High Voltage DC Transmission

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Module No. # 03

Lecture No. # 02

Let us start lecture number 2 of this module 3. Today, I will discuss about the HVDC link control characteristic both rectifier side as well as inverter side.

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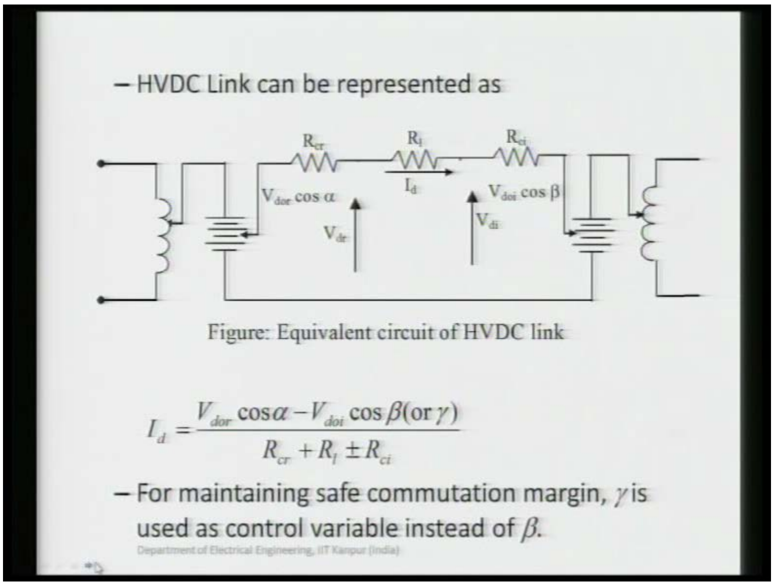

In the previous lecture, we saw this equivalent electrical circuit of HVDC link. Where we have your rectifier end, and where we already derive the variable voltage, that is V dor COS alpha and this is a commutation resistance, and this is your inverter side, and this R l is your DC line resistance and I d here, that is a control here, and that is derived by this equation. Also, I certain that it is prefer to go for the gamma control rather than beta control due to this negative resistance here, because sometimes operating the negative resistance your control characteristic may not be stable, and that is why we go for the here gamma.

Another reason for this gamma control that if you are calculating the beta, there is a possibility, if there is a voltage dip of this side, what will happen the commutation u angle will increase, and there is a commutation failure. So, one people suggest that why not we can go have a enough beta, so that even though that can be taken care, but if you are taking more beta, your power factor will be worsen, that will be poor. So, it is always better to have a gamma control here, and this gamma is maintained certain degree, that is a minimum degree normally it is 10 degree. And then we calculate the beta, we will see how beta is calculated, and then we operate in the constant extinction angle control.

So, here, in this circuitry if there is two possibilities here, if, there is no voltage change in either side for a given set of power control here, your Id is fix voltage is fix thus control link will operate without any change means whatever; the power you want to control here, the Id is decided accordingly; if, voltage here, fix here this is alpha and beta is fix if, there is no change here the voltage in AC side constant power will be flowing and alpha is constant here. Gamma is also constant, but we know our system voltage is keep on changing and due to this changes here, the voltage here the firing angle alpha as well as here, gamma should be controlled, so that we can operate the constant current in the DC link.

Already we discussed why we are going for the constant current controller rather than power control again are explain later on why we are not going for the power control, why we are going for the current control. To see, the impact of the voltage variation on both end rectifier end or inverter end here, the voltage may increase voltage may decrease and normally, the voltage increase is not very high; because these were the very extra high voltage buses normally, the voltage is not more than 5 percent, but the decrease may be anything due to the fault etc.

So, we will see let suppose even though already, we discuss about the voltage increase on the rectifier side on the previous turn now, here, I want to discuss if, the voltage is increasing at the inverter end then what will happen from the equation that is a current equation we will see, the voltage increasing means your V do I is increasing and therefore, your current in the link will decrease means, I use this expression all the time.

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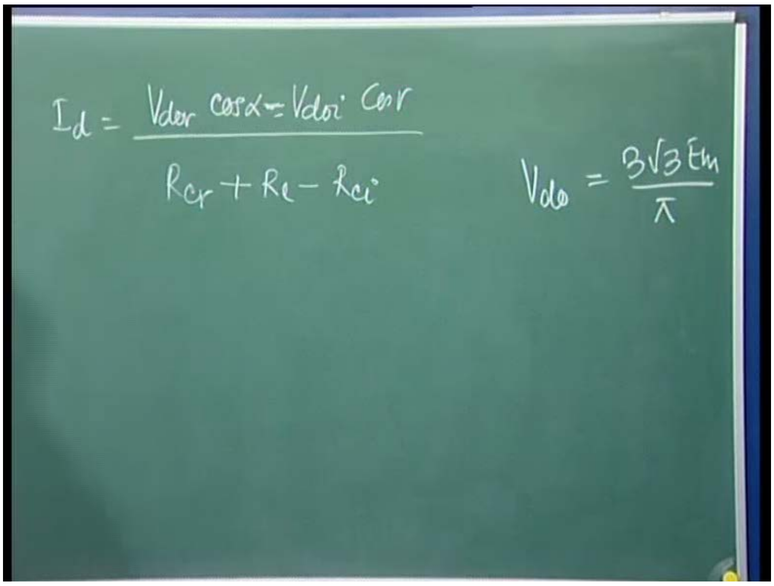

And here, I can say this is your Id was defined as your V dor COS alpha minus your V doi COS gamma. Here, your R c r plus R l, that is a commutation resistance of rectifier circuit plus here, your R l is the DC link resistance and here, minus it was your R c i.

So, you can see if this is increasing here, it is minus. So, here if this voltage is increasing means this is nothing, but this your V do. I am not writing R i here, it is we know it is under root 3V3 E m by pi. So, E m is basically, the phase voltage that is peak if it is changing. Now, you can see the current, this is increasing current is decreasing due to this increase here, what will happen this side? This controller will try to, what it will do it will also this cosine here, should also increase because here, we still we are not operating this one because this is slow control. So, it will try to increase means, your alpha will be going minimum side and it will be still, where alpha is reached at minimum degree, may be five degree even though this controller here. The current is not maintained to it is rated value then, we have to exercise either, this end tap changer or this end tap changer.

So, it is prefer to control the tap changer this side, because voltage has increased that side. So, it will wait there some time delay and it will try to decrease the tapping, that we can maintain this one, even though it is not fulfil. Then, we have to go here, to maintain the current, here in this your link. So, we have to operate our oil DC once. We have exercise all this firing that is, the valve control. The valve control means, either inverter side or rectifier side this alpha and gamma. We have to exercise first then, we have to go for these rectifier and inverter and oil DC transformer.

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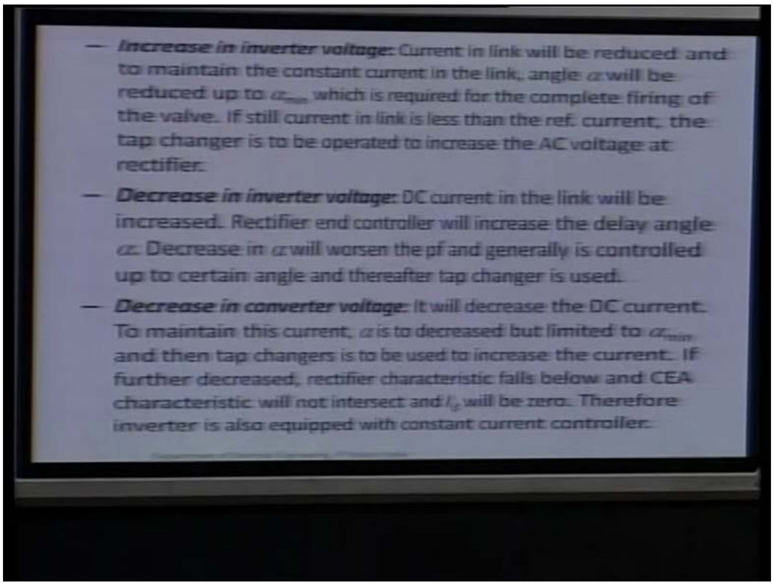

The scenario becomes very worst, when here this there is a decrease in this voltage. Once there is here, sudden decrease, what will happen this? You can say this current is going to be very excessive and due to this, what we have to do this? We are not touching here. So, this value should also decrease. So, that we can maintain here and decreasing this means, your alpha is going to increase and alpha once increasing because we have the limited reactive power support at that end.

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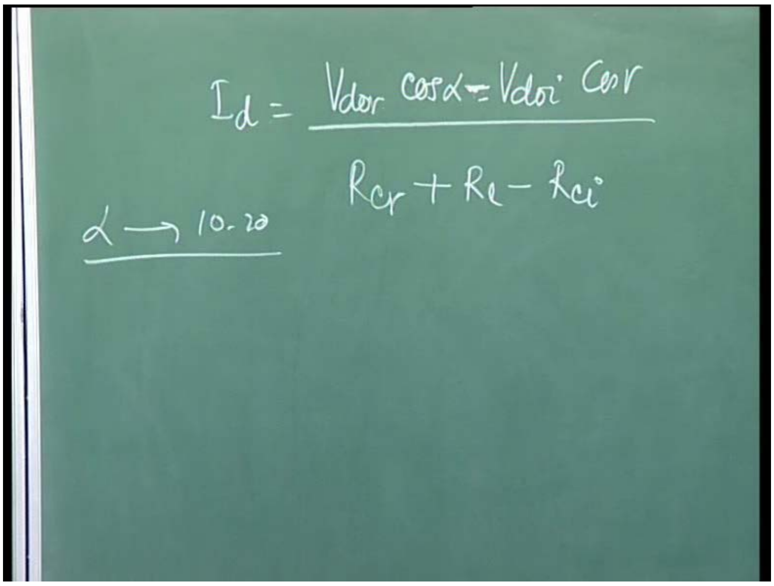

So, this angle is also restricted to sometime 10 to 20 degree and still it is not possible. Let suppose, the current is not maintained, because this voltage can go even the point one percent 20 percent. The huge short circuit is there so and this may not even the sufficient then, we have to utilize our, this oil DC transformer to make the current above. So, it is a tap changer is used. Now, another here, if your rectifier side voltage, this voltage is decreased. So, what will happen here, we have to increase and this increase again, alpha minimum will be hitting limit.

