DC Power Transmission Systems

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Lecture – 56
Converter control characteristics

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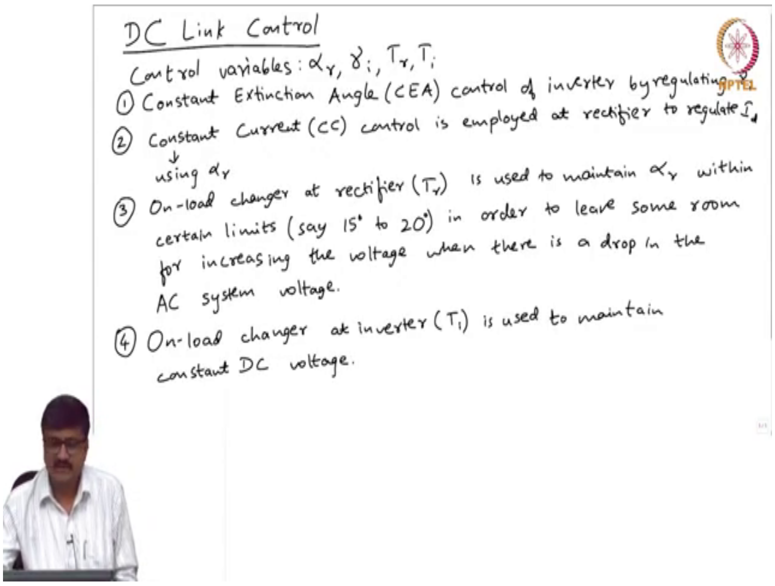

So, we are discussing the DC link control. There are four control variables, the delay angle alpha for the rectifier alpha r, the extinction angle gamma for the inverter gamma i. So, for normal operation, gamma i is also the commutation margin angle. Then the onload taps that are present on the transformer on the rectifier side as well as the inverter side, T r and T i.

So, what we try to do is, we try to regulate one of the quantities using these control variables. So, we do what is known as constant extinction angle control, constant extinction angle CEA control of inverter by regulating gamma i. So, gamma i is kept constant. So, that it does not go below that valve.

So, the intention is to see that we have a minimum commutation margin angle for the inverter. See for the rectifier the commutation is not an issue ok. Then we use the constant current control, what is known as we are try to regulate current. So, in the last class we saw that there can be fluctuations of the current. So, which can damage the V component that is the valves.

So, what we do here is employ constant current control which is abbreviated as CC control is employed at regulator sorry, in employed at rectifier, is employed at rectifier. Now when I say constant current, we are trying to regulate some current the current is the DCI current to regulate I d.

So, what is used here? Alpha r ok. So, this is using alpha r. So, that means, we change alpha r in order to control I d to the required value ok. So, if for some external disturbances I d changes if I d is tries to change we change alpha r in order to bring back I d to the desired valve.

Then we also use the two slow controls T r and T p. So, T r is the tap onload tap ratio actually, off nominal tap ratio of the rectifier side say, off nominal tap ratio means something which has a nominal value 1, T r nominally is 1. So, it I mean in practice it is close to 1 greater than 1 or less than 1.

So, onload tap changer at rectifier. So, this is T r is used to maintain alpha r, see alpha r is maintained within certain limits. So, though we say that having alpha r close to 0 or 0 in fact, we will have some advantages of improving the power factor reducing the dv by dt stress. But we want to maintain some a margin for control whenever there is low voltage on the AC system.

So, if there is a low voltage in the AC system then we can use alpha r to see that the DC voltage is regulated ok. So, that is why we maintain alpha r not at 0, but within certain limits close to 0 of course, within a certain limits. So, this limits for example, say 15 degrees to 20 degrees. So, this is done in order to leave some margin for increasing the voltage.

So, leave some room for increasing the voltage. When? So, when this necessity comes for increasing the voltage when the AC system voltage for some reason comes down. Actually, I say during over load conditions suddenly a large load is there on the AC system say on the rectifier side then the AC voltage comes down means the DC voltage will also come down. But by using this margin for alpha r we can actually increase the voltage.

