High Voltage DC Transmission

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Module No. # 06

Lecture No. # 02

Let us start lecture number 2 of this module 6. In the previous lecture, this lecture number 1, I discussed the A C power flow. And also I discussed the various type of A C, D C power flow. And we discuss about the sequential unified including the variable elimination method and the standard variable method. Today, I will be discussing about these methods in detail.

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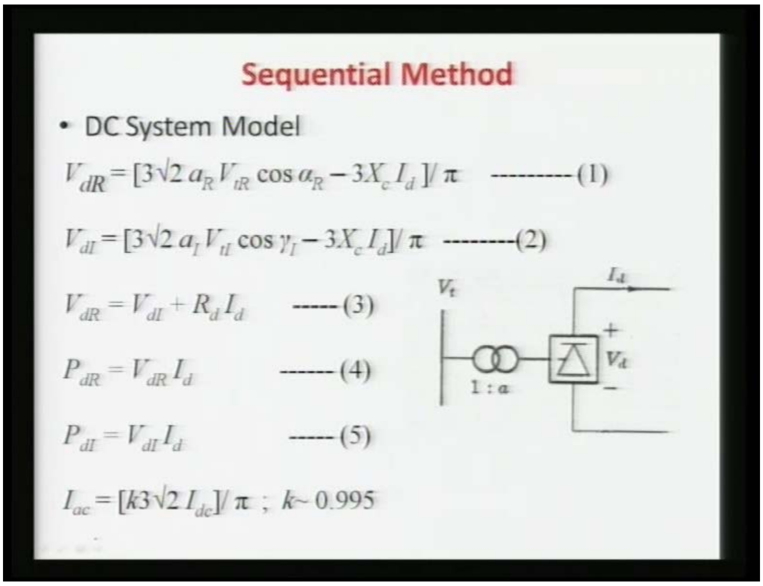

And before going for this in the sequential method or any method, these are the five basic equations those are already we have derived while discussing this h V D C course. Only difference here, you will find that the some of the terms coefficients are not matching. For example, if we will see the first here, is come something else rather than the previous one.

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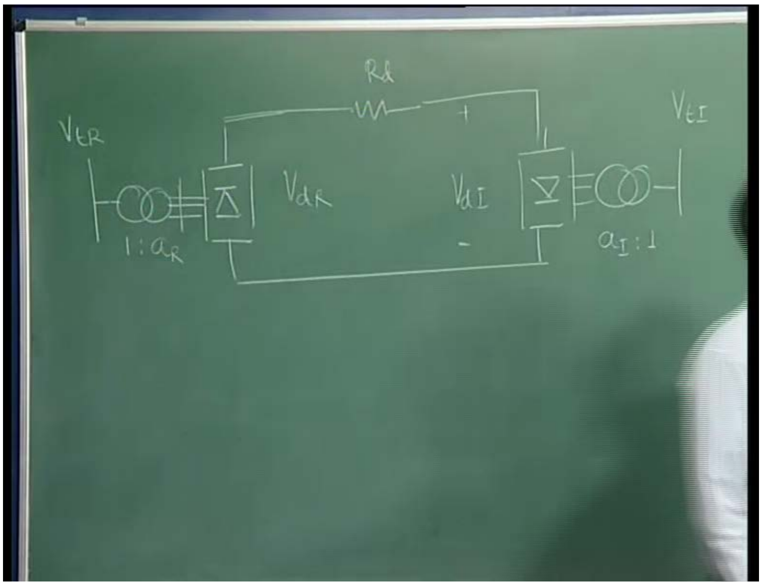

If you remember I wrote the equation that is V d that is your 3 under root 2 E m over pi here cos alpha minus here R c into I d. Sorry yeah 3 root 3 yes, so we wrote this equation we derived all. Now, you will see here is slightly difference then, what here I have written, we wrote this E m in the sense that if you will see your h V d c link here. Let suppose, this is your rectifier here we are having a transformer and this transformer is your o l t c transformer that is your online type changing transformer and here is your this. So, this is 1 is to a R I am writing I am writing from the rectifier side so R represent rectifier, whenever I am using here, I is used for inverter right.

So, this is your V d R which is written here in this equation, so this d here the D C and R for the rectifier here, we are having the resistance of the line R d. And here this side we are having your inverter that is here, it is I can write V d I and we are having again the o l t c transformer. In this case we are having a I is to 1 and your the V t R, which it is used here, t is the terminal voltage, R is your rectifier terminal voltage; here, I am writing V t I.

Now, this expression is written if this voltage, we are talking here, if some voltage are here but, we are now representing this side here, because we want that this transformer should be on the D C calculation rather than a c calculation. The reason for this this taping, that is why I am writing 1 is to a R, so taping this side so it is keep on changing it is a just a part of controller. If you remember h V d c, because here if the firing angle is heating we cannot use this controller as well.

So, if you are using in the A C power flow your y base matrices keep on changing, so we do not want this and that is why here, we are keeping this side, because anyway we are following the D C equations. So, this part we are trying to keep in the D C side and A C side this terminal voltage here, because your network topology is fixed your matrix is fixed and there is no problem.

So, that is why you can see here the taping it is represented in the d c side here, here also I am representing this side. So, this is the reason we represent this o l t c in this way for the solving our A C D C load flow. Now, this equation which we have written now, this is your peak if I write in terms of some voltage V here, that is R M S, then it will be under root 2 times V, the peak value is R M S value here; now I am writing any V here, we are getting this value.

Now, still we are not getting the expression, now this V is here we are talking, if you are transferring this side it is going to be your a R V t R, still we are there is one term missing here, under root 3. You know once we are writing the equation the line to line voltage we are taking here, because in all the power flow your base even though we take line to line voltage. So, this basically goes off and this equation we are having here; only difference here R c X c you can represent here X c you will get here 3 X c upon pi and that is your equation that you want.

So, this equation is you can see the similar to here, so alpha here also I have written in this 1 is here for rectifier R. So, it is clear for this end it is now we are getting, means now your this voltage whatever we are writing it is your line to line voltage and this V d is as usual D C voltage. So, this is similar to this no need to explain, this equation is a simple basic circuit equation, this voltage will be the drop here, current I d is flowing here. So, this will be equal to this plus this voltage which is written here I d is the current.

This equation the real power, which is flowing here, this voltage multiplied by this and the real power here this current multiplied by this voltage is your this is the I for inverter it is written. Now, these are the 5 basic equations but, out of this 5 only your 3 are the independent equations, because these are related to here itself. So, these 3 we will be using every time these are the basic D C equations that should be solved depending on your control modes.

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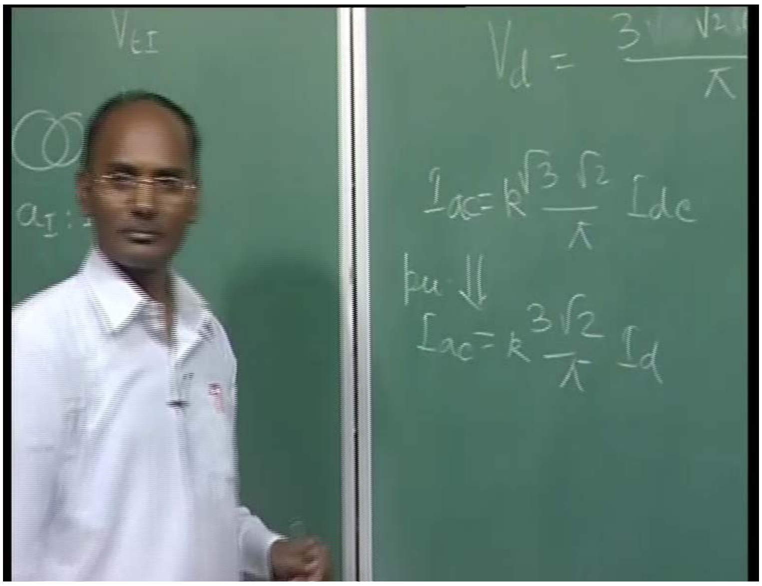

I will come later on now let us see this 1 here also if you will see this I a c I am writing it is we have proved this is A C if you remember, it was under root 3 under root 2 means I wrote under root 6 divided by pi I d c. We have already proved this this we have derived under root 6, if remember. The K term here and this was the case when it was the ideal means only the 2 valve operation.

So, we are using a word 1 term I can say, K due to the overlap once it is overlap is there due to this, the value of this value here is going to reduce; because if not overlapped you remember here this is like this your current in this here. So, we are getting here like this if there is some here overlap, then it is value is going to be reduce slightly. And that factor here is used as small k but, still again the coefficient is not matching matching it is not matching.