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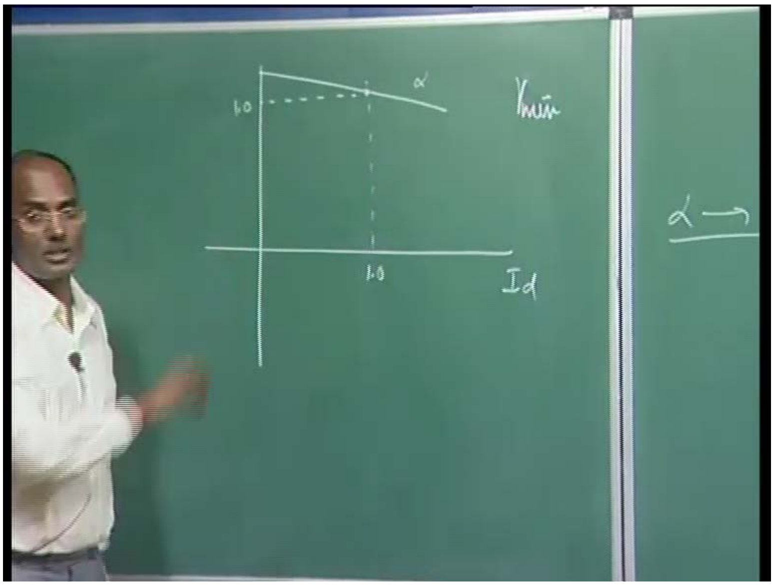

So, overall I can say here, what we are doing it? You are drawing here for given Id here or I d is 1 per unit. Let suppose, I want to operate then, we found that is we are having this characteristic here. The constant alpha curve, if you remember our, we draw the chart this characteristic is here. Let suppose so, this is basically your operating voltage, where your operating this voltage is normally, one per unit. Now, you can say if here, this current is 0 or the voltage is high. We can do it, we can just your tapings and transformer transaction in a such a way that, we can maintain here, because we want our rated voltage should be, one per unit and the current should be one per unit in the DC link. So, that we can have 1 per unit power, now whether we are decreasing or increasing, we want this one it depend upon the voltage rather than current. So, this side we are having this is your alpha control and here, we will see this side. We have no control of this, because we are trying to operate this gamma as a minimum.

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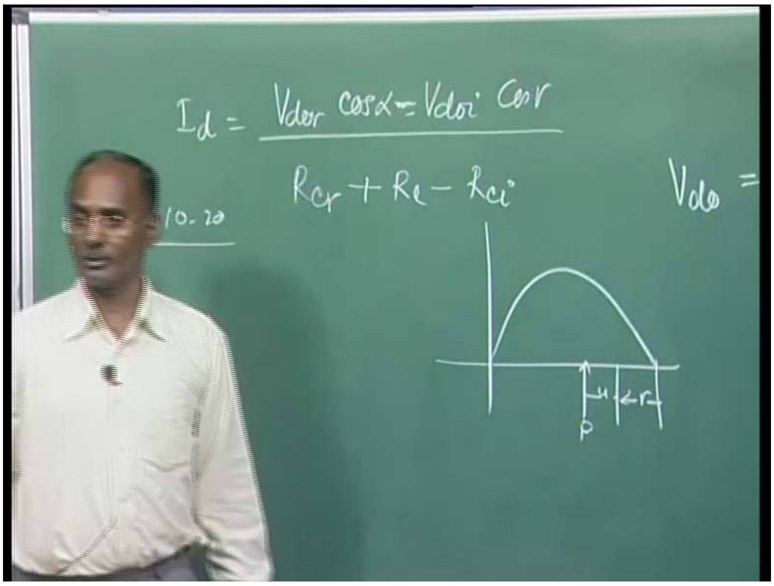

We can even though; this value can be for example, this is what is your gamma? This gamma in this here; from your beta here; this is your fire; this is your u and this is your gamma; you can go up to only minimum here, the gamma value that is your commutation should be successful. So, you can increase the gamma here, but if you are increasing gamma it means, your firing angle is also shifted here and the power factor is deterioting. So, this is maintained the minimum. So, it is possible, that we can go for the gamma here more, but it should be also having certain limited gamma minimum; that is a gamma minimum should be there.

So, if we will drop this characteristic; The characteristic for here, we should know what is the V d? If remember our V d, when I was drawing here, this V d is individually, you are drawing this is the V d this is V d. If, we were drawing separately but it is 0t. So, this is the characteristic, where both your inverter and rectifier on the same axis. We have to take whole link, where is your V d because we are having three resistances.

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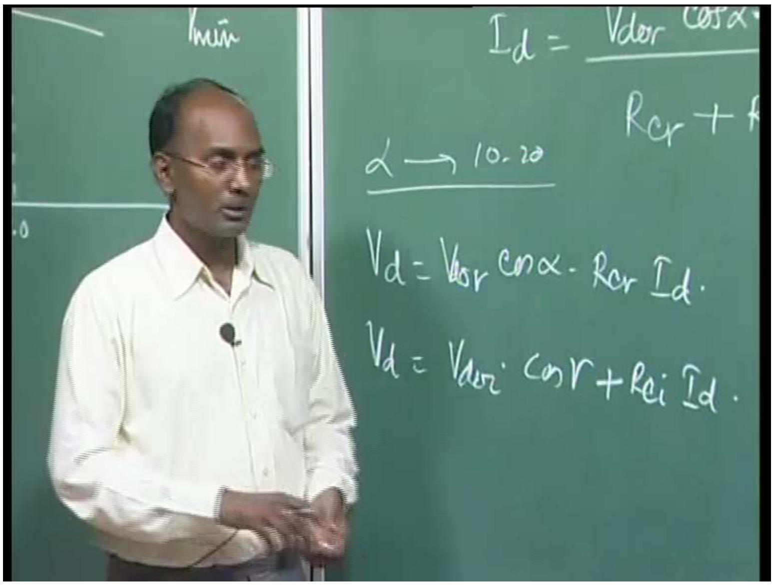

If remember for the rectifier, I just draw this V d. It is your V d o V d o r here cos alpha minus R c r I d; to visualize this here see this equation, we wrote for the rectifier similarly, we can write for our here the V d V d o i here, cos gamma plus your R c i I d.

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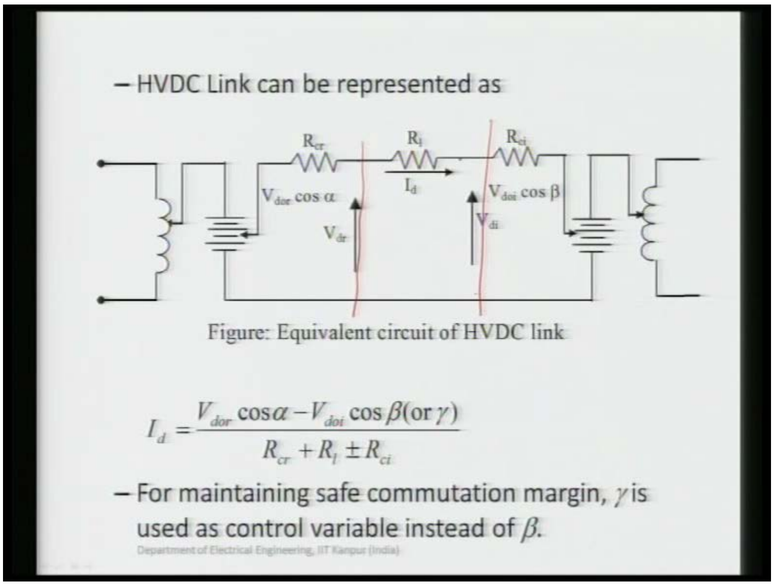

So, here, the voltages once we wrote if, we will see our in the previous here, the previous curve circuit diagram equivalent circuit diagram here, this V d the first equation the rectifier. We took this V d for the inverter, we wrote this V d. So, if you are drawing the characteristic the V d should be the same where you are talking here, the characteristic where you are taking the V d voltage here, V d there is two option you can take V d here this side is one equation this side another equation because V d same we are drawing V d the same axis.

So, we can take from here this one and either we can take V d here, this two resistances together if, you are taking here, V d in the some of the book you will find the V d people are taking here, somewhere people are taking here, as fully no matter because we are taking the V d the same either this point because this side characteristic and this side characteristic together on the same axis.