So, increasing the voltage when there is a drop in the AC system voltage. There is one more control variable that is T i. So, now, how do you use T i? How do you use T i? Ok. There is an onload tap changer at inverter. So, all of these are used to regulate one particular quantity to a desired value or within a certain range.

See for example, this T r is used to maintain alpha r within a certain range. Similarly, constant current control means there is no range the range is of 0 width. I d is you I mean I d is regulated at a certain value see whenever when you talk about control, most of the times you are talking about the type of control that we come across in power systems is either maintaining some quantity at a particular value at a desired value or maintaining it within a desired band that is all we want. We do not need any other type of control.

So, if I want to maintain I d at a certain value, I mean it is as good as saying that the band is of 0 width. In the, as far as the alpha r is concerned I mean it is not of 0 width no it is nonzero width say if I have given a example 15 degrees to 20 degrees. Similarly, constant extinction angle means 0 width I mean; we are maintain the extinction angle at a particular value ok. Now, the onload tap changer at inverter; that means, the variable is T i is used for what?

Student: Voltage, voltage constant.

Yeah. It is used to maintain the DC side voltage constant, is used to maintain constant DC voltage ok. So, this is how the four control variables are used.

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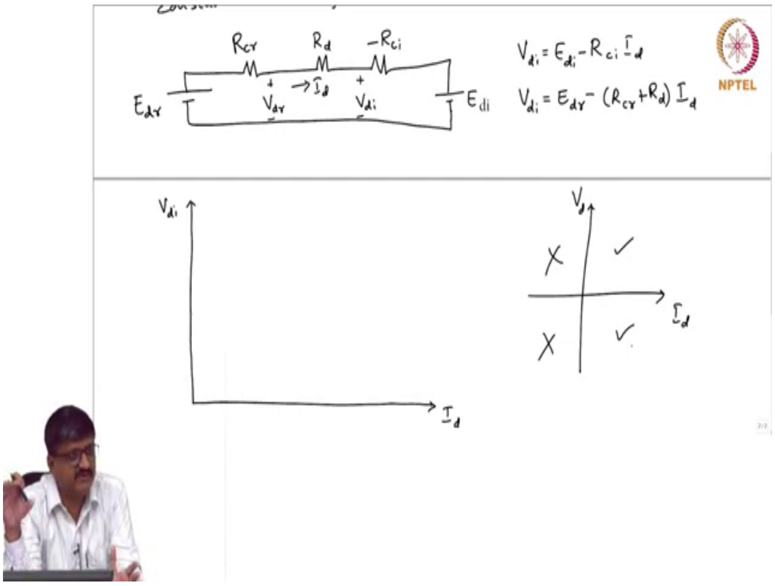

Now, let me just redraw the circuit that is applicable for the DC link. So, we derived this circuit see this just an equivalent circuit which represents the equations governing the system. So, I have the voltage E dr here, E di, R cr minus R ci, R d. R d is the physical resistance of the transmission line and the voltages which are actually present in a physical system are V dr and V di. And, I d is also a physical current that flows in the DC transmission, but R cr, R ci, E dr, E di are just representations ok.

Now, if I look at the circuit if I look at the inverter terminal voltage the DC side voltage V di, this can be written as E di minus R ci into I d. Similarly, I can also write V di in terms of E dr, R cr and R d. So, V di is also equal to E dr minus R cr plus R d into I d right. Now, let me try to take the graph of V di as a function of I d. Correctly draw this, V di as the function of I d.

So, should I consider all the four quadrant is the first question. Should I consider all four quadrants? Is operation say I just take V di and I d is operation possible in all the four quadrants yeah.

Student: (Refer Time: 10:34).

Then, then what?

Student: V di is always positive.