Because, there is under root 3 terms again here is missing means extra under root 3 is coming just like here but, the D C current here, it is this current, line current or phase current is same because it is not voltage. But, this is represented in terms of if we are writing in terms of per unit, then it will be the different. Now, come to the first proper unit then we will derive here why we are getting means our aim should be here 3 under root 2 divided by pi I d k will be there I c we want this in the p u system to see this here.

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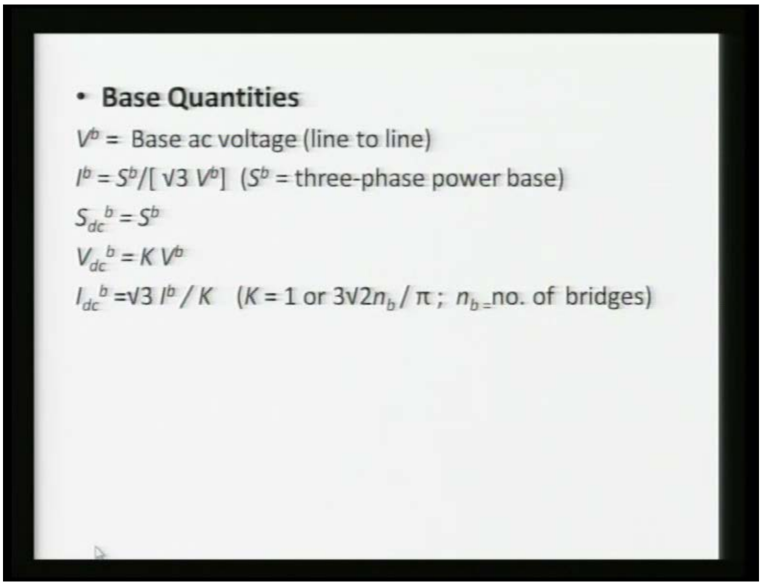

Let us see this slide what will be the base quantities.

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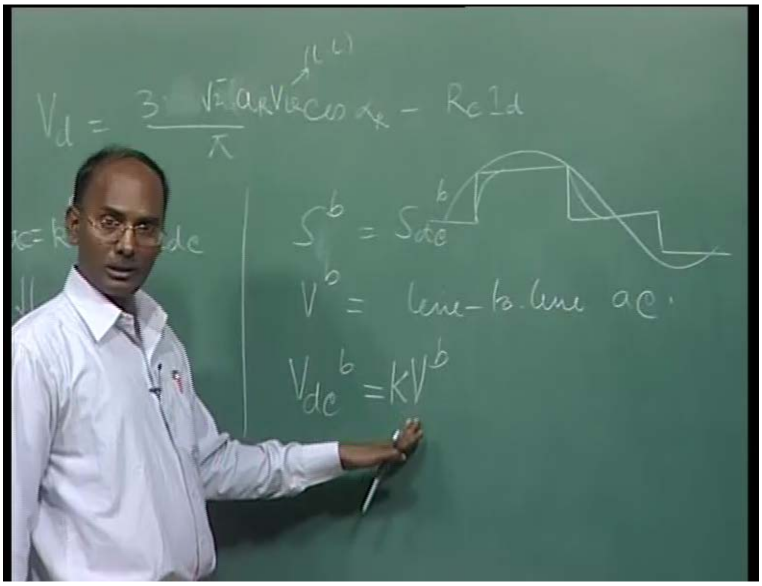

You know this base quantities in the A C system 3 phase, if you are talking the power, we normally take this S b here, I am writing if top; so it will be taken here S b this is A C power. So, A C power will be equal to your D C power and here it is I am writing the d c B only the difference, I can you can write a c here hardly matter just for the notation I am using. So, the A C and the D C power, we are taking the same the reason is true, because whatever the a c power here 3 phase is coming here, the 3 phase is going even though the system is class less here it is completely going there.

So, the base power here for A C and D C we are taking same, now come to the voltage base here we take this voltage base here, it is nothing but, your line to line voltage. Now, this this voltage is no doubt it is the line to line voltage, line to line a c voltage so if we are writing this V d c base option can be we can take this base is similar to your this is your a c base.

We can take now this 1 base we are fixing here you cannot fix here, because your current is also changing. So, normally what we do this base you can take equal or you can take in terms of bridges, so what we do here we write a capital term K, because either you can take 1 if you will see here, then your D C base voltage this voltage and this voltage here the line to line is equal to this.

So, the current base will be correspondingly will be changed you know the voltage base keep on changing throughout even the A C system itself due to the transformation. Here also you can change the even though this base here equal or you can change any value depending upon your number of bridges here. Normally, it is convenient we take either same so calculation becomes very easy or you can take here this term, if you remember this is terming under 3 under root 3 it is basically the this term was appearing.

So, that term you can take as a number of bridges, because you are having so many number of bridges, so you can 1 you just calculate and then, you can multiply it by the number of bridges, so then you can equate in that fashion. So, either you can take 1 or you can take this, for it is a simplicity in the calculation nothing else. Normally, we take K is equal to 1 is very simple; now once you are taking K is equal to here this unity means this base is equal to this base.

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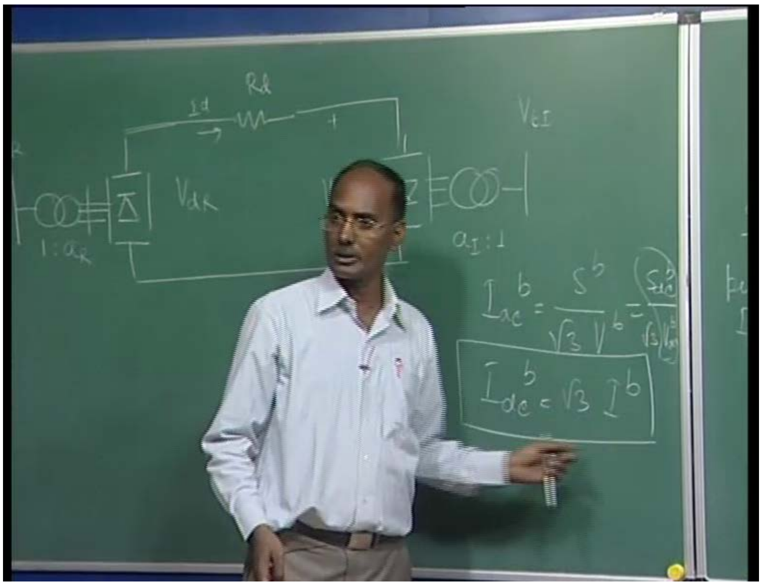

Now, if you will see the a c base the current now I want this a c base, it is nothing but, your S base divided by under root 3 V base. In the 3 phase system, this base is basically calculated fixing the two only, because in the 3 quantities one is dependent, so you have to fix two for third will be calculated automatically.

Now, because it is a 3 here line to line the power here is we write S is under root 3 V L I L. So, this is we are taking line to line then then it is under root 3 here if you are taking phase phase here, so it is 3, so this is coming. Now, I want this what is the d c base now, this base just you can see your here and you will find that we can calculate this will be your under root 3 I b base. Why? This you can put this d c equal this voltage you can fix that value and this divided by this is your I d base.

Basically and you will find this value here, not clear means just put it here you are getting this base is your d c base, this is equal here under root 3 here V d c base. The power here the current this is nothing but, I d base because the power divided by volt is here the power is equal to V d into I d. So, here you can say this is multiplied this side means I d c base here replace term and you can see this under root 3 term is appearing here.

Now, I will go back here if writing the per unit, here then you are dividing by here I b base, here you have to divide by I d base. So, then this we are putting I d, base here under root 3 term will be going up and this 3 will be coming here and that is why this is here.

So, the previous equation is valid if you are writing in the per unit term, this equation here this 3 under root 2 term is appearing it is clear. Now, here these are the basic 5 equations, now we have to go for the sequential method and let us see the flow chart.