So, here in this what I am going to write if, you are writing here, this is a minus resistance for the gamma. So, this minus this will be there the slope will be different than this value normally, this value and this value is approximately same. So, only matter is this is either here, added together here, subtracted together So, one slope will be more one slope will be less if, it is 0 both having the same slope because the characteristic here, you can see if, we draw here, this if both are same the characteristic will be the same one so, in this case what I am taking the V d in our case I am taking this is characteristic V d. So, this equation is one and another equation we are writing now we are incorporating the R l as well to calculate the V d here, means this voltage minus this voltage will be the V d in this case.

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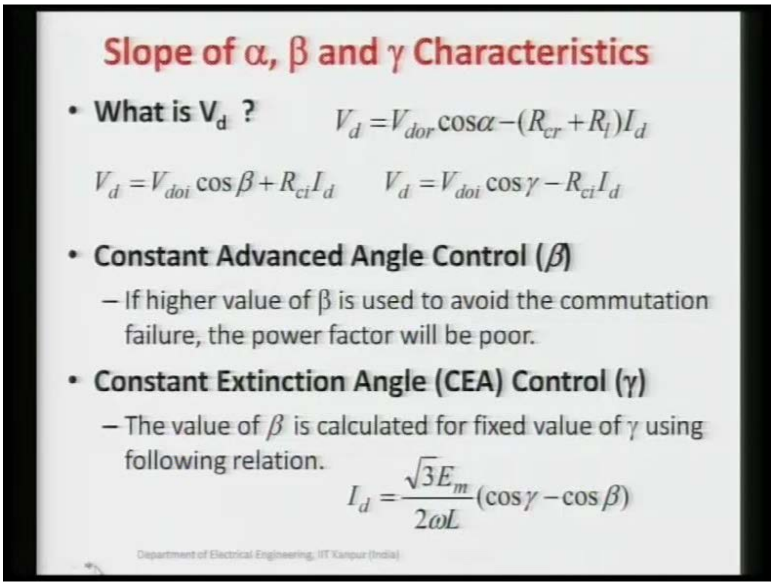

So, you can see here, this is I have written in the first equation here, R c r plus R l is added here, now it shows that is you are having more troop compare to this troop and then we are just drawing.

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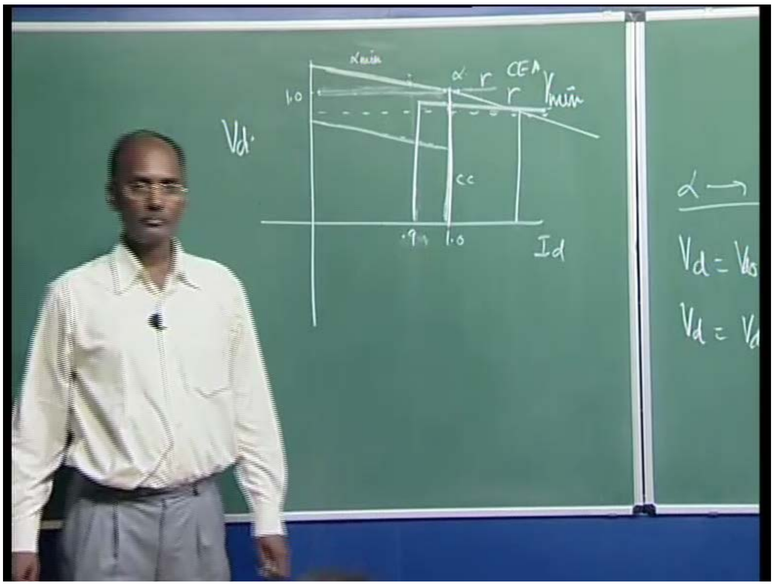

Now, you see this is your characteristic your this characteristic is I can draw this will be the more slope here, it will be less slope this is your gamma because this is more slope because here, the slope here, we are adding R c r plus R l here,, and this slope is minus because we are taking the opposite of the inverter. So, this is minus term here, the appearing.

So, this slope is more because this is a slope of Id. So, more slope is there here, is less slope so, you can see this is more negative slope here, it is less negative here means the intersection of these two is basically, your rated current which is flowing in the circuit and this circuit this the V d is there now this is a V d and this is intersection will be your I d. Now, in this case let suppose this is a characteristic. So, we can take this is your I d 1 per unit here, hardly matters just you can have a slope it is no problem. Now, I want to establish that if, the voltage this side is fall down or this side voltage has gone down what will happen let us, draw this is characteristic here, let suppose this voltage inverter side voltage has drop down what will be happen this is operating as alpha minimum this characteristic.

We have a some parallel value here, to this characteristic. Now, your I d will be this value if, you are not doing anything in the rectifier inverter and voltage has gone down and so, what will happen this will have a another characteristic because your this value is changed this is already minimum. We are operating other values are constant your I d will be here, which is increased tremendously and once I d is increasing. So, it is that we should not because this may damage your line and also it may damage your valves converter valve because more current will be flowing more loss and it may puncture your rectifier converters thyristor. So, it is believed that we should operate your rectifier end to control the current that it should not increase by changing alpha or changing the V d o.

So, this characteristic what we do here, we want that this rectifier end should control the current. Now, what will happen now even though this voltage has gone down your new operating point is this you are not going now here now here only because this is your alpha minimum, because we cannot go up because alpha minimum is there and your all oil DC exercise this is a boundary of this characteristic. Now, we are having another characteristic here, that is called constant current and this should be controlled by rectifier here, even though your voltage of inverter end is falling. What we require we require rectifier should control the current of the link and that is called your constant current controller.

So, your rectifier control characteristic here, you see your this here, now there is even the possibility now this characteristic here let suppose even though it has gone down here we can take any characteristic of this gamma. So, normally we either we can operate at this knee point, but it is preferable that we can operate slightly lower than this and here your the gamma characteristic is there let suppose this is your gamma that is called CEA constant extinction angle. Control because this is a characteristic related to your gamma minimum and here, the intersection point is your operating point.

Now, another characteristic you can see now, even though this voltage has fall down this voltage is going down what will happen there is a possibility your you are here, if this voltage is down means your this value is reduced tremendously, due to the fault etc even though you are hitting the alpha minimum alpha minimum characteristic will shift here, because it will come down this is a slope is a same, because this minimum value only this constant is reduced means you are going here, the voltage is reduced.

Now, you can see you are having one characteristic here, and another characteristic here, both are not intersecting to each other and what will happen your converter will run down and there will be no power in the DC link. So, in that extreme condition what is advisable that our this inverter should also have a current controller. Because we want to current should be controlled we should have another control characteristic here, and this inverter should take but we cannot keep both current rating for the inverter and the rectifier together because there is a possibility there, is n number of point of operation will be there and there will be hunting in the control.

So, always we device another some it is called the current margin we give some 10 percent of the rated value here, normally it is your 0.9 of this per unit.

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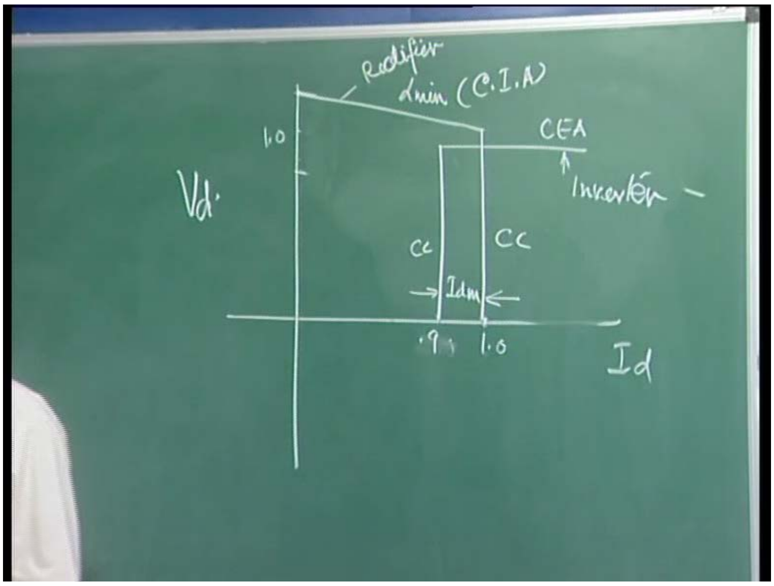

So, your complete characteristic here, now you can see we are going to have the control characteristic of this and this mode only I am talking means the first coordinate this is your alpha minimum and then we are having the C C constant current control. Then we are having here, this slope is less than this and then we are having another one here, this is your CEA constant extinction angle control this is your constant current control this is also, constant current control here, this value is called the margin I d margin and it is normally, 10 to 15 percent of rated this current link current.

This is also called constant ignition angle control C.I.A control. So, this is a general characteristic that is required, but we will see even though for several cases this is also not sufficient and we will we will see there will be some modification in this control characteristic here, we are talking only this is your if this is a rectifier this is basically, if, are inverter here, this is your rectifier characteristic. Now, here few comments I have again written why we never use the beta control. Because you can say that we can use this equation rather than this equation it is was possible to maintain the current here, as high value of b can be used to avoid the commutation failure, but the power factor will be poor so, we never go for this what we do we calculate the gamma based on the given value of gamma here, we calculate the beta for a given current. So, that is, why and in that case we are maintaining gamma that is very useful.

But there is also possibility, once you are computing this beta and then your voltage decrease there, because you have computed the value based on the previous instant. Now, once you are going to fire it voltage has drop down and then commutation angle again increases. So, it is also not hundred percent assured by the gamma control there are some risk but still that risk is less than this risk.

So, we will see as I it is written here the value of b is calculated for fixed value of gamma using the following equation, this is a equation rather this I d equation. Which we derived already you can see the beta is calculated this is known if this you are known you are measuring the voltage here, other values are known here, to you can calculate the beta very easily from here.