V di is always positive, I d. See the point is once I decide one converter as rectifier and one converter as inverter then say if you go back earlier we consider this graph V d I d if you recall. I d is always positive so; that means, operation is possible in the first and fourth quadrant because V d can be positive or negative depending on the converter access a rectifier or inverter whereas, this second quadrant and third quadrant so are not allowed.

Now, first and fourth are allowed because it is a same converter can operate both as rectifier and inverter, now I have two convertors now in the system; one is fixed to be rectifier another fix to be inverter. So, there is no change of role ok. So, if that is the case then the same converter operating as both rectifier inverter is rolled out. So that means, either I have first converter operation quadrant operation or second quadrant operation.

So, I have actually put the positive and negative sign in such a way that V di is positive.

Student: Positive.

So, always positive. So, only first quadrant is allowed. So, let me erase this. So, only first quadrant is allowed ok. Now if I take one of the controls see one of the controls is constant current control. So, far constant current control what will be the characteristic steady state characteristic.

Let us look at only the steady state characteristic. We are not worried about the transients. So, in this course we will not look at the transients that are involved. So, suppose I employ some controller to regulate the DC side current. So, that is constant current control. See just now I have mentioned constant current control is employed at the rectifier side to regulate I d which is done using alpha r. So, what will be the characteristics in steady state in this graph?

Student: Straight line.

Straight line, what is the slope?

Student: (Refer Time: 12:48) Negative slope and positive intersection

Positive intersection negative slope that will that give constant current. What is current, this what is this current? This current is I d. So, I d is constant means?

Student: Both the x coordinates are (Refer Time: 13:04).

Vertical line, that is all, I have just a vertical line. So, I have some vertical line here. What I will do is I will try to use a different.

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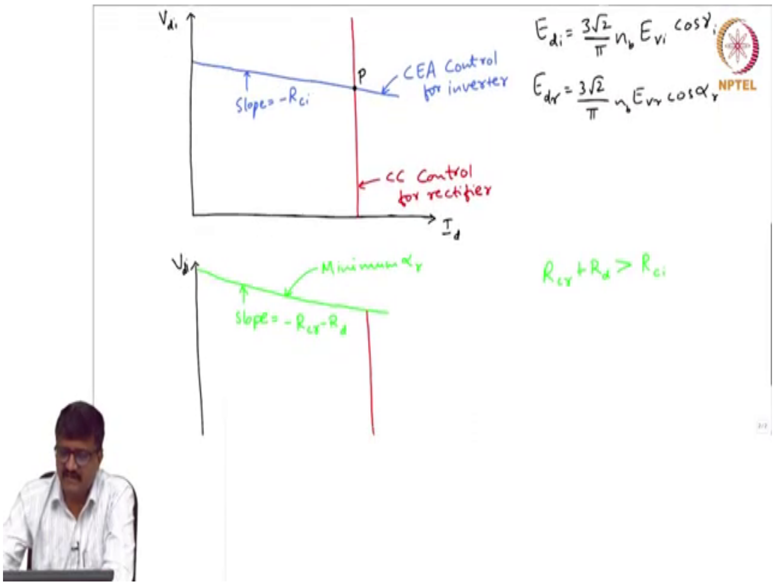

So, it is just a vertical line. So, this is a CC control this is cc control to be more precise I employ control at rectifier for rectifier. Now what do we do at the inverter? What type of control do we employee? See, if I just look at the first control that is the control of alpha r and gamma i. So, gamma i is actually.

Student: Constant extinction angle.

Constant, constant extinction angle. So, gamma r gamma i is constant. So, if gamma is constant then, what will be the steady state characteristics? In this graph; so, in this graph V di is plotted as a function of I d. So, what will be the constant extinction angle characteristic in steady state? ok. what is yes.

Student: Straight line.

Straight lane, slope.

Student: Negative r like.

What is the slop?

Student: Minus R ci.

Minus R ci ok. what is the I mean where does it intersect to the.

Student: V di.

V di axis.

Student: V di (Refer Time: 14:58).

