Electrical Distribution System Analysis
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Lecture – 20
Modeling of Step Voltage Regulators
Part III

Dear students, we are studying Modeling of Voltage Step voltage Regulators. And in the last class we have seen line drop compensator circuit. And we have seen that it is basically used to control the voltage regulator based on drop which is happening inside your feeder. And then we have gone for three phase voltage regulator.

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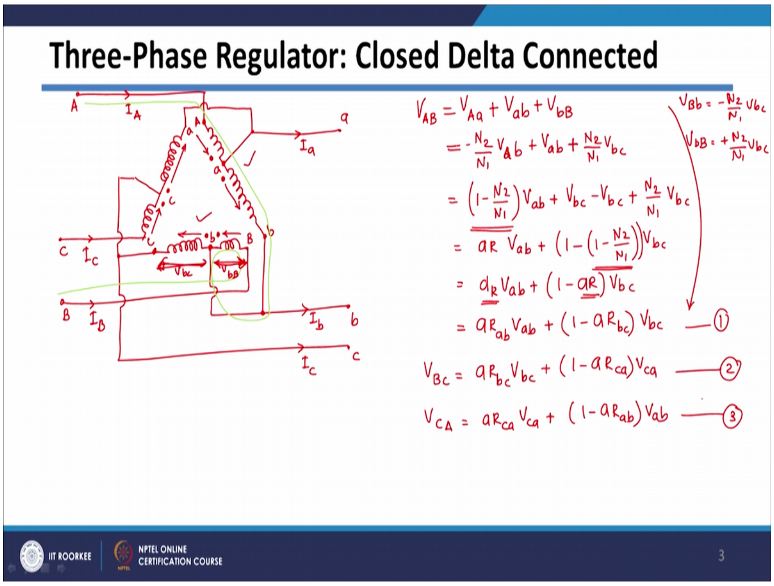

In today's lecture, start with three single phase regulators if they are connected in delta fashion. So, if they are connected in delta fashion, the connections will be something like this. So, it will be in delta. So, again there will be regulating winding. And this is your common winding for one phase this is regulator and common winding for second phase; this is regulating and common or shunt winding for third phase. Now, connection of these will be something like this. So, your A phase will be connected here; so this is capital A. Then your B phase will be connected here; so this is your B phase. And your C phase will be connected here.

And then this regulated terminal. So, basically we know that this is regulator terminal, which you are taking out and this will be small a terminal; this regulator terminal we are taking it out. This will become your small b terminal. And if you take this regulator terminal out, it will become your small c terminal. And to connect this in delta fashion, what we need to do is we need to connect this with a, and we need to connect this with b here, and we need to connect this with c here.

So, in this case also I am considering this single phase regulator which are connected in delta, I am considering for raising position. So, when you are raising, we have seen that your dots are placed at the load terminals; both the dots will be at load terminals. And in that case your currents will be this current is small I small a, I small b and this is I small c. This will be I capital A this is I capital B and this will be I capital C.

And then current direction here the I a current is entering to this node means it should leave to this node it is entering means it should leave this dot this is entering to this dot means it should leave this dot here. So, this is basically if you see this terminal a terminal is coming here; your b terminal is coming here; and your c terminal is coming here. And this is your capital A terminal; this is your capital B terminal and this is your capital C terminal. And this is again small a terminal which is same; here I am getting this as a small b terminal, and here I am getting small c terminal.

Now, to get the voltage and current relationships, we can write equation for say V ab. So, if I write voltage V ab, so basically it will be the current this circuit I am considering from here to here, and then from here to here it will go like this, and then from here to here and then it will be coming like this if you. So, if you consider this loop here, it will be basically voltage V ab. So, if you write the equations for it, so V ab will be nothing but the drop which is happening from this point to this point it will be V A small a plus from this point to this point it will be V A small b terminal because this terminal is small b. And then this terminal is same as here, so then plus V small b capital B.