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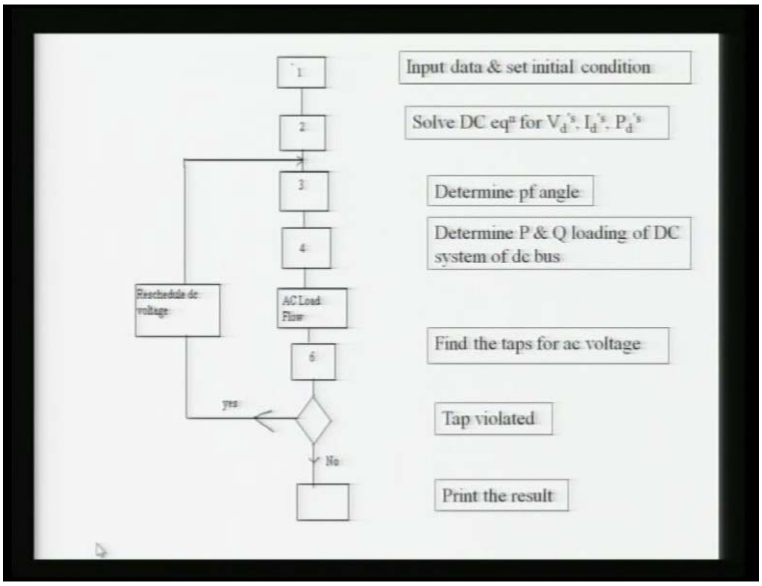

As I said in the sequential load flow methods, we solve first a c then we go for D C AC DC and D C always AC DC AC DC AC DC and finally, we will get the conversions. But, it is not so simple like A C D C you have to see we require something we have to calculate the something stopping criteria.

Sometimes, we have to calculate some variables because if we are calculating the a c load flow you are getting this voltage. If you are solving this this may not be mismatching, because this is related to the V d R, so what we do first no doubt we have to have the input data, means whatever this parameter of the D C as well as A C. Then initial condition for the A C as well as the D C you require, because you are having the non-linear set of equation 1, 2, 3 were the non-linear equation, because cos alphas are there. Then you have to solve the D C equations the first 2 3; 1, 2, 3 you will get the V d ‘s, I this I d ’s and this P d ‘s etcetera you can calculate.

I will come later on, what are the variables in these 3 equations, you will find there are 7 variables go back again here (Refer Slide Time: 15:41). If you will see this here in this complete 3 equations you are having the 7 variables.

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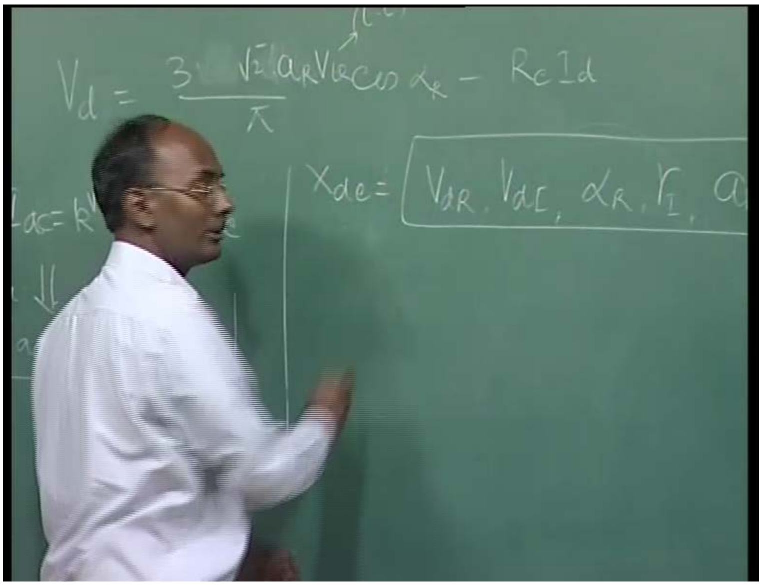

And your variables are, you see this what are the variables your this V d R you are having V d I, you are having alpha R, you are having gamma I, you are having a R you are having a I, you have having V d I, I have written R d is constant the parameter I d yeah. So, you are having 7 variables and you have only 3 equations, you cannot solve it you have to set 4 then only you can solve it and you can get the unique solutions. Because, we require number of unknown should be equal to number of equations. Now, this is called X d c these are the d c variables having 3 equations, we are having the 7 variables.

So, normally I will show you later on what we do out of this 7 we fix 4. Why? Because you know the control modes how they are working. Now, the control characteristic is coming into the picture based on its operation, whether inverter is controlling your current or voltage. And in you know vice versa, one will be controlling voltage and one will be controlling current; based on that few things are fixed and remaining things are calculated. So, here only we require 3 unknowns others are fixed in that particular control modes, so based on that given values, we are going to calculate.

So, I will come back again in that flow chart, we are solving this equations for given I will come to the control modes later on even though in the next slide. So, we are solving the D C variables and we can get it here, you can see we are getting V d ’s I d ’s and we are also getting the V d I, then we are getting the P d, means we can can calculate here these variables based on these solution. Now, then we determine the power factor angle, once we have determined this D C variable the power is going we can now, what will be your power factor angle.

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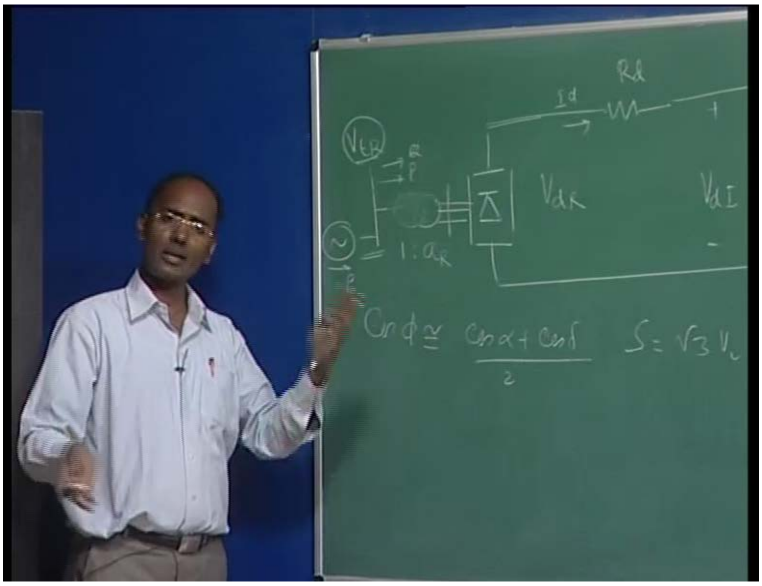

And you know the power factor angle is cos phi is approximately equal to your cos alpha plus cos delta by 2, this equation also we have proved it normally it is approximately equal. So, the power factor angle we determine because alpha may be unknown by solving you can get the alpha depending on the control modes. So, here also u is there so all involved here we are just getting this, means you can calculate u also based on that equations.

So, calculating this you are just calculating the power factor, why the power factor because, at this bus we only have the real and reactive powers. Because, what is load here is going it is your P and it is your Q; P is basically say, we are assuming if it is loss less, we normally assume the loss less and we take it.

So, the P is say, we require Q and for Q we require the power factor. So, here the power factor is dependent then you determine P and Q loading of the D C system bus as I said we had required this P and Q. Because, this P and Q require in your a c load flow, because if here what we do this d c we take as a load here P and Q and solve our a c network.

Because, in A C load flow we require P and Q at any bus that you can just calculate it, in the D C we can calculate this from the solving this D C equations. So, once you adjust after power factor the P and Q loading of the D C system, once you have calculated here the fourth stage. Then you have to solve the A C power flow, means first we solve the D C, then we are going for the A C with the initial guess.

So, then you are calculating solving this, what is happening now you are getting the different V t R. Once you are solving this as a load this whole A C load flow this voltage will change now it is a load bus because your initial guess is not perfect if it is perfect we will get the same; may be here also we had the initial guess in solving this non-linear equations 1 2 3. So, it will be certain different, then what we are doing, once here calculated the V t R and before that you assume certain value here what was this V t R.

You will take the ratio the tapings will be changing, because based on that whatever you have taken the initial guess on the taps based on now this, V t R you are getting different means your tap position is going to be changed if it is same means taping is same. So, once it is same here, then this is a solution (Refer Slide Time: 20:43), no need to go further, because here already you have solved and everything is clear now the power is flowing.

But, if it is not so, then you have to adjust your the D C variables here the voltage and then again keep on repeating, so that you can get the tapings as well the constant. So, this is your sequential load flow in this you have to solve the D C equations go for A C again then D C, A C and finally, you will get the converse solution. I will come again here this is your the P with the negative load and this is your Q.

So, this is also a load bus with the negative power, nothing else, we will get the P and Q here again the power factor here also means similar to this only the direction of P is here changed. Here, you are taking as a P Q load both are going away means as a load here is a negative load. In fact, if load you are taking the bus is coming out, load as a positive this is negative P Q will be in the same direction, this will be more clear, when we are going to combine the A C D C together, then certainly the P will be coming into the picture.

Now, here you can say what is this bus, it may be a generator bus here huge generator it may be hitting its limit again the Q you have to verify whether it is a generator bus or not. If generator bus the voltage is same this side, that side is there so this is a D C solution no problem; because the voltage is maintained the reactive power it is given reactive power will be taken this will now vary, the power factor will be changing nothing else.