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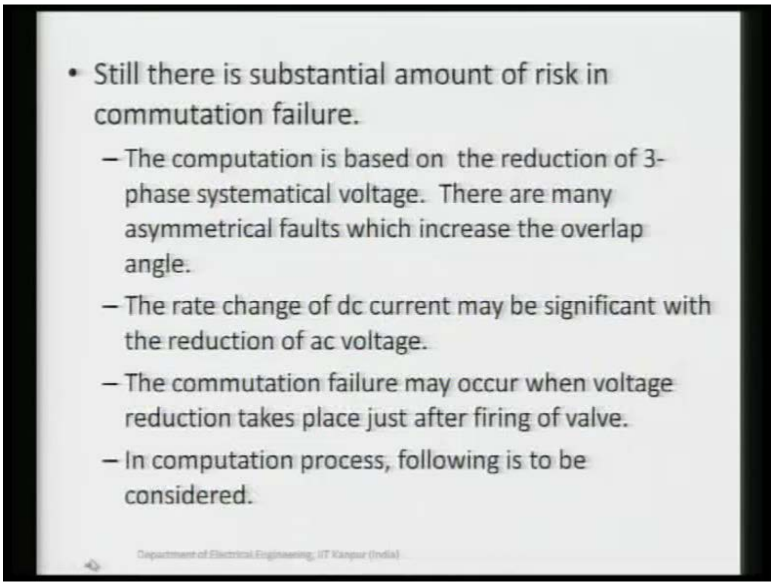

Now, see the there is risk and those risk here, basically as I written here, still there is some substantial amount of risk in the commutation failure due to this point you can see the computation is based on the reduced in the reduction of the 3-phase symmetrical fault even the voltage has gone down while calculating, before that even what you are doing this E m, which you are using this is we are assuming this 3-phase voltage value but there is possibility, if, there is line to line fault you are taking, one phase voltage that may be the same, but you are taking another phase voltage that may be changed and that may cause your commutation failure.

So, it shows that the there, is so many fault like l to g fault there is l to l fault so a symmetrical faults are there if, there is symmetrical fault means 3-phase fault is there this E m will be reduced and then you can calculate accordingly, but for the a symmetrical faults here, the overlap will increase for that phase and then it may create problem for other valves because whatever; you are calculating here, that is calculated the instant for all the valves.

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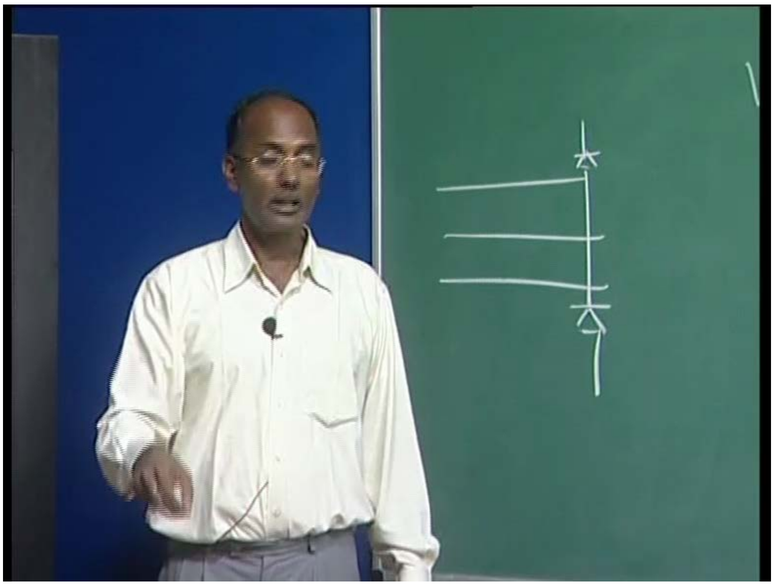

But you know are we have the 3 phases here, and from one phase only the two valves are connected if, there some problem here, that may cause problem to other valves. So, there is one risk here another here the rate change of the DC current may be significant with the reduction of the AC voltage. What happen, we are taking the I d as a constant I d may not be constant because suddenly, it is changing very fast if, it is slow it is because by that time. We are firing again and you will take care, but the sudden change in the I d may cause your commutation failure because your calculation may be not accurate you may increase at that time. Another here, the commutation failure may occur when the voltage reduction take place just after firing the valve as I said here.

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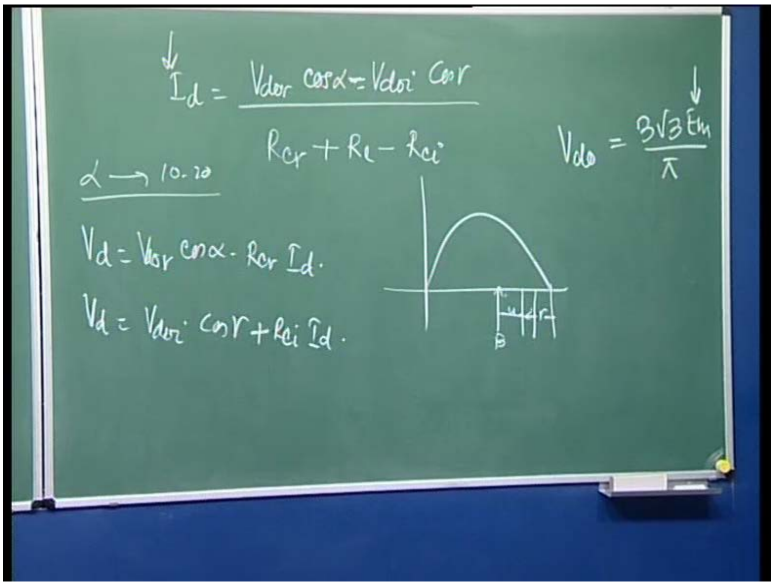

You have here calculated, this beta and this you are given the firing pulse here, and after that just let suppose there is a fault in the inverter side your voltage will reduce and this u will increase here, and you are not maintaining normal minimum and there is a risk of commutation failure due to this voltage dim. But again, this probability of this is very less very rare compare to others but still, we use this one to avoid all this things it is not only we should measure this, E m we should not only measure this I d we should also, measure other phase voltages.

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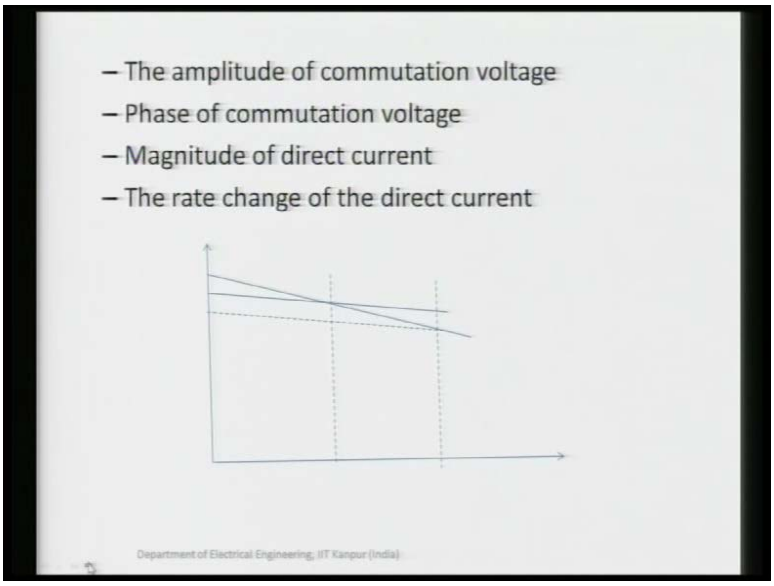

For example, here I have written that we can go for we have to calculate means measure the amplitude of commutation voltage this is your E m the commutation voltage magnitude then, we have to calculate the phase of the commutation voltage. Because which valve is going to come so that phase voltage also for example, here, one phase you are taking you have to take other phase voltage as well to take care of calculation of this we should also take the direct current magnitude which is going to change. It is not fix value you have to measure it and also sometimes you have to see the rate change. How it is very fast then that that correction is needed certain. So, we will see this correction is change in I d is also taken care in the deciding, what will be the angle that is alpha or gamma controller.

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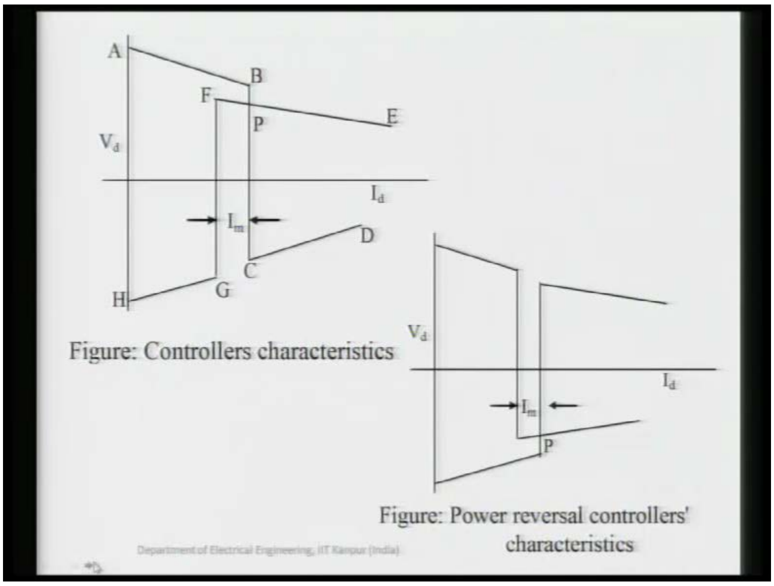

Now, we will see there is some change or some in this circuit, you can see just I draw up to here, even though this characteristic as I said we will see there is some modification required, but this is your the first coordinate.