Then we know that this relation between V aa and V ab they will be just related by your turns ratio. And if you see V aa. So, this to this voltage and V ab dots are in the same us you can say in a opposite direction. So, it will be minus N 2 by N 1 times of V ab because if you see this drops small V ab these drops are this drop across V aa will be just opposite of V ab because dots are opposite plus your V ab plus if you observe this drop from voltage from b to capital B and b to c since if you see this voltages drop drops will be in the same direction.

So, in that case your voltage V db will be N 2 by N 1 times of voltage V bc basically this voltage here from this point to this point. So, this basically this voltage is V bc and this voltage is V b b. So, this direction is V bb is like this and this direction is V bb like this. Since the dots are here the polarity will be same, so that is why I am getting plus sign here. If you it would have been V b b then it should be minus N 2 by N 1 times V b c. Since, it is V b capital B, it is plus N 2 by N 1 times V B C.

So, in this case I can take V a b common from these two terms. So, it will be 1 minus N 2 divided by N 1 V a b plus I am just adding V b c and subtracting the same term. So, it will be just V b c minus V b c same term I add it and subtracted no change in equation plus N 2 divided by N 1 into V b c. Now, it will be turns ratio we have seen aR. So, this equation we have seen that it is 1 minus N 2 by N 1 we have considered aR, and then V ab plus 1 minus 1 minus N 2 by N 1 into your V bc. So, in this case it will be aR into V A B plus 1 minus again this term is nothing but your aR and then it is V bc.

Now, this aR is actually controlled by this regulator which is between a and b phase and this aR is related to this second regulator which is placed between phase b and c so that is why to discriminate that we can say that this is a R a b into V A B, because this depends upon top position of regulator placed between a and b plus 1 minus this is since this is depend on b and c, it should be 1 minus a R b c into V bc.

So, if you apply same steps for other voltages, we can write them directly. So, V BC will be equal to a R b c into V bc plus 1 minus a R c a into V ca and then V CA will be equal to a R c a into V ca plus 1 minus a R a b into V a. And then we have got these three equations, this is equation number 1; this is equation number 2; and this is equation number 3.

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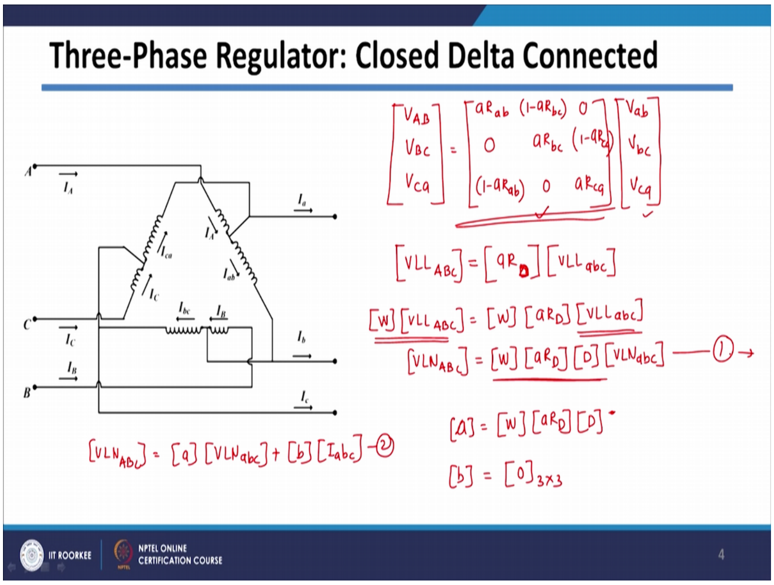

Now if you write these three equations in matrix form, I will get this term here. So, it will be V A B, V B C, and V c a on left hand side, we are having, and then in this matrix we will see what we are getting, and then left hand side, this three voltages V a b, V b c, and V c a. Now, if you see this equation, first equation is a R a b getting multiplied to V a b, and V b c is getting multiply by 1 minus a R b c. So, here, it is a R a b, and V b c is getting multiplied by 1 minus a R b c, and here we are getting 0. Similarly, from second equation, it will be a R b c, and here we are getting 1 minus a R c a, here we getting 1 minus a R a b, here 0 and a R c a.