Yeah. So, will just look at this equation. V di is equal to E di minus R ci I d. Now is R ci constant? R ci is constant for a given tap ok. Now what about E di.

Student: It independent gamma, but they are fixed.

Yeah. We are in fixing gamma it depends on gamma see if all things are look at the expression for E di. So, i mean i presume we have all we all have the expression for E di. What is E di? E di is if you recall we got the expression for E di as 3 root 2 by pi into n b 3 root 2 by pi n b is a constant number of bridges E vi. So, E vi is the rms value of the bus on the AC side of the inverter into cos gamma i.

So, if E vi is assumed to be constant then, by constant extinction angle gamma is constant so, E di is a constant. So, if E di is a constant then the plot of E di as a function of I d is a straight line with a negative slope. So, if I plot so, this has a negative slope and it intersects the V di access at E di.

So, this is CEA control for inverter. So that means, the point of operation is the intersection of these two characteristics. So, these two are steady state characteristics. So, at this point p the system operates. So, the value of V di and I d Vare obtained from the intersection of these two straight lines. Is that clear? So, we employ CEA control for inverter and CC controlled for rectifier means these two controllers will give to two characteristics in steady state which are both straight lines; one is a vertical line other one is a line with a negative slope.

So, the intersection of these two points is the point of intersection which gives the point of operation. So, the value of V di and I d are obtained as the values at this point of intersection of these two straight lines ok. Now there are some problems I mean; say as long as everything is normal it is ok, but sometimes what happens is if I try to again take the same graph, V di as the function of I d.

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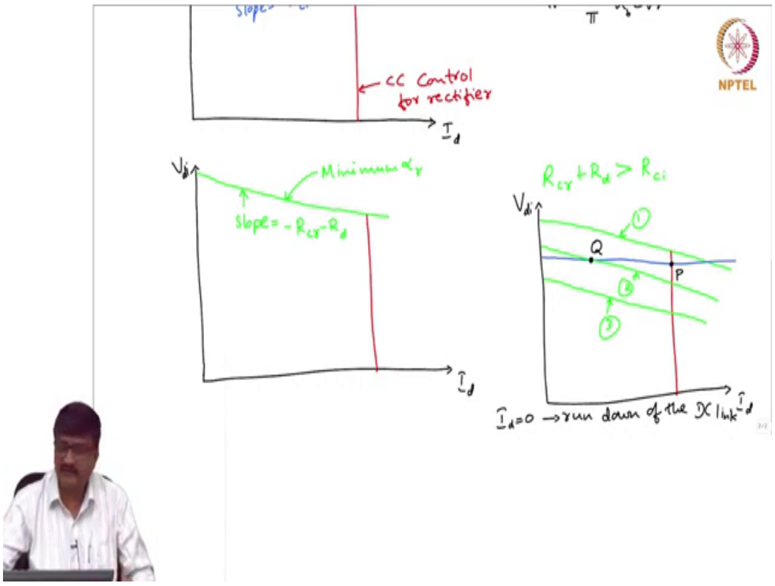

Now, if I take this constant current the least value of V di along this red line is 0. And what is the highest value? Can it go infinitely?

Student: No (Refer Time: 18:55).

Yeah. What is the maximum possible value of V di along this straight line?

Student: (Refer Time: 18:59).

Student : (Refer Time: 19:03).

No where does it stop?

Student: (Refer Time: 19:07) p

Now, suppose I just consider only the CC control characteristic for rectifier, I will come to the inverter later. So, can I say I am just taking one curve at a time now. So, earlier I said these are all infinite straight lines at least on one side. So, the other restriction is that it is lying in the restricted to the first quadrant, but I have not shown the other end of the straight line where it will stop.

See at least this vertical line it appears as if say the other one has a negative slope it may at some at some point cut actually intersect the I d axis and then we can say it stops there. But as far as CC control is concerned when I say it should lie in first quadrant it appears as if that the other point is that infinity. But in practice, what is the what is the I mean; what decides the other end of this vertical line.

Student: High voltage.