Here no, if it is generator bus here the P becomes whatever the P is going, P you know you have to write the P equation in the A C as it is no different. Whether you are taking as a load bus or generator bus it depends on, whether you are having a generator or not. If you are having a generator you can take as a generator bus, this will be the negative load at this and then you can solve it and you have to check it is reactive power generation whatever reactive power taken and this like similar a c load flow no change at all.

Only here, you have to take this D C system equivalent to the P Q load nothing else here also you have to take this P is negative and this is Q as a D C you can say the load D C system is just represented as equal and real and reactive power loads nothing else. Now, (Refer Slide Time: 23:21) let us go to your extended variable methods, in the extended variable methods normally, what we do we use the Newton Raphson method in the polar coordinate it is very easily we can incorporate it.

But, we have to go for the you know in the Newton Raphson load flow we write, the power mismatch equation, now I can remove this, because it is you are not going to use.

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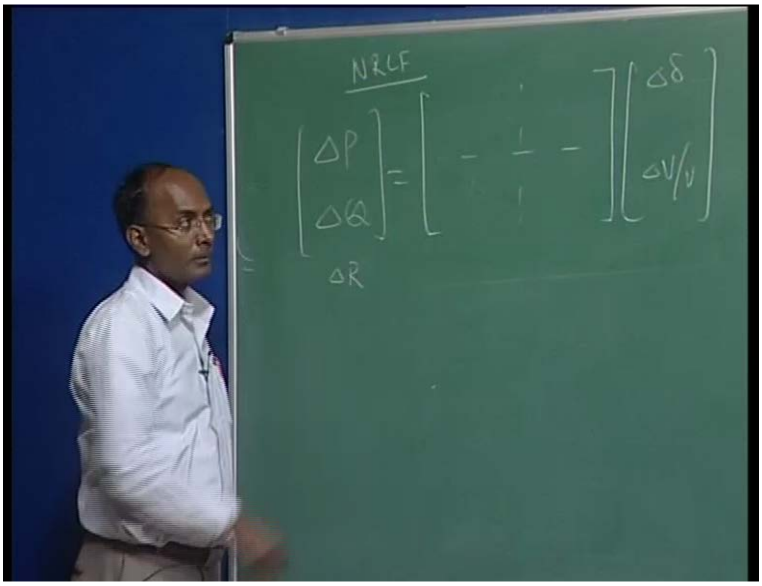

You know this in Newton Raphson method here it is your P it is your Q already I just just just reviewed it in our previous lecture, that is lecture number 1. Here I am using the delta, here I am using del V by V here, we are having the Jacob this is your Newton Raphson load flow methods in polar coordinate.

So, you can see in this equation if you are going to include your D C here and now I am talking the extended variable methods, means we have to extend it; we have to extend the variables here, corresponding to D C. Now, if we are going to extend it here, now we had the 3 D C equations as I said the basic 3 D C equations 1, 2, 3 that was your here it was your R, I am writing means you are having R 1, R 2 and R 3, 3 equations. Here, you know it is again the P 2 if 1 is slight P 2 to P n, here if it is the how many load buses it is corresponding to this, because these are the vectors.

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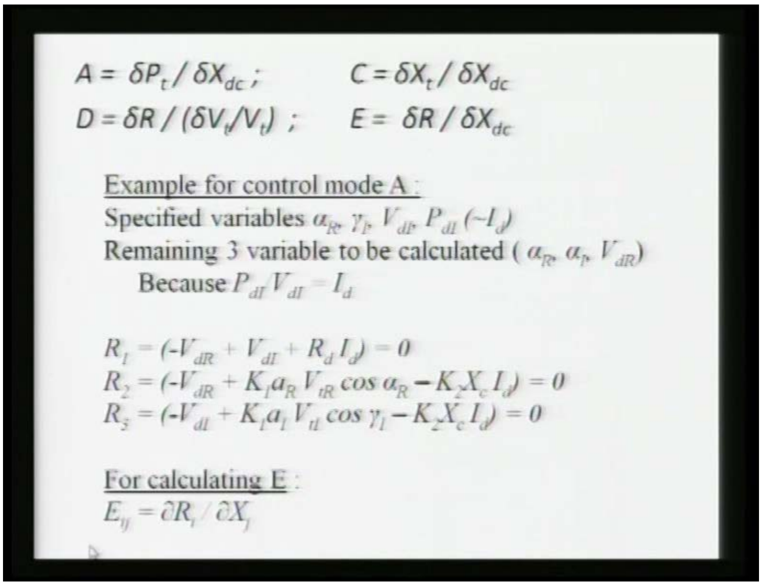

Similarly, here R I am writing means your equation number 1 what is this R 1 you can see this this is R 1 and R 3 you can see here. This is you can say this is R 1, this is R 2, this is R 3 hardly matter (Refer Slide Time: 25:22), wherever you are writing again this you have to derivate you have to add the elements here written. But, these 3 equations what we did R 1 just it is f X equal to 0, f X 1, f X 2, f X 3 this is the same equation 1 and 3 just I wrote 1, 2 and 3.

So, this was 1, remember this was 2, this was 3 (Refer Slide Time: 25:41), so here R 1, R 2 again you can exchange its up to you but, accordingly yours this Jacobean elements will be modified, it is not that you have changed here and you are writing their derivative in different one.

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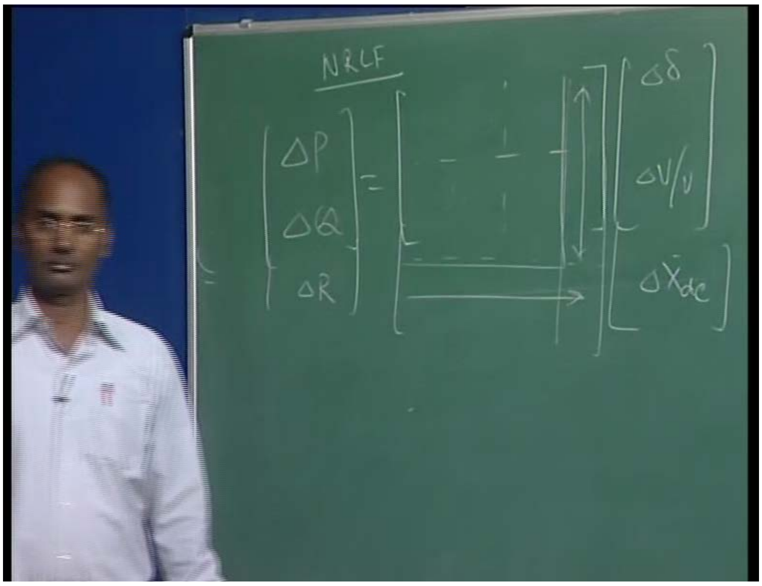

Now, with this we are going to have some extra elements here and that corresponding to here, your X d c. Because, this is corresponding to we are going to solve the 3 unknowns and the 4 will be specified, so now again this matrix is going to be square matrix.

So, what we are doing, we are adding here the elements corresponding to this one and corresponding to this one. Earlier it was size was less corresponding to only this now we are adding the elements corresponding here there will be some elements I will discuss what are those elements and we are also adding the elements here. So, this is called your extended variable methods that is in terms of you're here, the Newton Raphson polar form before that let us combine the equation.

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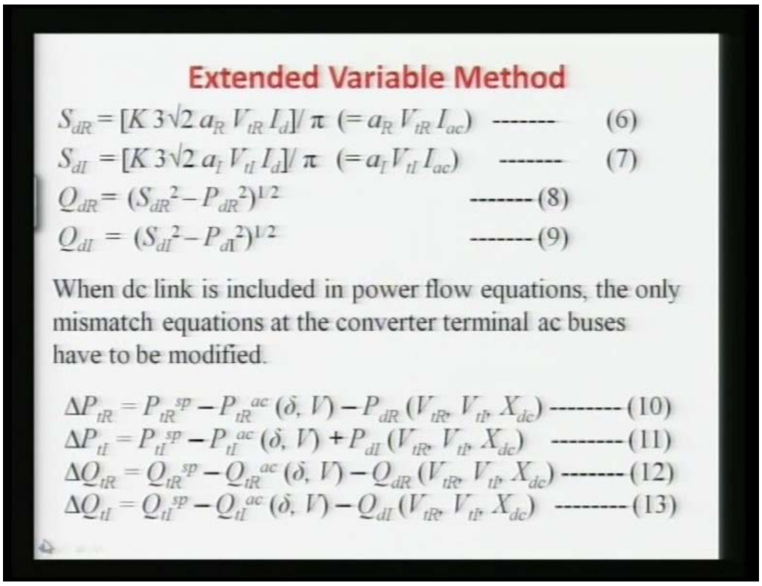

And I will come back and we will see what are the various elements we require this reactive powers here as well for the rectifier end and your inverter end. Because, these Q d R and Q I S are required, because you are writing the equations for the D C, here what virtually. We are doing the D C equations, we are writing but, the Q d R and Q d I we are representing that will come here the Q d R and P d R are the functions of this, because this at any bus.