So, we have got now relation between voltages. So, collectively I can write, this is V line to line voltages of all the three phases on primary side that is why capital A B C, this matrix I can say a R matrix of your delta, or I can just write D, instead of delta D. And this will be again these are line to line voltages, so V line to line small a b c, because they are on secondary side of regulator.

Now, to write the write it as the a b c d parameter, we know that we need line to neutral quantities. To convert these quantities into line to neutral, what we can do, we can multiplied by W matrix, which we have seen in transformer modeling. So, it will be W both the sides, we are multiplying it by W, multiplied by a R in delta fashion, multiplied by V line to line small a b c.

And we have seen that this quantity is nothing but V line to neutral voltages on A B C side, so we have got required voltage relation, and then W into a R D basically this matrix, and this line to line voltages, we can convert into line to neutral by multiplying, or you can say D multiplied by V L N a b c will basically we can get it, this V L L term. So, we have got this term here, and we can compare this with our normal a b c d terminology, which is V L N a b c, we are having a matrix V L N small a b c plus b into your I a b c

Now, if you compare equation number 1, and equation number 2. We can write your a parameter for this type of regulator will be given by W multiplied by a R D, which is basically this matrix here multiplied by D matrix. W and D matrix, we have already seen in our transformer chapter, so this is your a parameter. And your b parameter will be equal to matrix of 0s, so it will be 3 by 3 matrix of 0s, because there in this equation, equation number 1, there is no term related to I a b c.

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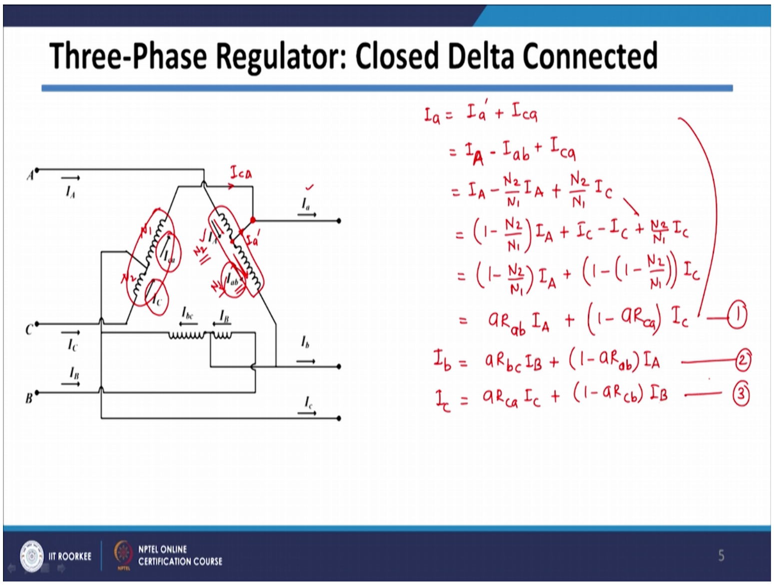

Now, similarly we can get relation between currents. Now, to get the relation between the currents, so that we can get c and d parameter, what we can do we can apply kcl at this particular point. And to apply kcl at that point, I am just I am saying this current is I a dash. So, this current we already seen I a, this is I a, this is I a dash, this is I capital A.

So, if you apply kcl at this point, and from this side, we have seen that this I c a current is coming. So, it will be, so current I a will be equal to your current I a dash plus current I c

a. Now, if you see I a dash, I a dash having two parts, so I a dash is nothing but I a minus I a b, because I a current is coming like this, and I a b is going like this. So, it will be I a I capital A minus I a b plus I ca.

Now, if you see the relation between current I a and current I a b, they will be related by your turns ratio, this is turns N 2, and these are the turns N 1 here. So, we can easily write I a b, this current. So, I A minus, it will be the current direction is same, so it is just N 2 by N 1 times of capital I A. So, I a b, so this current will be N 2 by N 1 times of I a.