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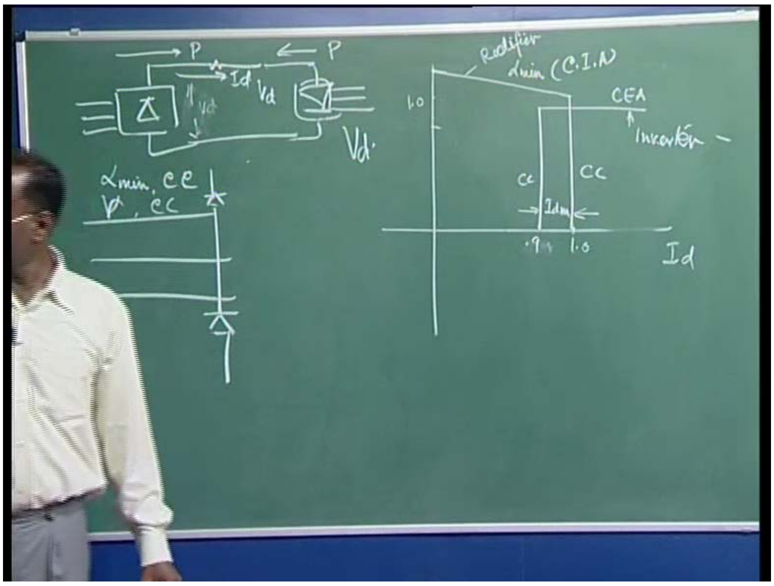

When the power is flowing from your rectifier to inverter end, means your power flow from here as I said this is your rectifier the power is flowing here, that is I d and this is your V d positive; V d we are taking including a line as well here, it is your V d. Now, if the power reversal is there now, come this side; what happens now, you can see this is operating here this CEA the constant current. Now, it is going to be alpha minimum, because now this inverter, which was here, now operating as a rectifier; and in the rectifier it is alpha minimum control is there. So this is three part one is your alpha minimum control, this is a constant current, and then there the CEA that is a extinction angle control; means the rectifier which was here, alpha minimum and it was the C C; now, it is going in the inversion of the power reversal case it is your gamma and it is C C. So, you can see this is half of this current, for this case it is C C, and then it is your CEA control. Similarly, even it was inverter it is CEA, then C C but here alpha minimum is going is going to be control. Now, you can see here, the intersection point P is possible in the rectification, but here, there is no intersection in this one. So, you cannot operate with this characteristic in the power reversal case.

So, what we do we never change the characteristic only we change the margin you can see here, the rectifier in the normal case the rectifier was rated as I d which is rated current. Now, there was some margin here, I d m I m here, it is written now what we do we change it here, in this mode because this is only 10 percent so 10 percent change setting is very easily possible. If, you want going to change huge amount it is not possible, but 10 percent you can change the reference, now you can see here this is going to be increased this current earlier this current was less than your rectifier end current. Now, this is coming this side and this is going this side and then, we are operating an intersection point is possible.

So, in the power reversal what we do we simply this C C is coming this side and this is going to be this means this is high in this case larger vale this is lesser value in the inverter end and now, in this here this value becomes less and this value becomes larger. So, that we can have the intersection and this will be your operating point this will be your V d this will be your I d and this is the power because negative here, the power is flowing from this side to this side, but again, the current is flowing the same direction you can see current is always positive only we are changing the voltage.

So, when this was a rectifier your V d was positive here, and the current was flowing here, we had this characteristic at the top and the power is flowing from this end this is power and going this side. When the power reversal is required from this end to this end for the power which is flowing here, we have to change. Now, this is operating as a rectifier and only we have to change the I d setting of the controllers. Now this controller earlier it was inverter now, this should be the current of this margin and we have to reduce this margin by that percent you can see this is reduce here, this current and this is the characteristic now. So, in the power reversal case this normal operation here means negative side. We change exchange to each other. So, that whenever there is a intersection, we can have the complete characteristic.

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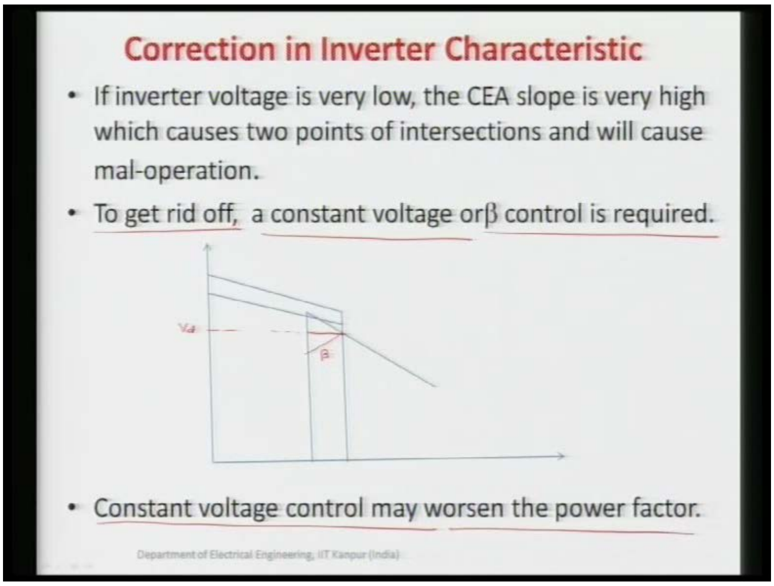

Now, we will see it is still not enough, because there is some possibility, here if the inverter voltage is very low, the CEA slope is very high which cause two point of intersection, and will cause the mal operation. What happens, if your the voltage inverter side voltage has gone down due to u, your R c i is also changing with the your overlap angle, because this commutation resistance is taking care of your overlap period; this R c i it is nothing but it is your means responsible for your overlap.

If voltage is more down, your R c i is more, slope will be more. Now you can see if the slope is more here in this case, you can see and this voltage is less this side anyway, you can see we are having the intersection here as well as here; the two intersection here there even though you can say we are having so many 1, 2 and 3. But this current is more, so it will be you can say this or this will be the intersection, and your controller will hunt this will be the operating point; in this case we are having one intersection here, here and here, of this one. So, there is many possibilities that you may have a several operating point and your controllers of both sides will start hunting to each other.

So, what we have to do? We have to see to avoid this characteristic, so that we can get proper, you can say that there should not there should only one intersection, and we can operate our DC link smoothly. There is two possibilities here, because we have to shift only characteristic between this period. It is possible that we can constant voltage or we can go something else. Now, you can see what we can have on this axis here, if, this is your characteristic we can have your constant voltage control here, this is a constant voltage because here, is the V d is constant. We can achieve this one or we can have another characteristic here that is here the constant beta control means we can this beta axis here, it is value it is going slope is positive.

So, this slope is the positive of this alpha here, it is positive characteristic or we can have the constant voltage and in this case whatever; you are going to do always there will be one intersection and means you are getting only one operating point option as I here, as written it is to get rid of a constant voltage or beta control is required here, the constant voltage control worsen the power factor the constant beta is constant voltage is not desirable because if, you are here, doing this voltage your beta may change accordingly, to maintain that voltage and then, your power factor will be poor, but here, for assuring that the beta you are maintaining certain beta and in that range your power factor will be better. So, it is a prefer that we should go for the beta control here, rather than voltage control.

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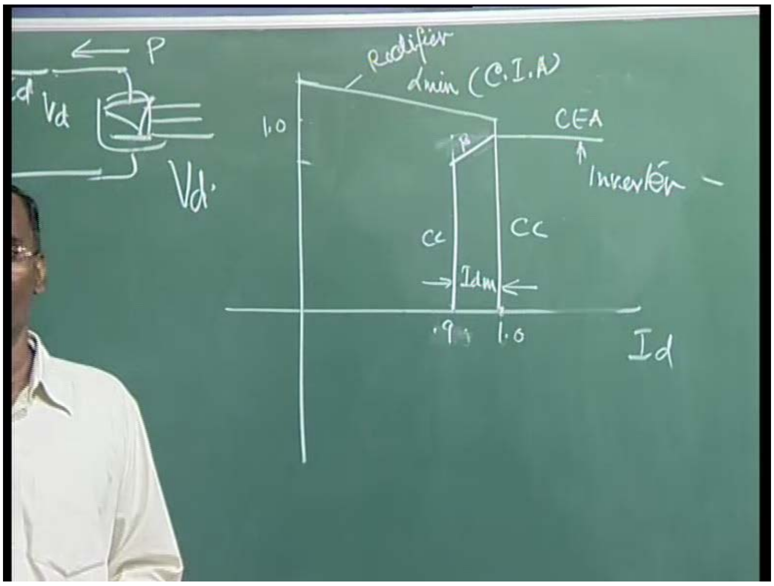

Now, your this characteristic here, now it is changed and we are going to have this characteristic here this one. So, this is a CEA here the constant beta control now in this section only. Now if you are reverse reverting here then this will be this was your inverter this was your rectifier here this is going to work as inverter and then again this characteristic will be here, in this lower side as well means this is repeated. Now, you can see this characteristic is used still this is not sufficient.