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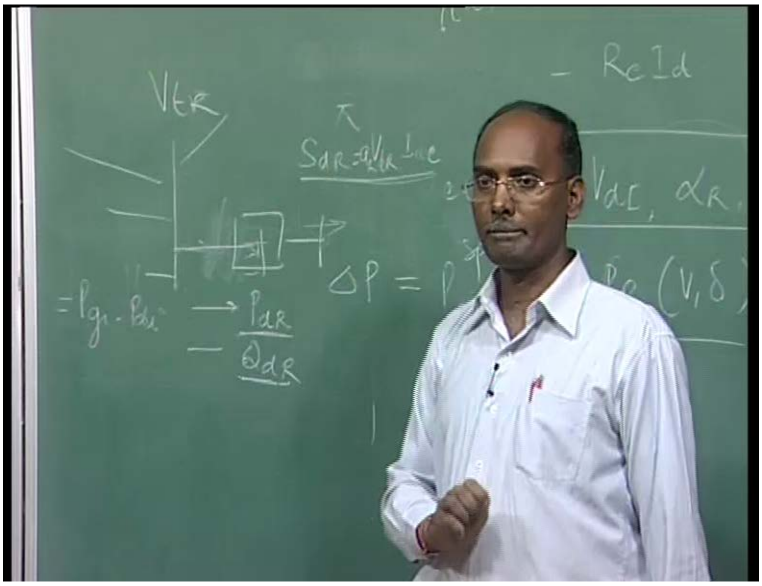

Now, here this is your V t R what happens we are having so many lines the A C lines and we are having corresponding to your the D C means at this bus. If you are writing the power balance equation, means here I can say the P is rigified this P i, here it is your P g i at this bus I am writing. So, I can write the R not I here oh sorry P d R this was your equation if you remember when there was no D C, it was equal to your this is a function I can say or I can say P R is a function of V and delta.

Now, I am complicating the function it is nothing but, if you remember what was this it was the summation of V i V j is equal to 1 to n here G I J cos delta I J plus b I J and delta I J mutual function means it was a function of voltage and here I can.

So, in simplicity here I am not writing this I am writing here is a function of voltage and delta, when there was no D C. Now, if I going to have the D C here means this is going to change and you know the D C is equivalent to we are going to take here some power here P d R and your Q d R. So, if you are writing the P d R, which is taken as a load means, this I can say it is just like a P d R if it is a rectifier, mind it what I did here this is we are taking now including the D C.

So, minus this is coming here, because it is a load in the rectifier I am writing, inverter it will be plus. So, this we are writing the expression here, I can remove this because, we are not going in detail about this, because the a c already load flow we have studied. So, here we are having this expression.

Now, what is this this is nothing but, you will see this value is your specified here at that bus, because this is changing how this depends upon something is going somewhere; this power generation and the load here at this, because this is just like a line this is going here and there. So, whatever here we are writing that is the P g i minus P d i this is basically specified power that is we have what is generation, what is taken away others are going here and there.

So, this value is nothing but, your P R specified at this bus that A C load you know the D C load you do not know, because this depends upon the control mode how power is going that is varying but, this value is known to you. Now, if you are taking this side here this becomes minus, here this is minus and this value already it was minus here I can say P d R this equal to 0, got it what I did. This is your P g I minus P d I specified this was that side I keep this side the minus sign, it was already minus here we were subtracting.

So, we are writing a equation that is f X is equal to 0 which is a non-linear equation we have to solve. In the A C Newton raphson without d c we solve this equation is equal to 0 remember. And this we want to put as some change in the P this should be 0, that is a mismatch we always calculate it should be 0, so that we can say we are exactly we are matching this here. So, this equation here, you can see this is written the equation here I have written the P t R, P t R (Refer Slide Time: 31:50).

Now, I am writing this A C here is written that we are taking at this converter end this value is your here we are taking the P t R that is specified R is rectifier terminal. Basically this is known as the rectifier terminal that is the A C here, it is a inverter terminal specified, I have written. And then minus this is your usual A C, connected A C network this is corresponding to your D C.

Now, here in the D C we are having it is related with your this t R and the t I as well we want to see whether is related or not and then X d c variables are there. Because, there P d which is going to be there it is a function of V t R, V t I and X d c no doubt out of them everything it may be only dependent on V t R. but, we are writing in general it will be dependent on your this terminal voltage of inverter, rectifier and some d c variables may be other will be 0 but, I can write in general it is a function of this. So, here I am writing this should be equal to 0; similarly, if we will go here it is the inverter basically, inverter is again here up to this is similar, because this is a bus A C bus.

So, this we are not considering the inverter, because in a c side there is no change but, here you can see here, I have written plus. The reason is obvious I explain that is the power is going to the A C system. So, instead of this here it is going to be added that is going to be injected in the inverter side, so this is your plus that is P d I which is going the A C system. Similarly, you can write for the reactive power at the 2 terminals your this rectifier and inverter here but, in the both cases here, it is negative the reason both are absorbing the reactive power.

So, already I explained, so that here the sign is minus and minus so, this 4 equations, we require and then we can include this. Now, come here if you will see this Q d R and Q R we have to write S d R square minus P d R, because we want now D C here the Q d R as well P d R already we wrote in terms of the D C variables.

But, the Q d R here, now we want to in the sequential method, we are calculating the power factor here we want that we can write in terms of terminal voltage and the d c variables so it will be easily accommodated. Because, there it was possible you are doing the sequentially, then you can calculate other variables. Here, it is inside because here the power factor is not a variable it is not any variable here, we want the this Q d R in terms of your D C variables.

So, what I am going to do now you can say what is the S d R in this equation, the here this power which is going here at this terminal, I can write this this power which is going in d c side here. What is the current going here, you remember it is your, I can write this is your this S d R will be your V at this point now I am writing in the per unit. So, this into your I a c, which is going at this point, because this the voltage we are taking the same base, here the V into this value, what is this a c here this is value we are taking this is going to be inside the current we are calculating in terms of the d c variable.

Now, if we are taking this terminal voltage here, it will be here a R t R here into there and this value will be there this is a complex power at this bus now. Once you are having here now you can put the value of I a c we already we derived in the per unit here and if you are going to put this value, you are having why I want because here the V t h R. We want to be a variable here that is already that is the function here the V d h here will be appearing, so this equation is also dependent on voltage.

So, we are trying to accommodated because is extended, so that it should not be decoupled. Once you are having decoupled means it is a sequential method, so this your equation is having the V d h here, the voltage dependent on this here and that is why we are relating here. So, we are trying to eliminate some of the few odd variables and here we are writing in terms of this, so the V t R should be there.

So, here I wrote here this complex power at the rectifier terminal taken by the D C system that is a converter here, we can write here a R (Refer Slide Time: 36:57). This is rectifier o l t c this is a terminal voltage, where we are this we are calculating this and I a c that is current through going there. So, this value for putting I a c value here in terms of d c you are going to get already we proved it here. Since, we are writing in the per unit mind it this K term is appearing again you are taking it as 1 or this because now every base should be same.

So, the current here you are writing in the per unit this K will be appearing here because now we are writing in that here complete this equation is written in the per unit basis. So, that is why here K is appearing, means here we are writing a c in terms of per unit so this value is giving this terminal voltage is a c. So, base is divided by the related value so that is nothing. Similarly, I can write here for the inverter the complex power here, we can write in this form.

And now the P d I and P d R are not in terms of the d c variable you can write, so your this reactive power at this bus that is your D C side require the reactive power here rectifier and this is a inverter you can write in this fashion.

So, you can put this value here, you are writing this is here and that is means you can say this is the function of V d h here is V t I and V t R is coming and the D C variable as well these are the d c variables already I defined. So now, from this you are writing some more and here we can write the mismatch factors, if you are having 2 terminal A C system mind it. Here in this case now we are going to discuss only the 2 terminal, if you are having the multi terminal, then whole the scenario you are going to write another equations as well.

Means we are assuming there is one rectifier, one inverter so we are having 4 equations one for real power one for reactive power. Similarly, we are having one real and reactive this is for rectifier here, this is inverter equation now. So, that is why here it is written when the D C link is included in the power flow equation only the mismatch equations at the converter A C buses have to modified; means only at this point we have to modify.

