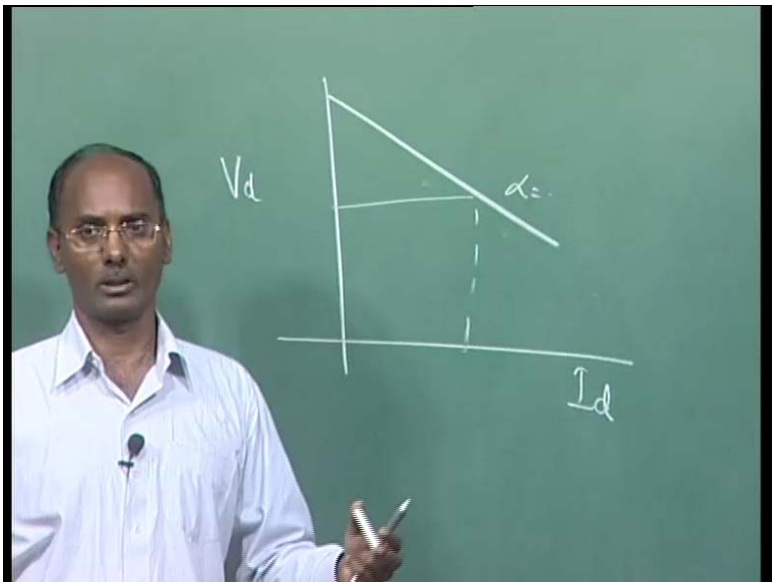

For example, in any chart, suppose in this case I will be going for here the voltage and that is a DC voltage here, I will be going for I DC test a DC current. So, in this if you can draw the some set of curves for a constant value, then from that curve for lets go this is a curve that is like this. So, this is some constant, this is your alpha for a given value; so, for knowing alpha, we can just know what will be our V d and I d directly from this chart without evaluating the characteristic.

So, this is one example just I am quoting. So with the help of chart, we can get what is your voltage, what is your DC current, for given value of this or if this is known then you can find what will be the value of alpha. So reverse is also true. Means it abides the calculation and you know, there is a source, sine, cos etceteras are there, so directly knowing this value you can find what is actual operation mode of the your converter circuit.

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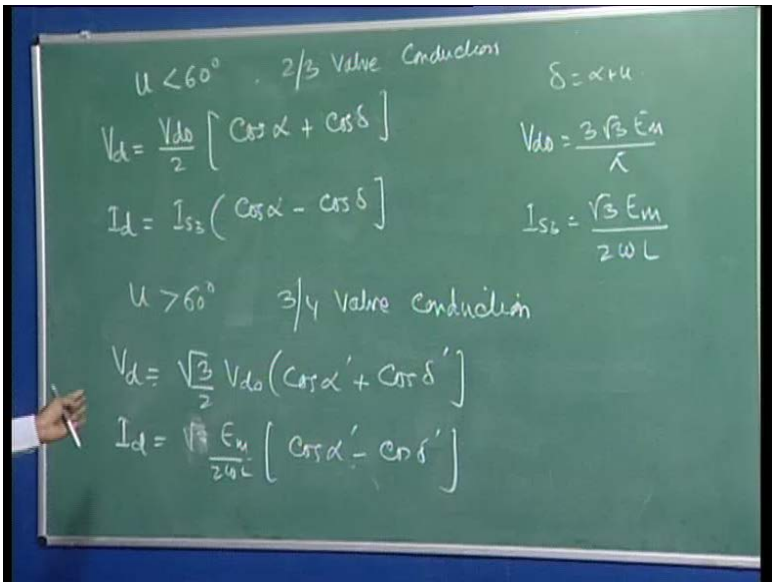

Now, you can see we have the various variables in our derived equation means if you remember when u is less than 60 degree, we derived our equation here V d, which we will be using again in this lecture. You have to give your V d o by 2 here cos alpha plus your cos delta. This delta is nothing but your alpha plus u, we also derived our current here. It was your I s 3 cos alpha minus cos delta here your V d o is nothing but three under root 3 E m divided by pi and your I s 3 it is your nothing but this is a E m divided by 2 omega L. So, this is the case when u is less than 60 degree or I can say here it is 2 to 3 valve conduction mode. We also derived for u is greater than 60 when your the conduction valve that is 3 to 4 valve conductions conduction mode and here we derived our V d it was your under root 3 by 2 V d o cos alpha prime plus your cos delta prime and your I d was your under root three E m by 2 omega L. Let us say no it was not having root three and here it was cos alpha prime minus cos delta prime.

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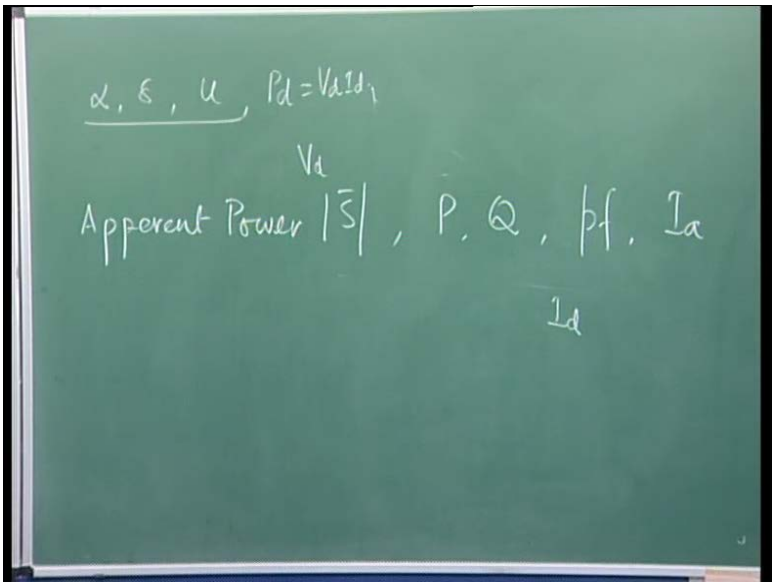

So, from these equations we can see the equations your DC side of your inverter or converter circuit means. The various variables we are having now here I can say alpha delta. The delta depends on this two so we can have the characteristic in terms of currents V d as well as a voltage. We can have the three variables here so, the DC side quantities which I had written here. We are having this alpha delta and u on this other two variables so, our x axis will be your I d and your y axis will be your V d and then, we can for a given constant value of alphas or constant value of delta or constant value of omega here. We can draw the characteristics so, these are the simple equation but only here difference. We are having the two modes one is u is less than 60. We are having a different set of equation and here if it is j x u is greater than 60 we are having the two different equations compared to the previous one so, these are called the DC side variables, because we are controlling our converter circuit based on these parameters. Your output voltage as well as current is decided based on these parameters

Also, I can say the DC side another quantity is your the p d p d is nothing but it is a multiplication of these two quantities. So, we have also the DC side completely these four variables are there which is nothing but here V d into I d now. If we go from the AC side, which means network side, I can say what are the various quantities that we can have and those can also be drawn on the curve and that is called the AC variables. So, the first one is your apparent power this is, your s of the complex here value we can also separately have the real power p. We can have a reactive power q that AC side we can

have the power factor, we can have the phase current. So, these are basically the 1 2 3 4 5 quantities, we can draw no doubt. This depends upon this or this three are related to each other. So, it means one converter chart will correspond to your DC variable and another will correspond to your AC side, although we can draw on the same curve but it will be very complex because, here you know we are having so many variables on the same axis means your V d and I d.