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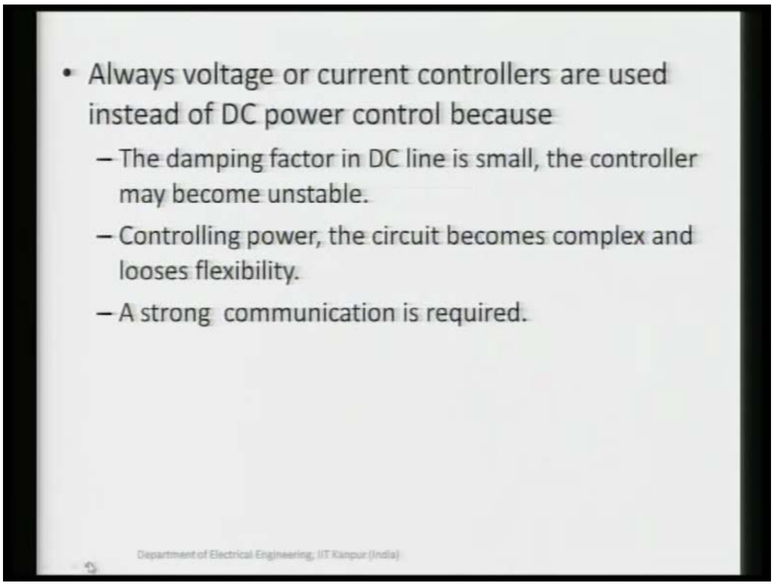

I will come back here, we will see when your voltage has gone down very tremendous there is no possibility means voltage of both side there is a sever fault in the AC. System voltage has gone down tremendous means you are operating somewhere here, this maintaining current is very difficult and also your valves etc is highly stressed so to avoid this, we go for the voltage dependent current order limiters and this characteristic here, is changed we will come down to that, one but before this as I said here, why we are going for the current controller not the power controller.

The reason for this you can see as I here, it is written always voltage or current controllers are used instead of DC. Power control it was possible that here, we can control the power rather than, current here, but we prefer to control the voltage and the current here rather that power due to the following reasons first reason here, the damping factor in the DC line is small and the controller may become unstable the damping factor is nothing, but your this value this resistance of this line this is very small because the damping. When there is a change in the power swing here, the damping this R value is very less and your power controller may not act properly, because due to I square R the current which is flowing and R is there very small. So, huge oscillation in the power will be there, and there is possibility your controller may dynamically unstable. Another reason here, the controlling power the circuit becomes complex and the loses flexibility.

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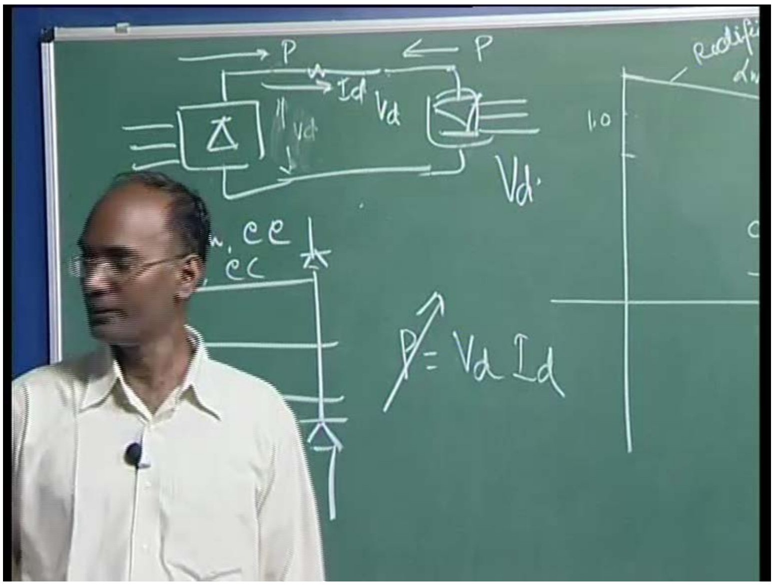

Because here, as mention here the P is nothing but your V d into I d to this control here, the possibility here, both can be both will be controlling together or only one will be controlling here, and your controller becomes complex. You see as I said here, we are maintaining this constant, we are changing one to control the power, but only if you are controlling this the possibility that this is, also changing this is also changing or only one is changing and you know there is all the possibilities are there means this can change this can change both can change and upon both are changing it becomes very complex.

And also, it is believed that you require a strong communication link between both side to which one is controlling which one and even though there is just like here, the changing modes your again controller will unstable and your line will be rundown. So, we use your voltage and the current controllers.

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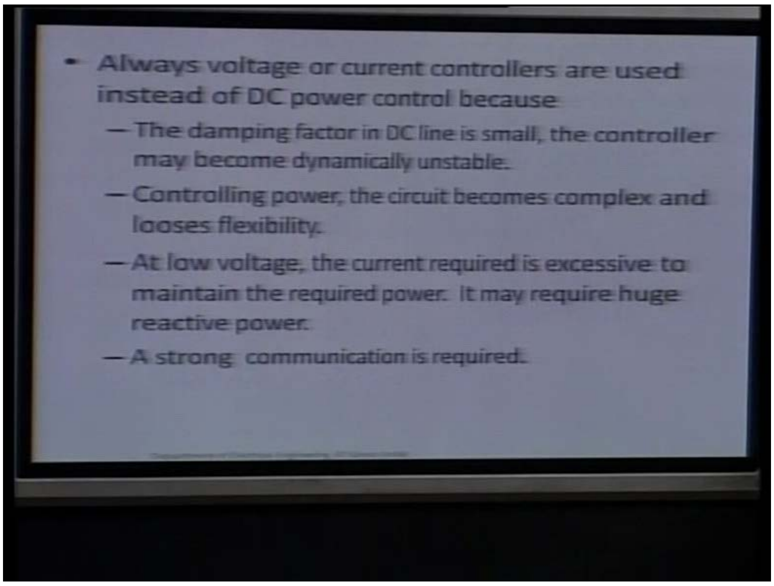

So, another reason for not using the power as a controller and we are controlling the voltage and currents here, in the link another here, you can see at the low voltage the current required is excessive to maintain the require power. If, you are controlling power here, means you are setting some power reference and then, you are measuring this value if, the voltage has gone down what happens to maintain this power your I d must be very high and once were I d is very high means you are not having any control over this is the huge power will be flowing through the valve huge current will be flowing through this your line and this line may be damaged.

So, it is better to use the current and also at same time what happens you are just firing in such a way that is reactive power requirement will be all excessive high one is the more current here, that may damage your converter stations and the same time it can damage your line and also huge reactive power requirement will be there, and therefore, it is better to use the voltage and current controllers rather than power controllers, at any of the end.

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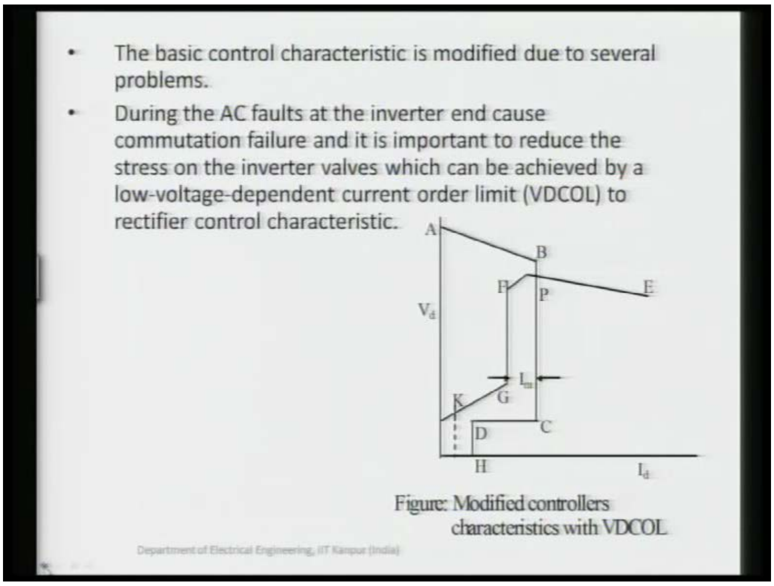

Now, to have the controller here for the low voltage that is one of the major concern especially that happens in the most of the time you are operating your here, in this slope either this voltage is slightly going up and down. You are anywhere you are just operating this but there is possibility if, there is a huge short circuit fault in the both end what happens we have to change here, the voltage has gone down. So, what we do we try to change some margin in such a way both sides means? We can change this margin here; somewhere that we can operate at the reduced voltage of this power line once you are operating reduced voltage reduced current means the power in the link is reduce substantially.

If, you are maintaining that power what will happen if, in the voltage has gone down that it is very difficult to maintain the current in the link you are maintaining this but this are highly stressed. What we do it was found this there is a possibility your this thyristors valves may be punctured here, and there so we try to reduce here, this one this limit is this side and finally, the characteristic can be shifted completely one option is that.