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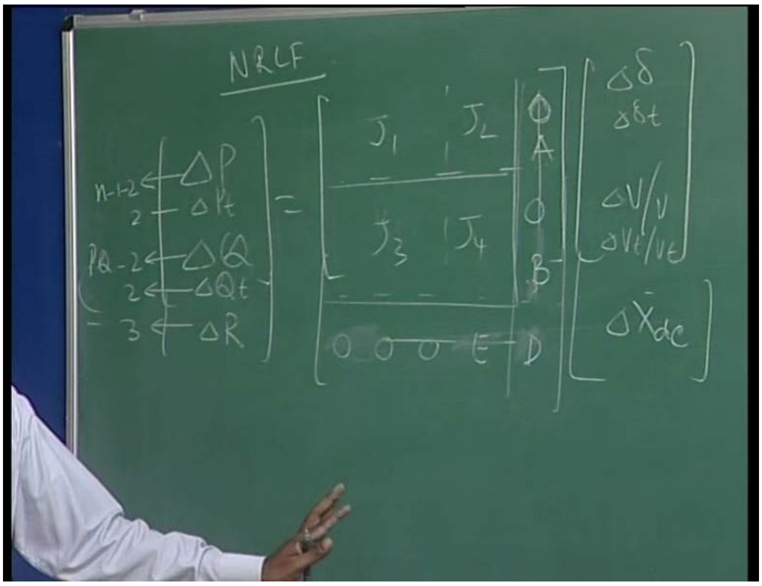

Now, you see in this P and Q we were having the buses included because in this here if you are taking this is V t R and you are having here V t I these are the a c side and they are in the analogous itself. So, they were here now what we are going to do and that is depending upon this X also, what we are going to do. We are going to write this equation to separate out the two corresponding to rectifier inverter, this is the P I am writing here the change in the P and other work means.

Now, this vector suppose you had the n bus, then it was your now n minus 1, because like we have to note it, so this is was this. Now, what I am doing I am taking 2 again here outside 1 for rectifier 1 for inverter now this is going to be your n minus 1 minus 2. So, this vector will be having, suppose you are having fourth bus is your rectifier bus, so you are writing here 1 is less.

So, you write 2, then 3, 4 will be not there but, there will be 1 inverter also, this is correspondingly we can take here. Similarly, here you are having the t is basically the terminal, the t is related to terminal and it is h V d c terminal. So, you are going to have here the 2 elements here, again the load bus is minus 2 and here you are going to have 2 means here I can say P Q minus 2 P Q buses. Now, this you are going to have 3 vectors 3 elements that is R 1 R 2 and R 3 here.

Similarly, here also we have to change here, we are going to have delta t the again angles are terminal of h V d c here also we are going to V t divided by V t and this is there. So now, what we do what we did we just take out this 1 the corresponding to this here, if you are derivating this there is no a c there is no change mind it. But, if you are derivating with this the value will be changed.

So, earlier whatever you were having this Jacobean you can say J 1, J 2, J 3 and J 4 it will be intact it will not change, because a c side you are derivating no d c variables. But, if you are talking here other than these two buses, if you are differentiating with this it will be 0 because independent is a partial derivative. So, it is independent and that will be 0, now corresponding to this with this it may happen.

And I can write here some element a, this is a matrix what will be the order of this matrix? 2 by 3 because 2 this is your elements here 2 by 3. Now, here it will be 0 corresponding with Q, because other than these two buses, here we can say it is your b matrix it should be there, it will be again 2 by 3. Now, come here this 1 with effect to delta have you seen any delta, in even though the d c bus including even here, in this equation it is no delta. This is not that delta mind it is not delta u plus alpha, this delta is the power angle of this; so it is not there so it will be 0, so corresponding to this even the both total here 2 it will be 0.

Now, corresponding to this it will be not here but, here it will be there because V t R and V t I is appearing. So, here I can write though if you want to take it separate out, so I can write 2 here (Refer Slide Time: 43:40) one corresponding to this one corresponding to this one corresponding to here, this is 0, one corresponding here I can write E. And 1 corresponding to this here, I can say D, any doubt, because this is 2 and here X d c is 3; so this element basically a.

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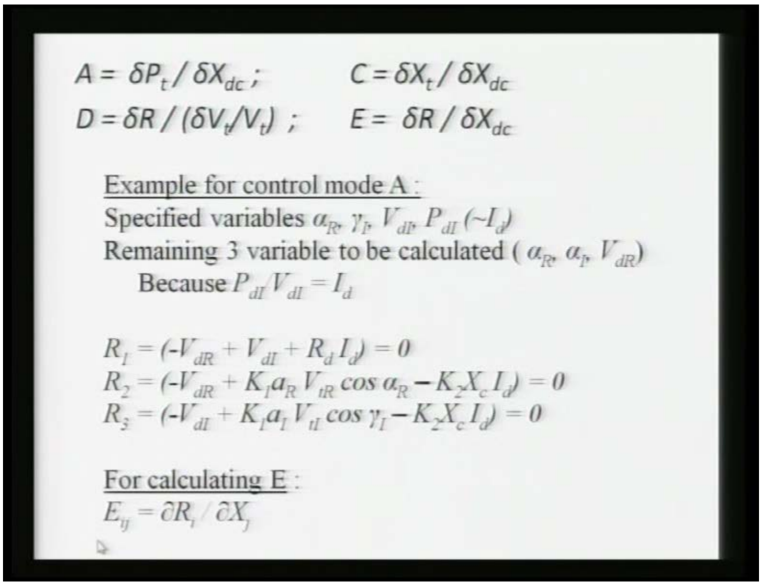

I will come back here we can see you here A is the P t this power at the terminal buses differentiated with this X d c. Here this is corresponding to this corresponding to this here we are not changing, because it is a c side and there is no change at all, only this due to this P t only the 2 terminals are appearing this will be this otherwise this will be 0. Because, the X d c is independent of outside these 2 buses, only these 2 buses where the d c and a c are related mind it. Other buses only a c and here, it is a c and d c again where here, we are writing the V t also no del V upon V we are writing del V t upon V t we are writing no, no this is corresponding to rectifier and inverter.

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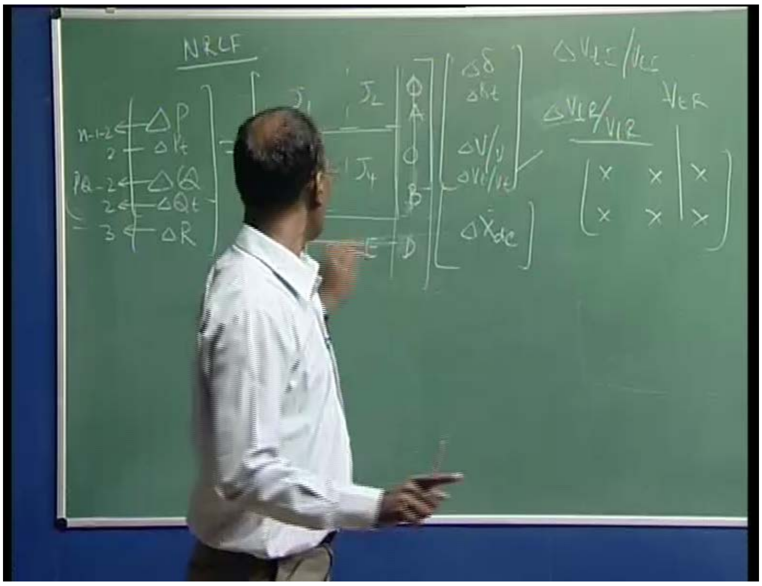

This is a vector 2 by 2 is a 2 means R means this is your del V t R, this is basically this is del V t R by V t R 1 element. And another is your del V t I by V t I this similar to here we are writing, this is earlier in the polar form same here we are dividing again. This is the same reason you remember it is due to the giving the quadratic conversions that why we are dividing if you are not dividing.

Basically you can solve this power flow no problem only it will raise larger iterations and sometimes it may not converse. But, here by dividing this the function why is it dividing already it is explained in the first lecture, so that is why here the only what I did here it was the voltages all the P Q buses, I have taken 2 out. So, that is why here del V t upon V t we are again writing to make the uniformity this otherwise the Jacobean will change if you are not dividing here.

We want this Jacobean should be as intact as A C power flow no change only this 2 buses we are taking out and for this we are just talking here. So, this d will be you can see again I will come back but, let us see the basic principle here what we are doing. Now, here as I said we are having in your these 3 equations, we are having the 7 variables here.