So, we can just separate two locus, one is corresponding to DC variable and another, we will see for the AC variables again, here as I said that we are having the two modes, one is less than, one is greater than u and we are having the two different governing equations and therefore, we have to have the different curves, now u is less than 60 degree first.

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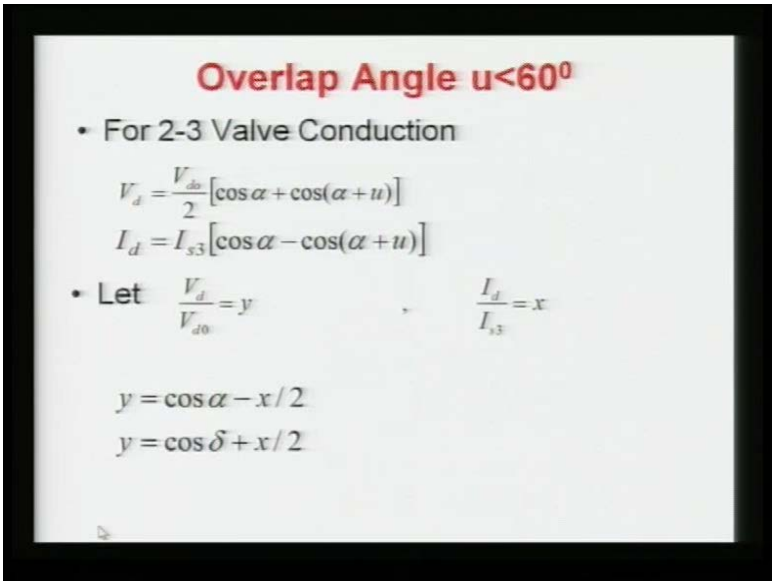

And as I have written that, these are the equations now we can simplify here. We are going to denote this by V d divided by V d o.

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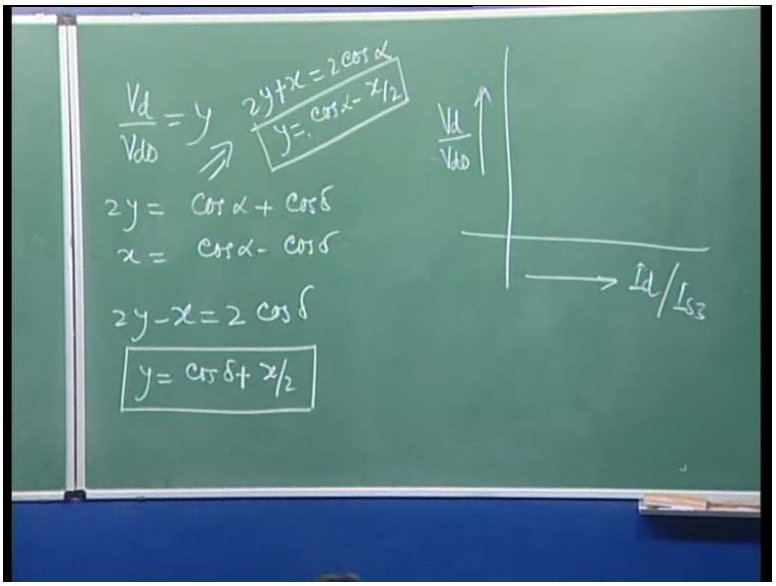

I am just denoting it as V d which, we are going to denote here as a y because we are representing voltage on this axis your x axis here. So, instead of writing V d here I am just writing here, the V d o basically it is nothing but it is the per unit value.

We are dividing the voltage by the rated value with or without alpha. So, here it will become 0 to 1 or lets the value of u be per unit. Similarly, this side also we are just dividing I d divided by your I s 3. It is denoted as x so, once you are going to do this two, then you can find what we are getting. We are from this governing equation going to have two y from here, because V d divided by V d o is y and two is here. So, two y is equal to your cos alpha here, plus your cos delta from this. We are going to have x here your cos alpha minus cos delta from these two. We can eliminate this delta first so, we will have the relation between x y corresponding to delta alpha and we subtract here so we are going to have 2 y minus x is equal to your 2 cos delta.

If you are subtracting to get this, if your are adding this, will be cancelled. And you are going to get another one. This means, we are going to have y is equal to your cos delta minus x by 2. This is equation corresponding between x and y and this is your delta plus 6 here, because this is going to add. Over here we are going to have another equation. Which means I can write from here it is your twice y plus x is equal to your two cos alpha or I can say y is equal to cos alpha minus x by 2.

Now you can see the slope for this equation is 0.5, this is a positive, this is negative. So let us draft the characteristic, and then we will come back for the E u because u can be also obtained from this one by eliminating alpha because here alpha is also. Therefore, we can just manipulate something here add it here and we will find we are getting u term specifically. And then we can have another characteristic corresponding to this. So, for a given value of alpha here you can draw the characteristic between x and y and you can have a complete line similarly for here.