Student: High voltage average.

Yeah. Suppose the supply voltage is constant, the AC side voltage is constant for the time being and we just control we just consider the fast controls ok. So, forget about the slow controls assume them to be constants and the even the other voltages to be constant, the AC side voltages are constant, tap ratios are constant, the off nominal tap ratios. Then, how do we get the other end? Is there a limit first of all for the value of V di along this line. yeah What is that? How do you get that limit?

Student: Alpha r is equal to 0.

Alpha r is equal to 0, yeah see as you go up and up along this as you move vertically upwards alpha r actually is decreasing. See constant alpha characteristics we know right for a converter. They are all straight lines with negative slope. So, as you keep on increasing alpha you get the straight lines which are below the values which are for lower value of alpha. So that means, as you move along this line alpha r is actually decreasing. Alpha has a lower limit to ensure adequate voltage across the valve to turn on.

Now, the question is, if alpha is fixed at the minimum value; what is the variation of V di as a function of I d? See I think, you have forgotten this constant. See there are three types of characteristics that we studied right. Constant alpha characteristic, constant gamma characteristic, constant u characteristic. They are only three types of characters that we studied. Now, in this case we should not even bother about u greater than 60 that is abnormal operation. We are looking at only normal operation u is less than 60.

So, we have already studied all these types of characteristics. So, we know how the curves of V d as a function of I d will be for all these things you know. So, if i say minimum alpha it is constant alpha, minimum alpha means constant alpha. So, constant alpha, what is the characteristic?

Student: Straight line.

Straight line with a.

Student: Negative slope.

Negative slope. So, it is a straight line with a negative slope, what is the slope?

Student: Minus 1.

Minus.

Student: 1.

No, you are talking about per unit, is it? You are talking about per unit, here I have not actually normalized I am taking the quantities as it is.

Student : Sir.

Yes.

Student: R cr.

R cr plus R d, look at this equation. See, go back to this equation ok. It is R cr plus R d. Now, first of all is E dr constant, what is E dr?

Student: E dr is 3 root 2 (Refer Time: 23:10).

So, E dr is 3 root 2 yeah instead of gamma we will have alpha r that is all. So, 3 root 2 by pi n b.

Student: E vr.

Evr cos alpha r. So, when I say alpha is minimum; that means, it is a constant. So, if alpha r is constant at the minimum value then E dr is a constant provided evr is constant. So, we will assume that E vr is constant. So, E dr is a constant.

So, if E dr is constant then the variation of V di with respect to I d follows a straight line. But, what will be the slope? The slope is R cr plus rd. So, is the slope greater than the CEA characteristics slope or less than that. See the previous CEA characteristic, what was the slope ok. Let me go back to this curve what is the slope of this? Slope is minus.

Student: R ci.

R ci. Now for this case, in the case of a minimum alpha r, the slope is equal to minus R cr minus R d ok. If I look just look at the magnitude of the slope, which one is larger? Now please note R cr and R ci are almost same. The only difference is because of taps that is all. Because of taps, the leakage reactance depends on the tap position. So, that is a very small variation.

So, due to tap change tap changer we have different values of R cr and rci, but they are close. So, R d is much larger than the difference between R cr and R ci. So, that that is why the slope of the minimum alpha r characteristics is larger in magnitude compared to the slope of the CEA characteristic for the inverter. See what I am trying to say is R cr plus R d is greater than R ci. Because, R cr and R ci are close and R d rd is much larger than the difference between these two ok.

Now, what is the implication? See, if just look at these two graphs. So, in the first graph point P was the point of intersection of CEA characteristic or CEA control characteristic are for inverter and CC controlled characteristic for rectifier. Now due to reduction in the rectifier side AC rectifier AC side voltage then, what can happen is alpha can keep on decreasing, alpha can keep on decreasing. But at some point it can what I will do is, I will try to draw a graph where both CEA characteristic is there and minimum alpha r characteristic is there ok.