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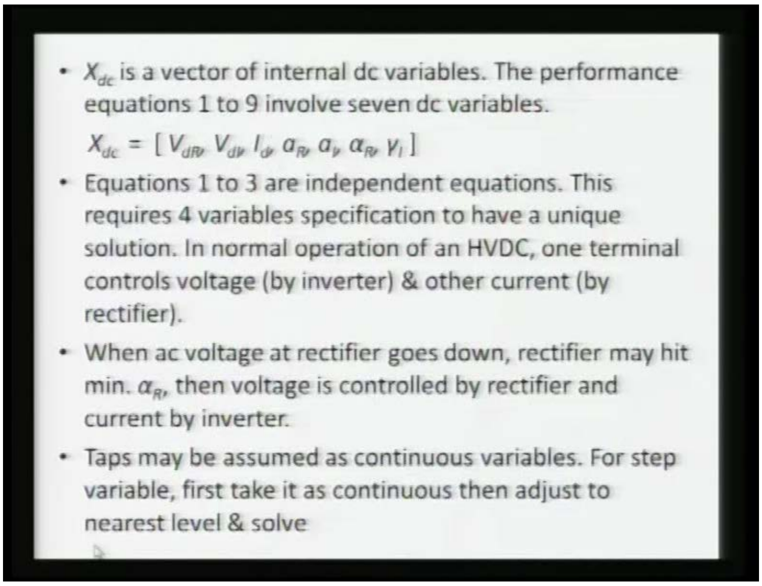

And that is why it is called X d c, so here with whatever it is appearing here this X d c is represented by this 7 variables here. And we are having only the 3 basic equations means the 4 should be stratified, so here it is written in the sentence the X d c vector is internal d c variable and the performance equation 1 to 9 involve the seven d c variables we find all this variables here. Already, I have written completely here, equation 1, 2, 3 are independent equations, so we can use it and this requires four other variables to be specified to solve this 1, 2, 3.

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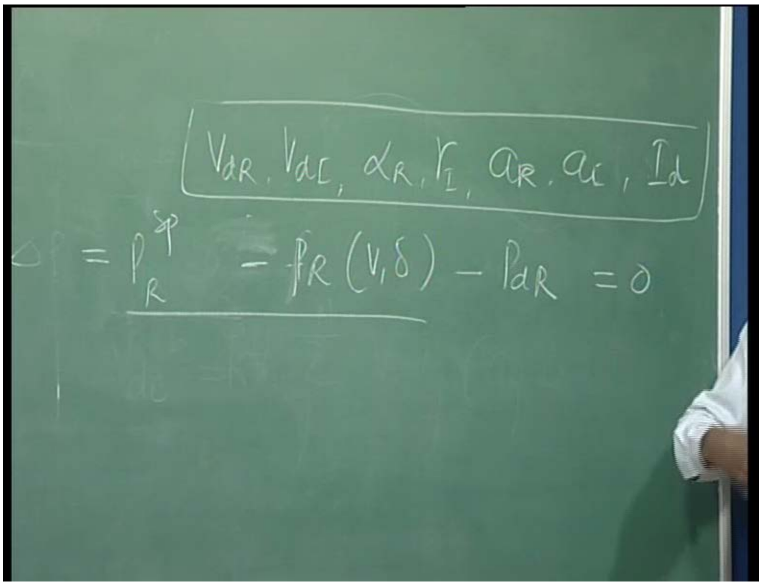

So, already I explained, we require here this out of seven we require four, six and three we can solve it. So, in normal operation what we do normally the one terminal controls voltage normally inverter controls voltage and your rectifier controls your current. But, again it keep on changing depending upon the scenario and the control modes are changed. So, here also if you are taking starting with 1 control modes if there is a some heating value here and there voltage and terminal voltage are not there then you have to change the control modes as well.

Another here that is what here written if the a c voltage and rectifier goes down the rectifier may heats alpha minimum value and then voltage control by rectifier and the current here is shifted. The types normally it is not a continuous variable over here in whole this we are just solving as a 1 variable. And variable means it is a it is not a discrete we are talking as a continuous variable but, type cannot be this cannot be in several fractions.

So, what we do first we take as a continuous variable then we fix it is near value and then again we solve it and we see it. So, the tapings even though in A C also in the A C load flow also that o l t c transformer is there. So, tapings are taken as a your continuous variable then we fix its nearest value and then we again solve it. So, that is why here it is as assumed to be continuous variable.

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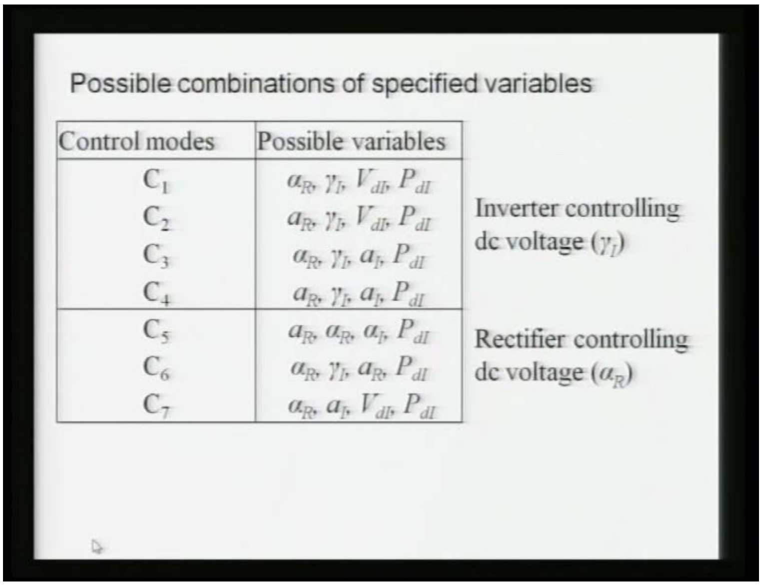

Possible combinations of specified variables

Control modes	Possible variables	
C_1	$\alpha_R, \gamma_I, V_{dI}, P_{dI}$	Inverter controlling dc voltage (γ_I)
C_2	$a_R, \gamma_I, V_{dI}, P_{dI}$	
C_3	$\alpha_R, \gamma_I, a_I, P_{dI}$	
C_4	$a_R, \gamma_I, a_I, P_{dI}$	
C_5	$a_R, \alpha_R, \alpha_I, P_{dI}$	Rectifier controlling dc voltage (α_R)
C_6	$\alpha_R, \gamma_I, a_R, P_{dI}$	
C_7	$\alpha_R, a_I, V_{dI}, P_{dI}$	

Now, come to the control mode means we require 4 variables should be specified. Here, you see if this inverter controlling the D C voltage means here you will find the gamma is everywhere, means it is in C A control.

If here rectifier controlling the D C voltage you will see alpha R will be everywhere no no, no alpha R, alpha R, alpha R, it will be only the sequence is changed. Now, here in this 7 I d I have written, here I am writing the P d I, if at V both are same, here if the V d I is there divide this it is current the current is small. So, basically from the V d I you can calculate the current here, so it is the P d I is I d is almost same and then that can be taken.

Because, in the D C link what we do instead of knowing the current, normally we know the power more variable here how much power is flowing here and that end. So, it is taken this I d is basically related with this P d, so the P d is everywhere and this is 1 of the this power is fixed, that how much power you are flowing in this link.

And then remaining you can calculate the control mode basically, because power normally set in the D C link, this is the beauty this how much power you are setting if your power here keep on changing you can change the different power and you can again calculate the d c variable.

So, you can see this is I d is everywhere I can say and others are here alpha, gamma V d I all this here the fixed the various control modes normally we call the seven control modes are there. And then we will see if these are the possible specified variable remaining are to be calculated for example, if we are taking the control mode C 1 here what are the unknowns.

Here one is your V d R, V d I is there I d is there alpha R is there means your a R is missing, gamma is there means a I is missing. So, we have to calculate your a R, a I and means we are requiring this, this and V d r (Refer Slide Time: 51:05). So, this 3 that control mode should be calculated from there.