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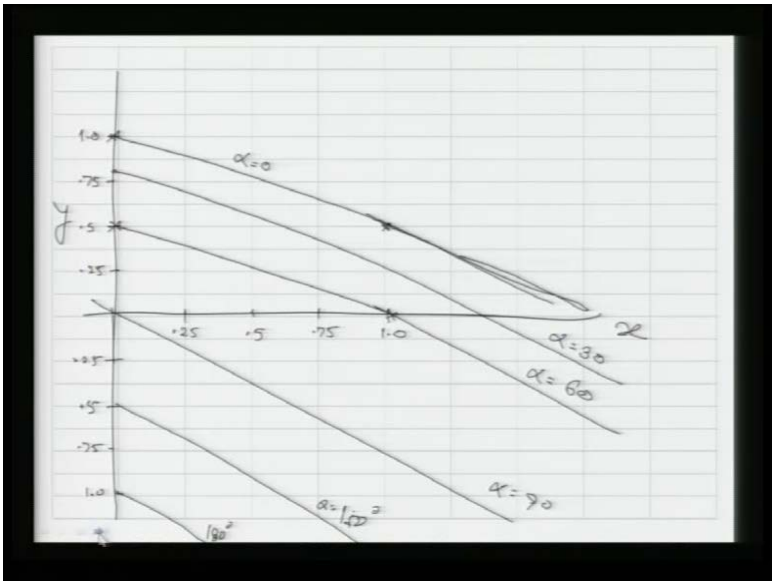

So, to draw it here from these two equations we can just simply draw x and y axis. Where your y axis here it is your x axis now I want to draw the characteristic for this. There is no doubt, is a straight line having slope 0.5 with a negative and let us suppose alpha is 0 or we can draw as alpha is equal to for the different value of alpha is 0, alpha is 30, alpha is 60, alpha is equal to 90 and so on so for.

Then we can have the set of parallel lines, because here slope is same, only this constant is changing means, only the intercept and the y axis is going to change nothing else. So we will have the set of parallel lines for the different value of alphas here and this slope will be the negative. To know this here we can write here it is 0.25 just mark here 0.5 here 0.75 and here it is one this side also we can mark here it is 0.25 here 0.5 here 0.75. Here, I am going to draw for the different value of alpha on this axis, now you can see

alpha is equal to 0. First take this equation, if alpha is equal to 0 then we are going to have y is equal to 0.5 x leave the negative sign 5 means when x is 0 alpha is here 1.

If x is 0 means we are getting unity, we are somewhere starting at this point now once x is your two it will be 0. It is better we can put x is equal to 1 once x is equal to 1 it is a 0.5 and the 0.5 here. So, we are going to have a characteristic like here that is your alpha is equal to 0 means to have a line you require two coordinates for given value and then you can just make it. This is your straight line although it is may be not so straight but it is straight line we will show again in the clear picture later on. Now I want to go for here alpha is equal to 60 if you are putting alpha 60 here is 1 by 2 means here we are getting by two and now we can just see if x is 0 we are getting 0.5 here. And when x is your unity it is 0 why is x is 0, means we are going to have this point and then we can make it.

Now if we are having two lines then all this alphas will be changing from alpha, is equal to 0 it can go down means, it will be the parallel line. Here alpha is equal to 60 so your alpha is 30 what will be this? If you are going to have alpha so, it is under root 3 by 2 into 0.5 x and this is value approximately 0.78, 0.83 and 0.86. So, it will start here and we will find it is a straight line here alpha is equal to 30.

Now, if alpha is 90 this will be 0 and we are going to have a characteristic y, is equal to 0.5 x, means it will pass from the origin and it will be again the parallel to this and we have alpha is 90 similarly, we can also draw here 0.25 here 0.5 0.75 and unity here means we can have another line. We can have parallel lines because this side is your nothing but your inverter operation below this. And this side we are having rectifier operation so, this side here is alpha 90 this is going to be your alpha. And the alpha here 180 and 150 here, alpha is equal to 150 only there just put alpha 150 here and we will find what is the value you are getting or you can see it here it is alpha 120 it will be not alpha 120 because, if a putting alpha 120 here it is 0.5 minus. So, the basic characteristic for a constant alpha, all are parallel lines, means these lines are although it is not looking parallel here but these lines are parallel and straight line. So this is called constant alpha curve on the same axis. Now, we can draw for this and this is nothing but it is called constant delta curve and this slope is positive, so it will be going up.

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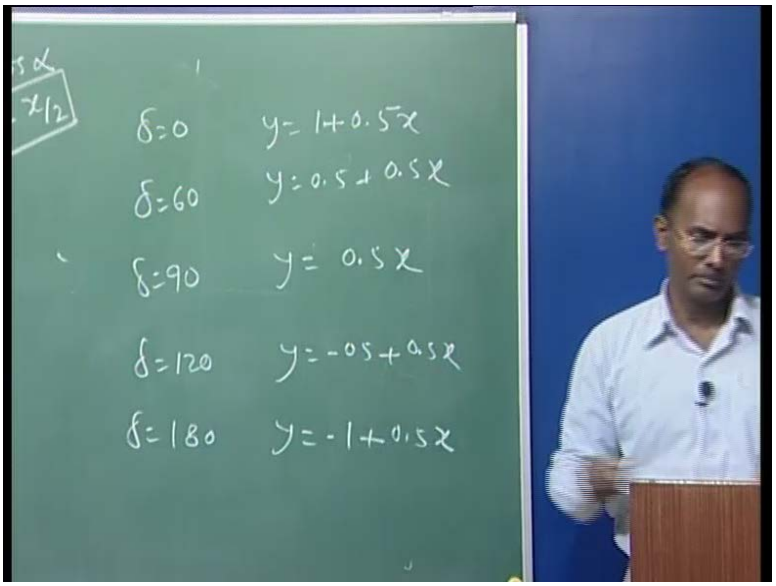

So, again for this characteristic I can write for the different value of delta here. The delta is equal to 0 means we are going to have y is equal to one plus 0.5 x here delta is equal to 60. I can say y is equal to 0.5 plus 0.5 x here delta is equal to 90 here y is equal to your 0.5 x here your delta is 120 here y is equal to minus 0.5 plus 0.5 x and here delta is your 180 here y is equal to your minus 1 plus 0.5 x so. These are the characteristic for the different value of delta and here it will be positive. So, we can start from here, if x is 0 we are going to get 1.5 for this value means your delta is going to be one 0.5 it is 0 then it is one.

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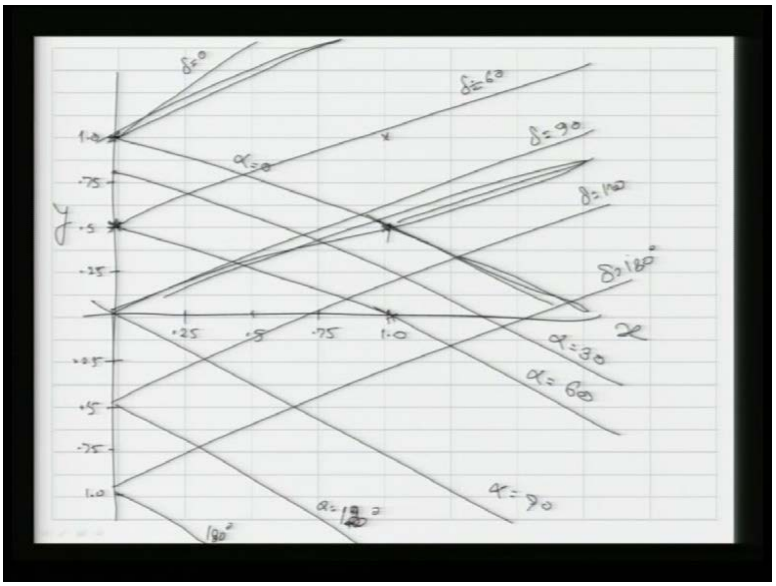

So, we are going to start from here see and the slope will be just it will be the past here means your delta here is 0 now for this here x is 0 it is 0.5. We are having this point here and when x is your unity we are going to have one means, we are going to have one here and this characteristic although it is not good I think this will be parallel to this because all these characteristics are parallel. So here is your alpha delta and your 60, when this is your delta is ninety here it is passing through, this means you want this is 1 it is a 0.5. Basically this will be passing through this line here because this is value and here it will be the parallel line.