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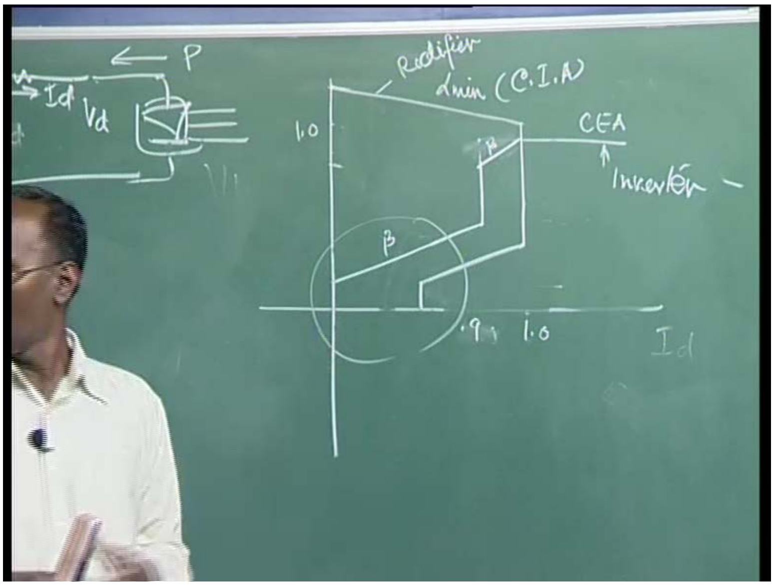

We can directly go here, this and here we are going here, means what we did this setting is the reduced drastically; both inverter as well as the rectifier here, and then we can operate on the reduced voltage.

But here, this again this is not advisable it was found it is not so, satisfactory in that case so, it is better that we can directly change this toward no maintain of this reference. Because this value has still gone down this margin we can maintain this side. We should not act for the current controller simply, it is your beta control and in the reduce voltage and this is called the voltage here, it is called voltage dependent current order limit means if, the voltage has gone down the certain limited less value your the current limiters are reduced because earlier, it was this one. Now, we have gone down here, and this is called V DC OL control modification and you can see now, we are having this characteristic for whole operation of the rectifier.

So, during the AC fault at the end causes commutation failure it is important to reduce the stress on the inverter valves which can be achieved by the low voltage dependent current order limit to rectifier control characteristic here, this change substantially. Now you can see this is the characteristic of your DC link controllers both rectifier as well as your inverter end even though always you know if, you are having them sharp voltages it is sometimes very risky at the D point B point here, now, people are still changing this characteristic here, with the some constant here, because whenever there is sharp here, there is sudden change.

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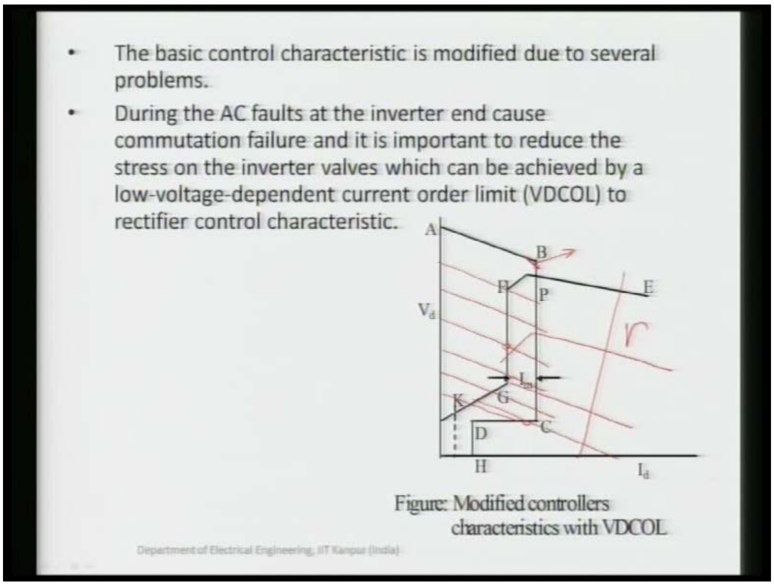

So, to avoid this here another characteristic is here, is used and this characteristic is which is this characteristic. We put some circuit some controller in a such a way just we introduce more slope at the corner then alpha and this characteristic is changed basically, this is used in the practical HVDC link controllers this portion here, we just this R point the change of alpha minimum here, we change in between we put another characteristic some because we change from here, to here, is not sudden. We just go for something some slope regard.

So, we had some controller that you can achieve this characteristic and it can go there we will find in some of the books in modern books. Because this is it is control in some fashion. Now, this is the complete characteristic of the your HVDC control in here, the first quadrant in case of power reversal same is repeated downward and again always, we should have the intersection of the operation which one is going this voltage down or this voltage down, we can find all the current law.

So, this is basically the complete control characteristic now, you can analyse from this characteristic if, your inverter voltage has gone very low means what will happen your inverter voltage has gone down means you are just achieving here, if it has gone the characteristic will go down because the V d o i is going to change still here, you are going to have this once because this is already beta if, you are going for here, another further here, you are operating here somewhere.

So, these are the parallel characteristic of your here the gamma minimum and only here, this value is changed due to the AC voltage. Now, if your rectifier side voltage has gone down and you are operating. Now, what you are getting you are getting this parallel characteristics tail you are coming here, so wherever you are cutting here, you are getting a characteristic means here, in this case you are having your operation voltages this one.

So, when the voltage of the rectifier has gone very tremendously, low we shift our current controller from this rectifier to inverter side you can see now, this is your inverter it is controlling current. Because is intersection is here if your rectifier end voltage has gone down tremendously, low in this case what happens our inverter is taking care of current control and this is here, alpha minimum control here and this is you can say all the way up to here, but if this side is control coming here, your this is still you can say the current is control by here, So, whole scenario your increase decrease and your rectifier and inverter end voltage can be very clearly seen here, we are operating very you can the stable and the reliable manner with this characteristic and also it is practically feasible to achieve this characteristic in the rectifier HVDC link controllers.

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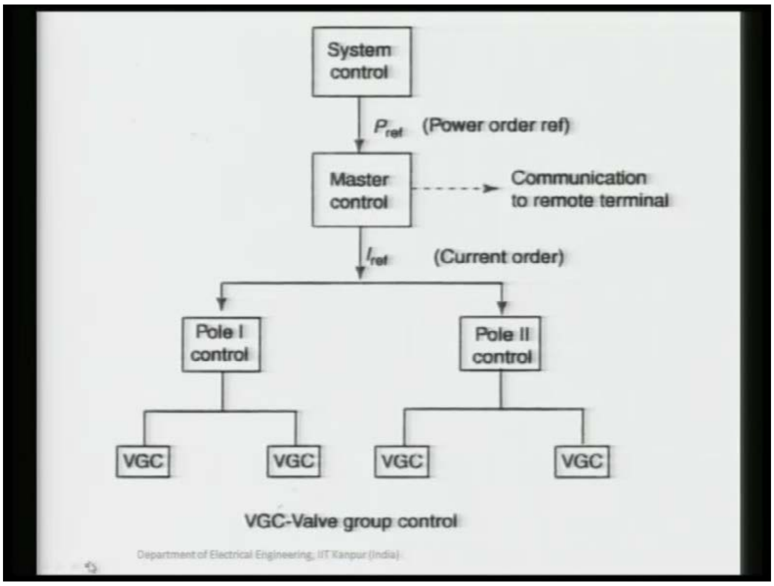

Now, in the total philosophy it was the characteristic now, and once this characteristic is there then you have to design a controller for all these characteristic both rectifier as well as the inverter. Now, you can see the control hierarchy here, we should have a complete the system control as your both inverter and rectifier end what is your philosophy? What is a power fitting? how much you are going to do this is a whole system control we call because and then, because based on this you decide what will be the power reference how much power you want to flow in this line in the normal case.

So, once a power reference is decided then you have to calculate what should be the current here, the reference then we are having the two poles if, you are having bipolar if, you are having only one pole this portion has come if, you are having two poles so both pole should be coordinated in a such a way that the same current should flow it is not that one may flowing the different current for example, as I said if you are having a bipolar operation.

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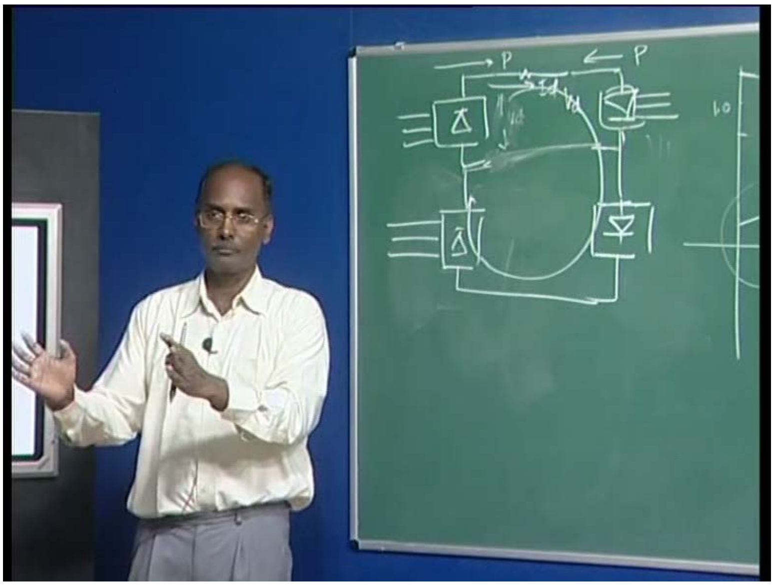

This is your grounded, you are having another here, rectifier this is your grounded here, the three phase. Now, this is one pole; this is another pole, as you know the current here, it is flowing the same current. If it is a bipolar in the monopolar. This current may be different, this current may be different then, and this total is flowing through the ground. If it is a homopolar homopolar you are having the same polarity and the current will flow through the ground in the monopolar. You have this so, it is only one hierarchy is required, but if you are having bipolar, the same current will flowing here, as well as here.