So, let me draw one more graph. So, I have V di, I have I d, I have minimum far. Now there is a CEA control also. So, CEA control has a slope which is less than the minimum alpha r control ok. So, please note, I will be using some fixed colors for the controls. Red means; CC control for rectifier, blue means; CA control for inverter, green means; minimum alpha r. I have marked all these things. Red for CC control, blue for CEA control and green is minimum alpha r.

Now, if P is the point of operation. Now suppose, the AC system voltage on the rectifier side actually decreases. Now what happens to minimum alpha r? See alpha r is alpha r is constant, but the AC system voltage and rectifier side decreases, what happens?

Student: Goes up.

So, the curve actually moves.

Student: Up alpha r decreases (Refer Time: 28:03).

Alpha r is constant. Alpha r is constant, the AC system voltage decreases, the DC voltage also decreases V di is DC voltage.

Student: Yes.

So, alpha r is constant ok. So, this minimum alpha r also decreases. Now it can go to a situation where the minimum alpha r can go down like this. Now if minimum alpha r goes down like this what is the point of with what point the system is operating. See earlier with this minimum alpha r the this one the first one the first minimum alpha r the point of operation was.

Student: P.

P, it was this first minimum alpha r is not even deciding the point of operation. The point of operation is decided by the CC control of rectifier and CEA control of inverter. Now when it comes to a situation where I have a reduced voltage on the AC system of the rectifier side, then the minimum alpha r is actually gone down. Now, what is the point of operation of the system? Intersection of course, obviously; it is intersection of two line segments which are those two let me.

Student: Green, red and green.

Red and green. See what is this green? This green is for the, see when you say red and green the point of intersection of red and green ci is not maintained ci is avoided. See if I want to maintain constant extinction angle I have how to be on the blue line.

Student: Blue line.

Constant extinction angle means; I have to be on the blue line that I cannot violate. So, intersection of the new green 2, green curve 2 and red line means; I am moving away from the blue line which is constant extinction angle.

Student: (Refer Time: 30:03).

It should be.

Student: Green and blue.

Green and blue. The green is the new control at the rectifier now. And blue is of course, the still existing it is constant extinction angle at the inverter. So, the new control is this. So, new control is the second green line and the point of intersection of the second green and blue is gives the point of operation. Now this is also slightly ok, but the problem is now the current is no longer regulated, current is not regulated.

So, see either you have to avoid regulating current or avoid regulating constant extinction angle. But what we normally do is, you maintain constant extinction angle. Suppose, this happens; now if this condition versions; that means, the voltage goes further down then the minimum alpha r characteristic will be.

Student: Below.

Even below. Suppose it can go to a it goes to a situation where this blue and green also does not intersect ok. so, ok. So, let me. so, this is 2, suppose this is 3, then there is no intersection.

Now what is happening? Say from 1 to 2, If I look at the original condition P and then the new case the new case is operating at say Q. Some P to Q itself there is a reduction in the current. Now when the condition versions to 3, then I d would have become.

Student: Sir negative actually.

0.

Student: But it cannot be a negative.

Id cannot be negative.

Student: Yes.

I d is 0. So, even before this green curve 3, there is a slightly I mean; a curve which is slightly above which intersects the blue curve just on the V di axis at that point itself I d would have become 0. So, when I d becomes 0 we say that there is a rundown of the DC link. So, when I say I d equal to 0 means; the term used is run down of the DC link ok. Now this has to be avoided say rundown of the DC link means no power transfer I d is 0 means no power transfer.

So, to avoid this, what do we do is; we provide what is known as constant current control even at the inverter.