So, this is your delta 120 here, delta 180 degree here. So this is the characteristic for the constant delta and another is corresponding to your constant alpha. Similarly, we can derive the expression for the constant u that is very important and for that we can use these equations again further to simplify it here.

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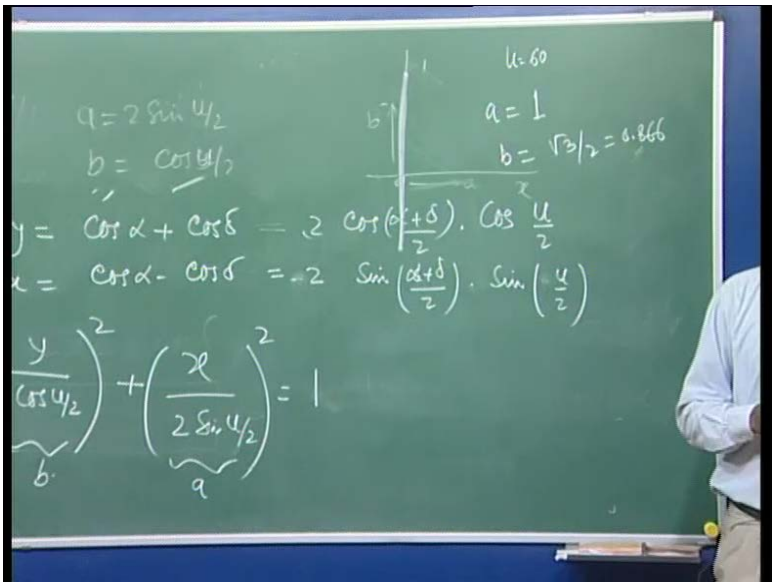

Now, we use the trigonometric identity from here. We can write twice of cos alpha plus delta by 2 into cosine alpha minus delta and this alpha minus delta is your u that is minus u and cos minus theta is minus theta cos theta. So, it is u by 2 for this we can again write it is a twice here. It is a sign alpha plus delta by 2 here it will be the negative sign and then I have to write here a minus b. Otherwise you are not writing here then it is a b minus a.

So, here I can write the sign minus u by 2 a minus b means alpha minus here alpha plus u gives this value. And we are getting this minus and this minus will be cancelled basically. So, I can remove this minus I can remove this minus here, now you can see this value is independent of any alpha here or delta. This we can also divide this side and then we can square and add it. So, what I am going to have here I can say it is y divided by your cos u by 2 that I can square it plus here your x by twice sine u by 2 square, it is will be equal to unity because this two I have taken this side so this two are cancelled. So, we are having this two sine here divided by x we are having this and this is square of this cos square theta plus sine square theta is equal to unity, so we are having this expression.

What is the expression of this is not circular is a hyperbola ellipse yes, because for the circle this should be equal. This is a b so here it is your b no doubt here the origin will be 0 because, this is the origin starting here there is no minus here so it is a origin here also origin now we will see where we are getting this characteristic here for the different value of this. Now I can write here a is your two sine u by 2 and here b is your cos u by 2.

Basically the distance from the origin from one half and here this is your x. So, this will be giving a and this side it will be your b. Now if u is 0 what we are getting? b is equal to 1, a is equal to 0, this is 1 so it will be 0 means your this value is a is 0 because I said here this is 0 means you are here and b is unity means you are going to have this straight line. So we are going to have for u is equal to 0 this is a one means. This is your b here and both aside here, it will be called your u is equal to 0 now if your u is your 60 degree now you can see once angle is increasing this value is decreasing this value is increasing is very obvious here.

If u is your 60 degree because that is the limiting point here so, what we are going to get a for u is equal to 60 degree here it is a unity because is a sine 30 here and sine 30 is half multiplied by 2 is unity this side we are going to have b is your the cos 30 that is under root 3 by 2 that is your 0.866 means for the u is equal to 60. We are getting somewhere value here even though this is a 2 5 is difference so, it is 8 6 I think somewhere here so and similarly, we were going to here and this is your unity means we are going to have a characteristic touching here u and it is coming here like this.

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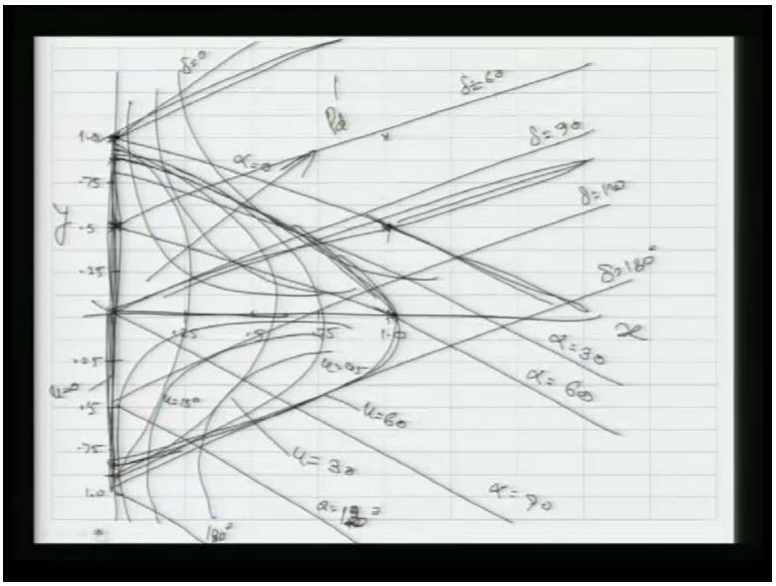

This is your u is equal to 60 now once your u is reducing we are not going beyond. Because this equations are only valid when your u is less than 60 so this curve is the limiting curve means you are operating for u is less than 60, you are inside only you cannot go beyond this because for the outside we will have the another equation here. And we will see how the characteristic will change so, it is u is 0 and u will 60 intermediately if you are using u is equal to 30 what you are going to have this is your u 15 degree this value will reduce slightly then one but it will be more than u is equal to 60. So, your characteristic here somewhere it is going to be here on the top its increasing but this value will be decreasing so, we are going to have u is equal to 30 degree.