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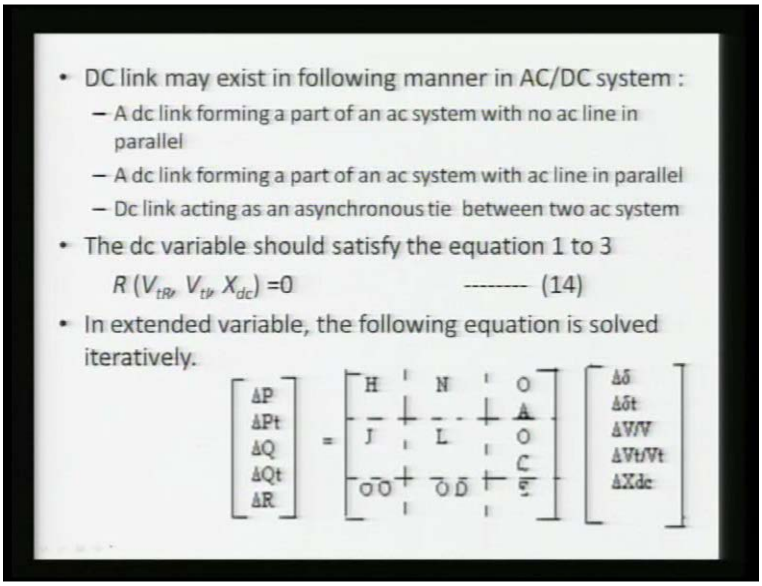

Now, let us see now, again how this h V d C’s operate you know there is various option as I said in the system here.

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There is a possibility that this system is having A C line and then you are having a D C line parallel to this or you do not have any connected in the A C system here itself. Means option a that you are having here no A C line parallel, means you are having this type of somewhere in inside the complete synchronized system is there. Another there is a possibility you can have the parallel direct A C line, another option that here the two systems, independent systems are connected by D C system.

They are operating to the different sequences, so the three scenarios can be there inside the A C system or it is the two different frequency systems are there. Now, if the two different frequency or system there, so they must be solved separately, because they are operating at the different frequencies. So, it is just here what is the P and Q and here also is a junction and you can just solve it but, if it is a inside embedded, then you require a c d c system combined together.

So, for this type of I just said one and two options, now you are going to modify it, one is there so independently you can solve it without any problem. Now, you can see here what I have written it is I have written here, you can see instead of here b it is c is written. The reason c is more convenient, because b looks like the b of y bus matrix you know.

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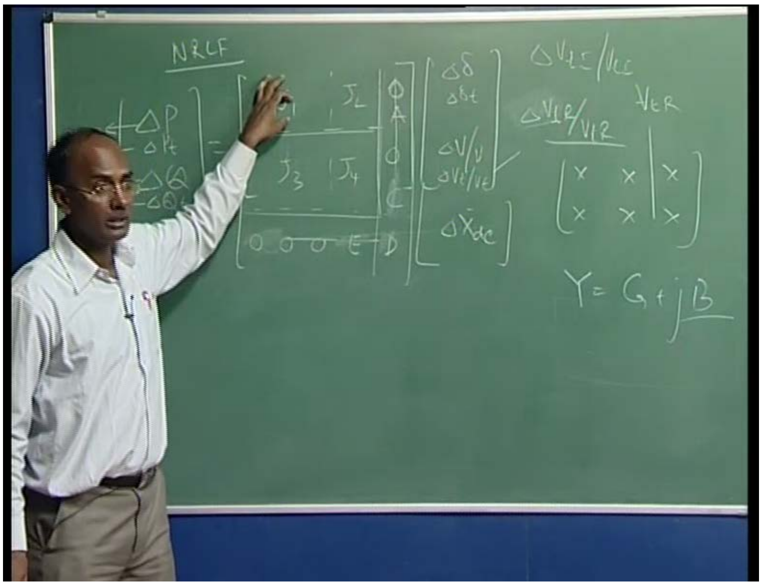

If you write here y it is your g plus J b, so to avoid the confusion it is better to write c so that is why c is here nothing else. Here J 1 g 2 sometimes if you write here h n J l in some books you will find, so purpose is here this h is your J 1 here is J 2 here, means this is a derivative of your real power with your delta. This is your real power with respect to voltage, here reactive power with respect to delta here again the derivative of your reactive power with respect to voltage.

So, these are here you can say same and now here you can say already I have written 0, 0, 0 here again, here I have written D and E. So, we have to write here D and E so that already I have written the equations corresponding to that, so otherwise we have to change it. You can give any name but, again if you are writing D, so it will be again now what will be order of this matrix.

It is 3 will be sure, because R is corresponding to this 3 cross 2, because this is corresponding to this and this is 2. This will be 3 cross 3, because this corresponding to this derivative of this. So, here you can find this you see now these are the value here, with that notation, now you can see this is a actually this is not so proper writing there is some change its a partial derivative it is not del. So, you can change it here, so you can see here the D, E and other values are written here and these are the matrix sizes, means it is of some order of matrix sizes and these should be calculated.

Now for a given here, suppose you are taking the control mode A or I can say C 1, now your these variables are specified means you have to calculate this 3 as I said here the 3. And then you have to if you are writing R 1 to R 3 here in this fashion, if again you can change R 1 R 2 anyone depending upon yourself. Then we can calculate these values for matrix sizes.

So, here now first I will calculate this E that is square matrix very simply right, now this is nothing but, you can see this R here, we are just differentiating with R to X d. Now, again here X what you are denoting, X if you are writing in this fashion if f d R, a R and your a I, then accordingly you have to differentiate it. Means this is your X d c 1 here, X d c 2 here X d c 3 or if you are changing then you had a matrix and this will be always consistent.

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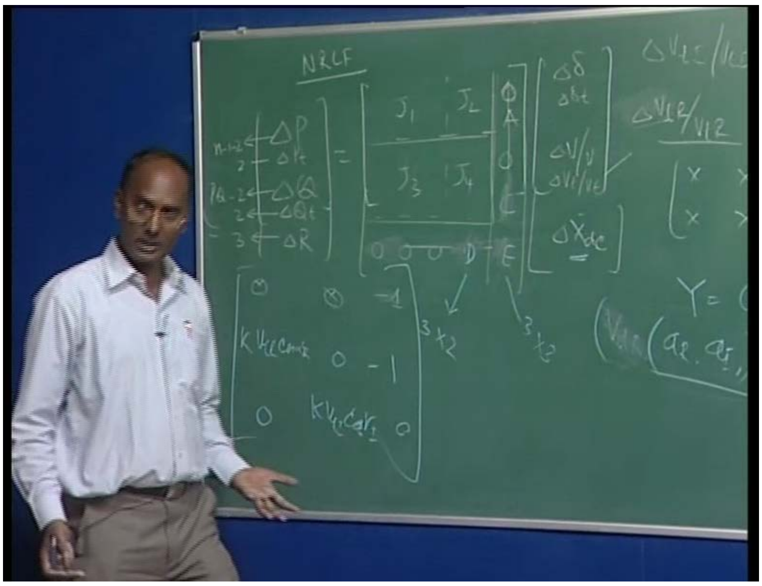

So, you have to decide R 1, R 2, R 3 you have to decide this unknown value accordingly. So, what I have decided here I am saying this is a R means I am writing in terms of this then it will be your, what will be X d c I am writing in this way. This is a vector should be calculated, that is why here it is written. Now, if you are taking R 1, R 2, so this E element here, E we are having this I can say, 3 cross 3. Now, R 1 is to be differentiated with this here, so if this is R 1 if you are differentiating with a I, what will be this value.

You know it is a partial derivative is independent, if R 1 is differentiated with a I, if you differentiated with this one, it is not 0 it is minus 1. Now, if you are differentiating with this the R 2, this is 0 here we are taking the term yeah this K is appearing here not K 1 is the K bus K yeah. So, this here the differentiating you are differentiating here this K V t R cos alpha R is appearing, so you are getting K this is your V t R cos alpha R what plus this will be 0.

No, no this is alpha, we are taking I a it is A basically it is a actually this is a typing mistake that is alpha and A all basically slightly confusion. So, this is you're a, this is your a I, so this will be 0 we are getting this value, now if you are here 0, next with this V d R again minus 1, we are going to have minus 1. Now, 3 here this is alpha a R 0 here we will get K V t I cos gamma I here, sure V d R not V d R yeah, so you can see these elements are calculated.

So, only you have to see that is your you have to sequence your X d c you have to write this and it should be throughout the same it is not that you have to exchange here and there because these elements will be getting modified.

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You need yes because then you otherwise you cannot fix the 4 variables so it is will given to you this is a control mode in basic it is operating then means these variables are fixed it is known to you and then you can calculate this yeah. It will be keep on changing if it will be hitting some limits, because let us suppose that tap is hitting you are calculating tap is coming something absurd, you have to fix that value.

And this is the fix now tap is no, then it will be going to different control modes. So, it is basically keep on changing like your P V and P Q buses, so here also it will be keep on changing. And then we can calculate E and similarly, we can calculate others and we will see in the next term again and then we will go for the variable elimination methods that will be end of A C, D C load flow thank you.