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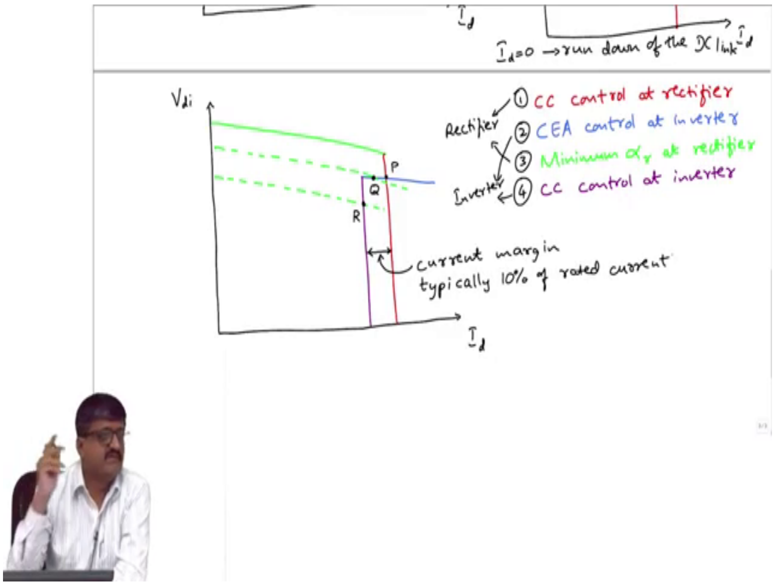

So, let me try to redraw. V di as a function of I d ok. So, I have shown one red line constant current control at rectifier, one green line minimum alpha r that is also rectifier, then CEA control. So, CEA control is the blue line for the inverter. Now what we normally do is; if the situation of rundown can occur then to avoid that we provide a constant current control even at the rectifier sorry, even at the inverter. So, then so, please note the red one is CC at rectifier, CC control at rectifier.

Then the blue one is actually CEA control at inverter, then the green one is actually minimum alpha r; obviously, at rectifier. Because, alpha r means; alpha the subscript r stands for rectifier. Now there is one more purple. So, this one is actually, CC control at inverter. Now what happens say we see that there are four line segments, there are four line segments.

So, 1, 2, 3, 4. Now among these four; 1 and 3 are for rectifier whereas, 2 and 4 are for inverter ok. Now, when the system is operating normally then the intersection is actually that of the blue line and the red line that gives the point of operation. Now, there can be a problem of reduced voltage on the AC system of the rectifier side then the green curve can actually shift down. So, I will the shifted green curve I will just show it as a dashed curve.

So, this so, I have shown as if the intersection of the new green and blue is possible. Now you see that the current has reduced, I d has reduced. See earlier the point of operation was the intersection of blue and red. Now, it is an new green and blue. Now if there is a further deterioration then the green one will not intersects the blue curve it will intersects the purple curve.

So, I have shown three points ok. Let me try to exaggerate the this figure at slightly unclear I am just trying to exaggerate. So, that there is clarity in the figure. So, the earlier point was P, the revised point is Q. If there is further deterioration in the DC and the AC side voltage of the rectifier then the point of operation is this r.

So, if you look at the point of operation; originally, it was the cc characteristic of rectifier and the CEA characteristic of inverter that is normal operation. Of course, you due to some reason the voltage and rectifier comes down then it is no longer the CC characteristic of rectifier coming into picture here. So, if you look at the green the revised green and blue intersection CC is not playing a role here.

So, it is a minimum alpha r characteristic of rectifier and the ca CEA characteristic of the inverter. Then if there is further reduction in the voltage the green curve is further reduce, I mean; further going down, then r is the point of operation which is the point of intersection of minimum alpha r and constant current of inverter. So, if you employ this additional constant current control at the inverter then we see that the current I d will not become 0 ok.

So, if you compare this with the previous graph that purple curve was not here. So, the purple curve is additionally introduced. So, in the previous case there was no purple curve. So, without the purple curve, I d will become 0, there is rundown of the DC link. So, we employee this current constant current control at the inverter also. So, that the current will not go to 0.

So, there is a small difference between the constant current employed at the rectifier and the constant current employed at the inverter. The current which is a desired I mean the desired value of current at the inverter is less than the desired value of current at the rectifier. So, the difference is called current margin. So, this current margin is typically 10 percent of rated current.