If you are going reduce this so, this will be b will be increasing slightly and will be having like this here. It is u corresponding to your 15 degree if you are going to have u is equal to 45 degree, it will be slightly less here and we are going to have here that is a u is equal to 45 degree. So this is the characteristic which we are getting now. You can see this is our boundary limit because these characteristic even though that is valid but it will not go beyond. We will have to stop here within this constraint because the governing condition for your delta u etcetera in this zone only, we derived all this thing based on this so, characteristic now lying only between this for u is less than 60 for u more than 60.

Now, we are landing somewhere else, this is basically we are coming outside but the alpha and delta will be changed because here we have slope of characteristic, is also going to change now on this scale itself. If you want to draw the power, the DC power here, the DC power as I said it is a p d for constant DC power it is your V d into I d, so if you want to write in this per unit here because we are dividing by V d o here on I s c 3 here. So, we can say it is a p d prime am writing so pd prime it is a per unit value here it is your x into y and this is nothing but it is a equation of your what is this is a parabola or hyperbola. So, what will happen here for the positive both positive here it will be positive for one positive here it will be a one negative it will be negative.

So, in this characteristic it will be nothing but it is a just like a inverse equation here. Some constant p d here prime divided by x it is the inverse equation so we are going to have the different value of this here and we are going to have this here, all this for the positive side similarly, we can have our negative side for the different value of p now you will see if your p is increasing means your y for given value of this p is increasing y will increase means. The power here starting here it is your p prime d is increasing this curve is going away when p is 0 means you are again here this straight line because you can see p is 0 here either 1 of this is 0 or both are 0. So it will be on that axis so it will be like this either side and this side which is undefined.

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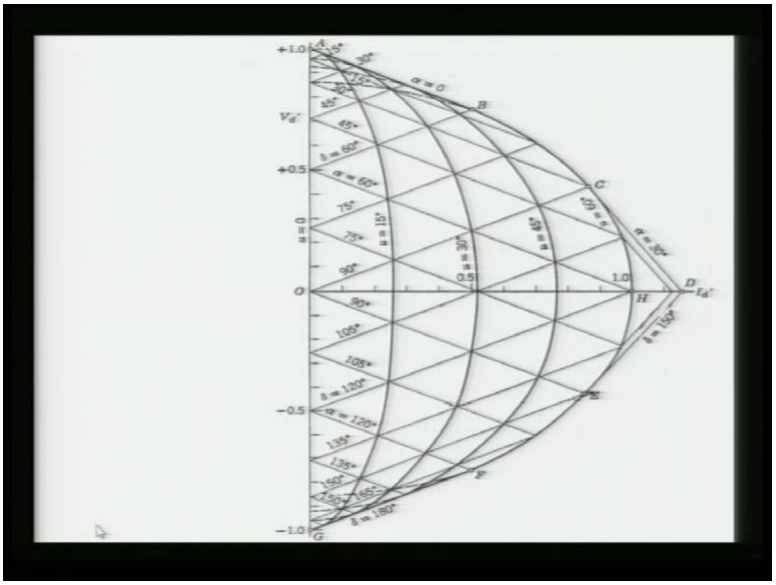

Now let us go for another side and to be very clear you see this graph which is drawn very nicely, what I draw here is the similar we are having here, these are the delta constant delta curve these slopes are the constant alpha curves and these are our u constant u curve and here u is 60 and this is the boundary where we have to work for this mode of operation power is not drawn here but it is clear that we are having this type of ellipse for the u and the straight line for alpha and your delta.

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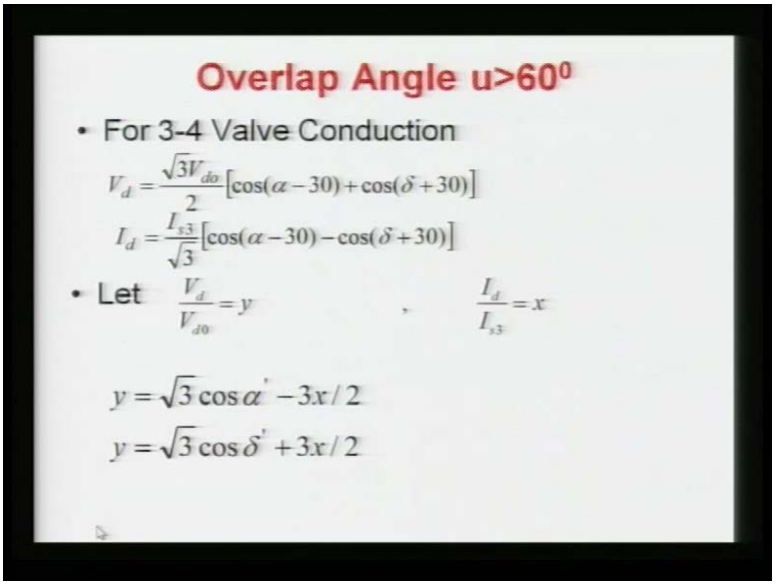

Now let us see if alpha going for u is greater than 60 and now we are having the governing equations. These two equations now the we have to see the slope and what will be the equation now since we are drawing on the same scale our assumption of x prime that is a on the here the per unit and the voltage side and per unit current is not going to change.

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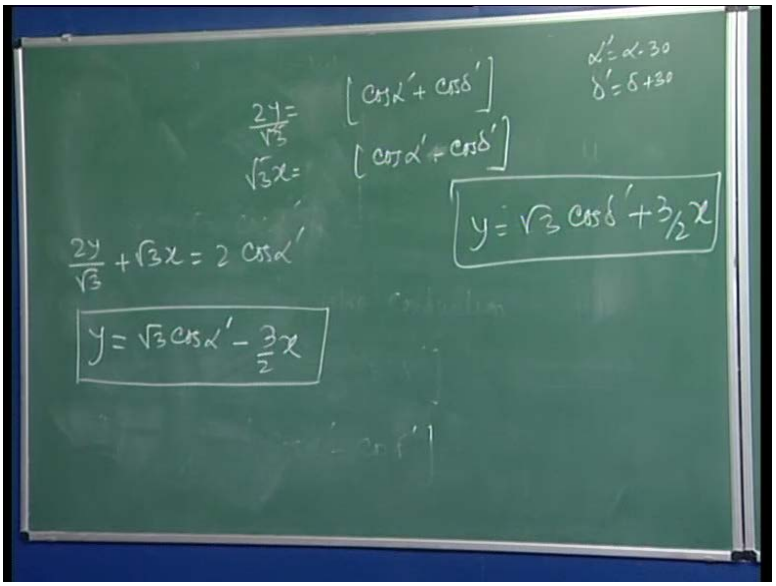

So, still we are assuming here our V d divided by V d o is your y and I of d upon I s 3 is your x so with this assumption, we can write our equation here you will see here we are going to have it is a twice y is equal to under root 3 here your cos alpha prime plus cos delta prime we know that alpha prime it is nothing but alpha minus 30 and delta prime is your delta plus 30 already we have derived this equation.