So, we have to set the current reference for this and for this. The same that is why here, it is written, the pole two control pole one control this is a pole one; this is a pole two and then, we have to go for the valve control valve control here. Now, current reference is decided. Now, we have to fire the valves of this bridge, as well as this pole together. So, this is called you are the valve group control, because we are having all six groups and then, we have to control based on it is characteristic means your I reference here.

So we will see, how this is a control design is going to be there, but whole hierarchy is first one is this then, we calculate the what is the power reference is in this link is required then, we say the what will be the current reference value and therefore, we are going for all these pole control here, this master control is required because this master control says that you have to control your rectifier and inverter together; This system control is whole AC DC network in this system control. Because there is the low dispatch centre, you can say there is substation whole system and they are deciding how much power will flow in this link.

So, this is decided by the system controller may be the larger aspect having AC DC network then, this power reference is decided that this will flow here, now once this power is decided, this the power will be communicated both end this what power is flowing means, rectifier end and your inverter end then, your reference current is calculated and this message going to the another one, through the communication to the remote terminal that is, inverter or rectifier and then, we can go for pole and then, the individual thyristors must be controlled to give our desired objective this is control hierarchy of HVDC control here.

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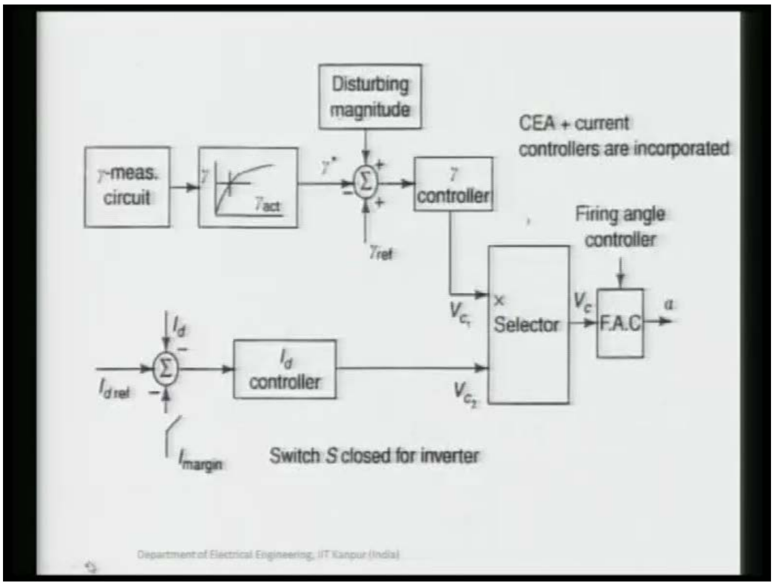

Now, in the here your the valve group control VGC here, we are going to control means, we require some alpha, whether this alpha is for your rectifier or this alpha is for your inverter only, difference for inverter this alpha is larger more than ninety degree and for rectifier it is a less than ninety degree means, very small value. Now, you can see here, this portion will come to later on how they are going to be realized. Different schemes are there to achieve this alpha, but in the block wise direction. I can say, we are having the I d reference then, we are measuring the I d from this actual how much is flowing. We are talking at the rectifier and now, this portion then this difference is going to your current controller of rectifier end. It is just changing it is basically, what is the controller it will give some voltage magnitude and based on that it will going to some logic, some something the based on this error here, this is looks a voltage really, it is voltage and this voltage is basically, deciding how much alpha it should be changed from the previous instance.

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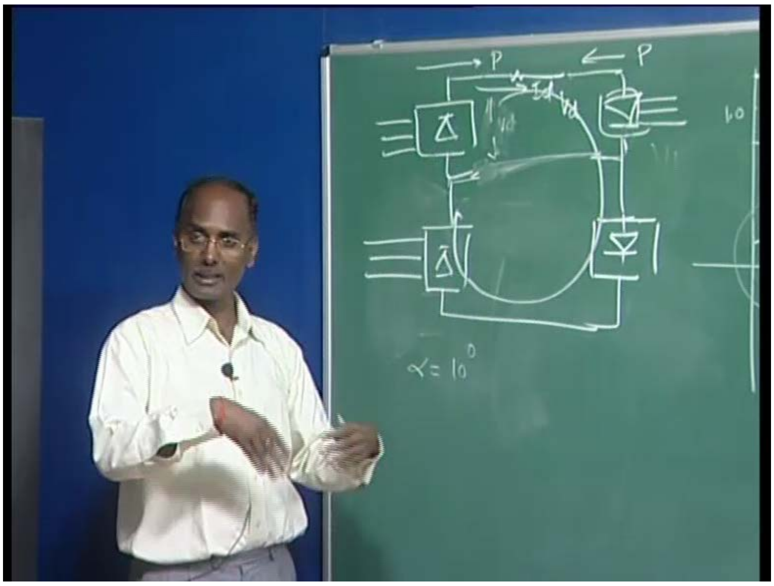

Because once alpha was earlier, let suppose, 10 degree; now, if there is any change in the current here with the reference value, this alpha should be changed. If the reference here, this and this is equal, this will be 0, and this alpha will be the previous calculated; it will keep on firing. But whenever there is a change mismatch here, it will be there is some voltage will be generated and this voltage basically, is given to the some oscillator circuit. And this oscillator circuit generate, the six pulses and this six pulses again 60 degree delays. It is given to the six valves of the six bridges, six pulse converter circuits. So, that alpha is here, that is called firing angle control.

Now, how it is decided alpha; how it is related here. We will discuss later on, how this is going to visualize it. Different schemes are there this is your rectifier end gate here, one switch is given here, and this switch is acted, because this is negative. When there is a power reversal, because this I d is now going to change margin. We are changing as I said, if this is going to be your inverter, because of power reversal case the reference here, is here it is changed in this mode here and that here current is further is changed here, then the margin here, and then we have to change alpha accordingly, so this switches only closed when we are power reversal is there in the rectifier end.

Now, this is your inverter side inverter side here. We are this gamma; we are this measuring circuit is there. Now, you can say, how you can measure the gamma circuit?

We are visualizing with the some circuit, because we require some 0 crossing here always.

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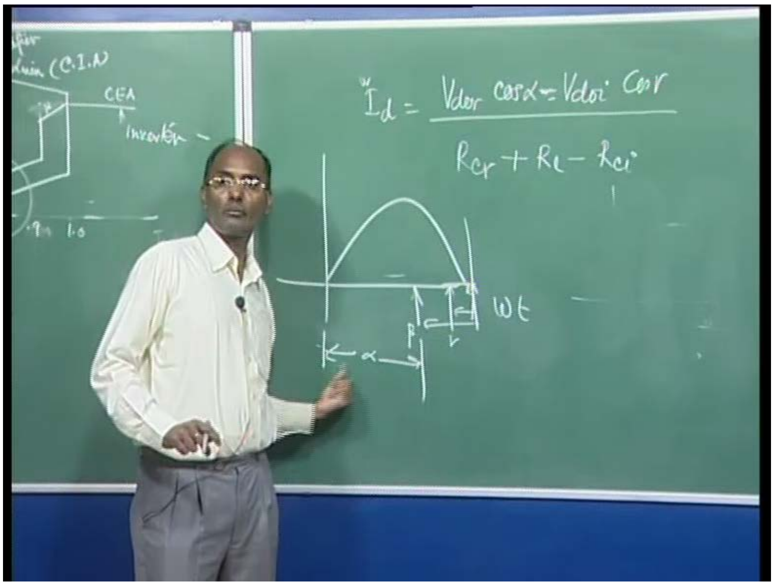

How we are going to measure this is the 0 crossing is calculated. Now, this 0 crossing because you are calculating here, you cannot estimate this 0 crossing, we have to go from this 0 crossing because already, this is a positive this omega this is changing with the time you are moving this direction. So, this beta here, your gamma this angle basically, this is your beta angle. We are assuming some measuring, some 0 crossing of this commutation voltage and based on that we are calculating your gamma all this here, the calculation part is done with the measurement circuit etcetera and then, we are this gamma controller again, if there is a some change is require from gamma, whether you want to your gamma.

This is minimum; this gamma minimum; you want to here, increase the gamma it is possible, but power factor will poor and also we can go only up to the 20 degree of the gamma not more than, that because if, you are going for further power factor will be worsen because we have the limited reactive power support at that end. So, then here we are just error is there and gamma control is there, if there is any difference and finally, this is also generating some voltage signal and this voltage signal is given to the some pulse oscillator circuit and this oscillator circuit is giving your gammas basically, here we are not talking about the gamma here, again we are going to calculate the beta or you can say alpha in the inverter side. Here you can say this is beta, you can say this is alpha as well, because this value is your nothing but from here it is alpha. So, basically it is also alpha that is a firing angle control and then, this alpha is decided that is we call beta, I am calling beta because we are using in this equation the beta earlier we use here but basically it is nothing but the alpha here that is we are calculating.

So, this part here, is your inverter this is your rectifier and both end it is equipped if, you are operating in this mode your rectifier mode, then this will work otherwise you have to go for the gamma here, in that reversal and your alpha is the firing angle control is basically, decided and then, you are giving the pulse side to this in the next lecture. We will see, how these are going to visualize there many schemes basically, the is called individual phase control equal distance pulse control many control schemes people have devise for the better and better controller always our intention again. We saw the features that it, should require the minimum reactive power support there should be less commutation failure in the inverter side all this features can be visualize by the various control schemes and the next lecture, we will see this all those controllers. So, with this I can end this, of this lecture 2 and in the lecture 3. We see the various controllers as well for the HVDC link.