Corresponding to this here see under root 3 term is only missing so, we can write under root 3 is not there so we are having x under root 3 cos alpha minus here cos delta prime. So, here under 3 root because normally for 3 4 valve conduction mode voltage reduce drastically and current increase drastically. This is the equation and based on that it will be prime and then we can again derive the equation for the constant alpha prime constant delta prime. We also draw for your u characteristic has value in this region because now u is also changing and that will be drawn from here.

Now, we can use the similar way here, we can add and we can subtract and we will get the expression for your constant alpha prime and the constant delta prime here you can see this stay constants just add it here if you are adding you are getting twice I plus x is equal to your under root 3 cos alpha prime and that will be two times more. We are having y is equal to under root 3 cos alpha minus so from this equation we see this is I d is equal to I s 3 by under root 3 cos alpha prime minus cos delta prime here this under root 3 will go this side and this is divided here means we are getting here under root 3

here x will be this equation result will be your multiplying here root three. So in this case what we have to do to add or subtract we have to first divide under root 3 here and then we have to add or subtract.

So, this equation again I can change here and this we are going to have here, under root 3 terms here now, we can just add it so, we are going to have 2 y over under root 3 3 plus under root 3 x here, we are going to get cos alpha prime or I can say here y will be equal to here this 2 and 2 is cancelled under root 3 cos alpha prime minus here, it is your 3 by 2 x. So, this is 1 equation corresponding to alpha prime and then if you are going to subtract this, you are going to get this equation, simple so this equation will be your y is equal to under root 3 cos delta prime plus 3 by 2 x. So, just subtracting here will get this expression for the constant delta prime.

From these two equations you can see, here the slope is changed and here the coefficient is also going to change, due to this slope change now, if it is a negative it is more negative, once it is a positive it is more positive. So, to draw the characteristic here again, we are going to have again I can draw a graph, so, this is your x, this is your y and now to have this, we want to see where we are going to get this alpha prime means, intercept I want to calculate means, where it is going to be 0, where it is going to be x axis cut, where is your y axis cut.

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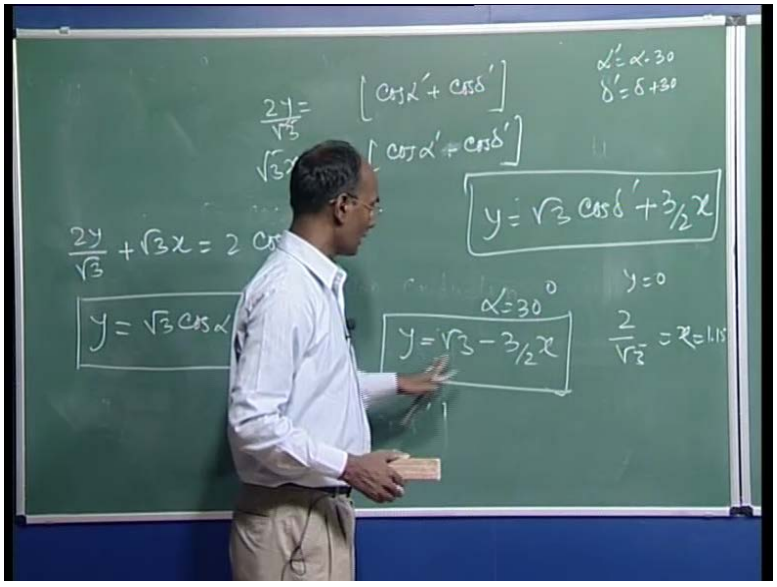

So, let us take alpha is equal to 30 degree, and this will be your unity because, this alpha prime is alpha minus 30 so, it is unity, we are getting the expression here y is equal to under root 3 minus 3 by 2 x. Now, to have this y is equal to 0, what will your value of x 2 by root 3 is equal to x, that is for y is equal to 0, this value is approximately 1.15, means earlier we were drawing here, I can say 0.5, here1, and now here it will be 1.15.

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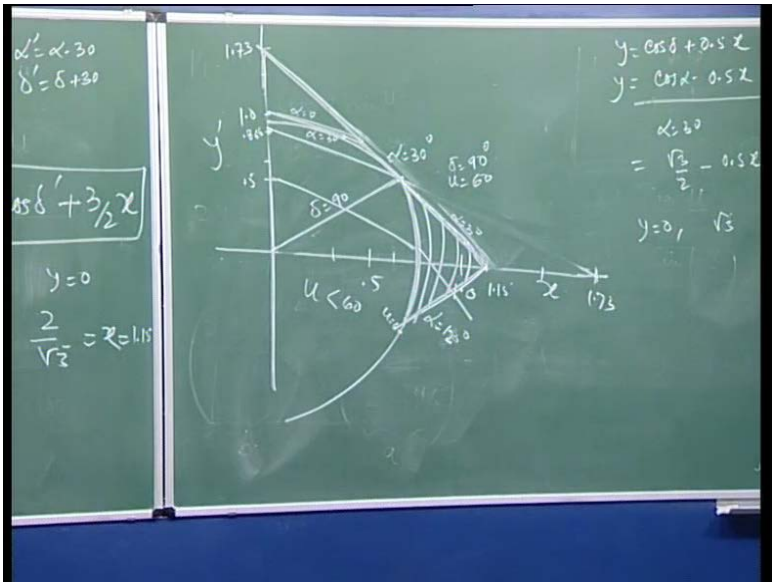

Now, if we are going to another side, when x is 0, we are getting root 3 and this is your 0.5, this is 1 and here it is 1.73 something. So, we are getting the expression, that is your alpha is equal to 30 degree corresponding to your u is greater than 60. Once, I am drawing again the expression here, that was your y cos alpha minus 0.5 x, I want to draw again alpha is equal to 30 because, that u is less than 30, this expression was valid when alpha is u is less than 60 degree, so alpha is equal to 30, let us see what we are getting this value is alpha 30 under root 3 by 2 minus 0.5 x

Now, once x is 0 here, we are getting the value 0.86 somewhere here and this is value for x is equal to 0 and once I want y is equal to 0 here so, it will be root 3 and this will be root 3 means somewhere here, 1.73 here, this is 1, it is 1.5 it is approximately correct. So, what is going to happen here, intersection point, means this expression is corresponding to your alpha 30 for more than this value.

Now, you will see what is the value here, at this point of intersection, this both characteristic are matching, when your u is 60 degree so, this point corresponds to u is

equal to 60 and here it was u is equal to 90 because u 60 means delta 90. So, it is no doubt this delta 90 u is equal to 60 and delta 90 was falling here, because we got the expression here y is equal to cos delta plus 0.5 x, so delta 90 is 0 means it will passing from the 0, and we also draw our characteristic, which was falling u here means, u is going there

So, if you remember here our u was falling on means, going from this u because u is 60 here, it will be again this side also and we were getting this characteristic, for u is equal to 60 degree means, here at this 0.1, we had our alpha is 0, this will be parallel, here this is alpha is equal to 0 because, alpha 0 then 30 and then we were to 60 degree here the parallel, now we also draw the u characteristic, so this point where alpha is getting this point, there is some characteristic which is going to be for u corresponding to this here 60 degree, means we are getting 3 zone one is corresponding to your alpha, then corresponding to your u and then corresponding to another characteristic outside. So, here the same characteristic which I explained here, this is a intercept we calculated and now your actual characteristic for any alpha is equal to 30 here, now it is not going here, this will be the dash line because, it is outside this 60 degree, so it will be this one.

So, all these values here will be basically 90 degree here and then it will be slope like this, alpha cannot be here in this case, you must know this alpha cannot be less than 30 degree, so this characteristic cannot go here, beyond this side similarly, we are having the below one also here, in this alpha is 150 degree. So, we are going to have the characteristic u is greater than this, within this zone only because, beyond this we already draw here characteristic for u is less than 60, for u is greater than 60, we are only confined to this zone only and that is very small portion here and in this one if we are shifting here there’s so many problem because, the voltage is reduced drastically, you have to operate in this lower voltage and current has increased the tremendously value. So, to draw this again for the given u, let us see this characteristic.

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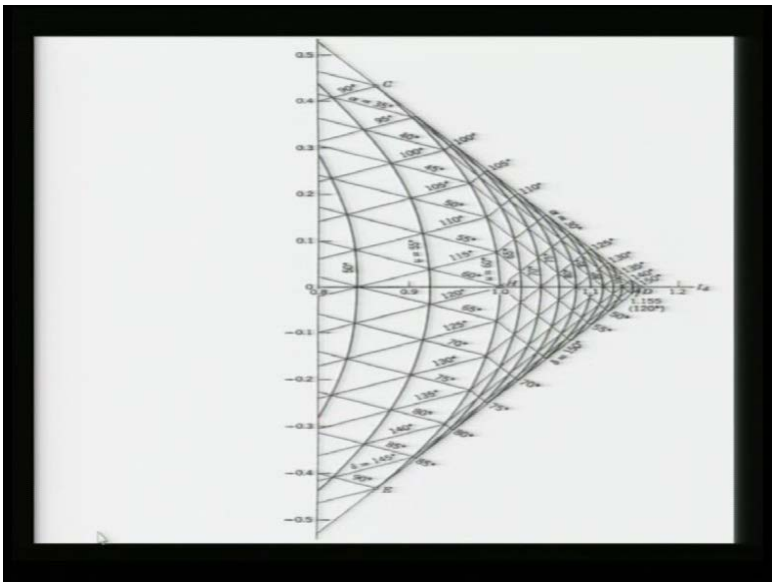

In this characteristic here up to 1, is u is equal to 60 degree means, what I did here the axis is shifted slightly, here you can see u is 55 50 degree and so on means, we are having this side, so this is reduced and now 1 to 0.5 here it is drawn this side. So, you see here the characteristics, almost similar again only the b value and a value is going to change, to have this a and b value we can again derive from here, from these two equation we can see what will be the b and what will be a in that zone. So, this value of alpha is equal to 30 and this alpha is equal to 150 its one 120, this value cannot be one more than 120 degree, so in this we have to draw again u corresponding to the different value. To know this again, let us draw what will be the a and b in this case. Similar to this we can use the trigonometric identity, similar to the previous case.

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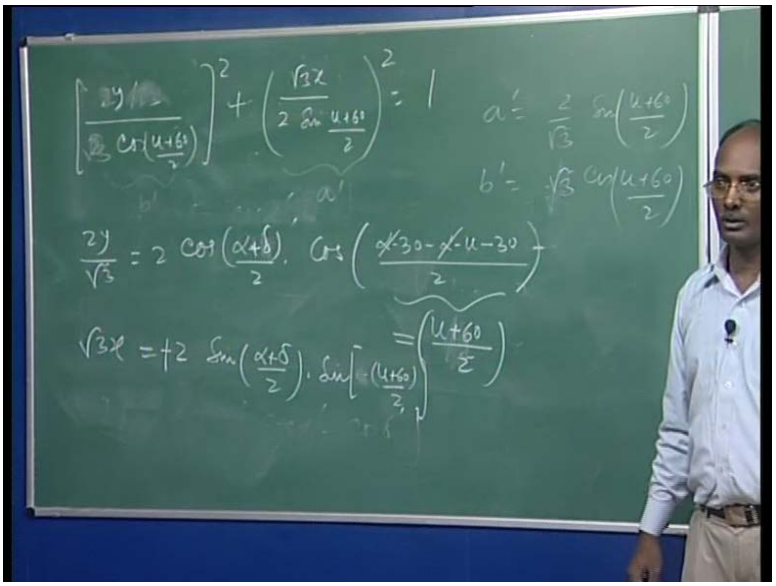

So, we can write here 2 y over under root 3 here twice of your cos here alpha prime plus delta prime, it is your alpha plus delta u because, if your adding, this is cancelled you are getting alpha plus delta by 2 into cos this minus, this so we are having here by 2 of course, so here alpha minus 30, minus alpha minus u, minus 30 degree by 2 because, this is your alpha plus u is delta and plus here because, minus was outside so, everything is negative and this value is cancelled out and here the minus sign cos minus theta is a cos theta so, we are going to get this value is u plus 60 by 2 because, this is u is there and this minus 30 and minus 30 is 60 and u plus 60 by 2 we are getting here.

Now, for this one we can write under root 3 x is equal to, now I can write this is a minus sign, so I can write minus twice sin, alpha plus delta by 2 into sin alpha minus delta we are having the same here and this is your minus u plus 60 by 2, this minus will be cancelled with this minus, so we can simplify this and we can write, here you can see again this value is independent of alpha delta, so we can keep this value here, we can divide this or we can square and add we are getting unity, so we are getting here 2 y by under root 3, here we are getting twice cos u plus 60 by 2 square, plus under root 3 x by twice, sign u plus 60 by 2 and square it, you are going to get unity here again.

Now, you can see what we are getting, in this case I can say this is b prime, this is your a prime so, a prime now is twice under root 3 sin u plus 60 degree by 2 and b prime, two and two is cancelled is under root 3 cos u plus 60 by 2 because, this two and two is

cancelled and I can write here under root 3, this is your b. So, we are having no doubt the different value of a prime and b prime this axis but the equation here also we are getting the same, as the previous one, only this values are changing but it is for the constant u and here you can see u is greater than 60 degree so, when you are putting the 61, 62 you are going to have the different value and they are going to intersect somewhere and these are the characteristic we can find here.

So, basically it is nothing but it is just related to your the DC quantities so, from here you can see, the two modes one is most of the a region are the wider region, where we are operating 2,3 and once u is decreasing your operation mode is going to be reduced in very significant, very less and here you are operating this volt is reduced, current is increased and again the more dense lines are there so, this is all about your DC quantities, that is chart corresponding to the DC constant value of alpha, constant value of u, constant value of p d, we already draw means it will be nothing but it will be changing for the different value of p, we can draw it in the inverter as well as rectifier operation.

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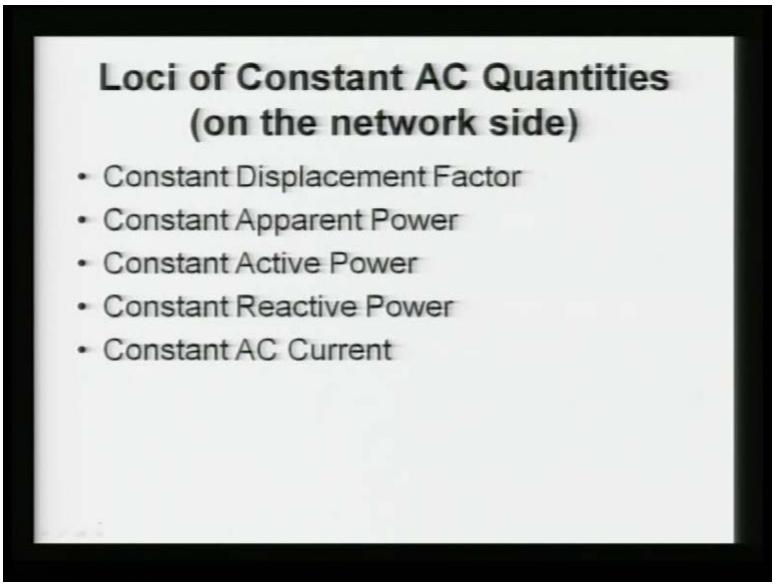

Now, another side is that we can go for the network side and so many variables, that we have to draw for this, first is the displacement power factor basically displacement factor it is called there is a some difference between the power factor and the displacement power factor. The power factor is basically related with this the fundamental current

component of current corresponding to the cosine of the angle difference between the fundamental of the voltage and the fundamental of current cosine of this so, that is called the power factor.

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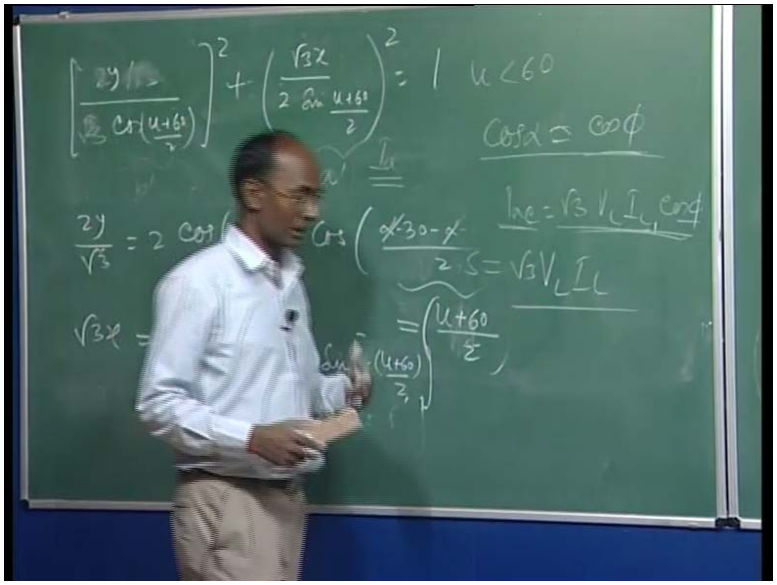

The displacement factor is basically the RMS value of whatever this current means, power whenever you are calculating in this mode when u was less than 60, we defined the cos alpha was equal to your cos phi so, this phi was nothing but it was the power factor means if you are writing p AC it is under root 3 V L I of cos phi this I L, it is the total RMS current, it is not the fundamental if you are writing here the fundamental, then this power factor will be the displacement to write complete, it is total r m s value means including all the harmonics as well but in the power factor, it will be the fundamental component of current and then corresponding to this it will be that, so because we derived this expression and that time we were using this one, its then ideal condition we define this, when u is 0 we are going to get this, otherwise we will get by two and we will derive this expression for the different value of u as well.

Here, we are also going to derive this apparent power, apparent power is your s that is corresponding your real and reactive power. We are also going to see the active and the reactive powers and based on that, if active power is know then reactive power will be calculated from the apparent power, apparent power is again nothing but your v line under root 3 here, I line already, we have derived, what will be the r m s value of the

current, in this your AC side, what is the line to line voltage because, this is directly related with the DC output voltage and then here it is your s, we know this p AC power as well the displacement power factor is defined. So, we have to draw this characteristic and then we also draw the constant current, that is I a and this I a we are again talking about the r m s current, we can have even the different fundamental components also but we can also draw for here r m s current as well.

So, this characteristics, we will see on the AC side and I will explain again, how these governing equations are derived for all these things and then the axis will be not change, axis will be again the voltage axis and the current x axis and we will find the different for the constant value of all these 5 parameters. So, in this lecture basically we derived the chart corresponding to the DC variables, that is alpha, delta, u both u is equal to 60 degree and u is less than 60 degree and u is greater than 60 degree.