Plus if you observe this current, this current will be N 2 by N 1 times of I c, because this is this number of turns are N 2 here the number of turns are N 1. So, this I c a will also be N 2 by N 1 times of I c capital C is capital here. So, in this case also we can take I a common out, so 1 minus N 2 divided by N 1 into I A, and here just I am adding and subtracting term, which is I c, to simplify this equation. And this term is as it is, so it will be plus N 2 by N 1 into your I c.

So, from this I can easily write, it will be 1 minus N 2 by N 1 into I capital A plus, I can write this term 1 minus 1 minus N 2 by N 1 into your I c. So, in this case, it will become a R turns ratio into I A plus it is 1 minus a R into your I c. Now, a R in this case, for first case I A current related to the regulator, which is placed between phases a and b. So, this will depend upon tap, which is tap of regulator placed between a and b that is why I am writing a b. And this is related to this regulator here, which is placed between phase c and a. So, that is why, here it is c and a.

Exactly similar, up to follow the similar step, I can write other two equations. I can write equation for I b, which will be equal to a R c b into, or you can say b c, it will be b c into I b plus 1 minus a R a b into I A. And your I c will be a R c a into I c plus 1 minus a R c b into your I b. So, here also we have got three equations, this is equation number 1, this is equation number 2, and this is equation number 3. And we can write this three equations into matrix form.

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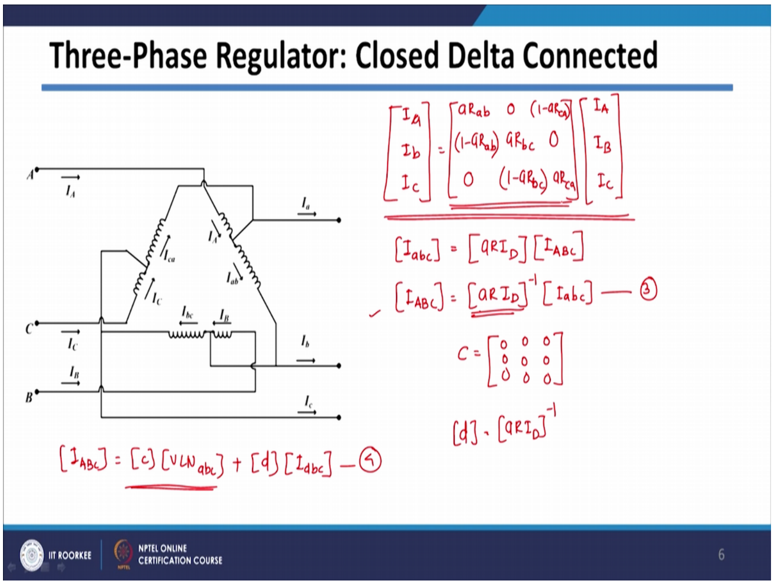

So, if you write these three equation into matrix form, on this side we have seen it is I a, I b, and I c, and they will be related by capital I A, I B, and I C. And in equation number 1, we are getting multiplied with respect to I A, and then 1 is respect to I c. So, in this case, it will be a R a b here, and 0 1 minus a R c a.

Then in second case, we are getting terms related to I B and I A. So, here we are getting 1 minus a R a b, and here we are getting a R b c, and this term is 0. And in third case, we are getting 1 minus a R b c, and here we are getting a R c a. So, we have got this matrix here, so these are line currents.

So, this I a b c collectively I can write it, and this matrix I can say another matrix, which is a R I delta connected, and this is I a b c. So, I can write your I a b c capital A B C will be equal to a R I into D inverse into I a b c ok. And if you compare it, with respect to our standard a b c d parameter equation, which is basically I A B C is equal to c into V L N small a b c plus matrix d into your I a b c. So, if you compare this, there is no term this is say equation number 3, and equation number 4.

So, if you compare 3 and 4, there is no term, which is related to V L N a b c into this equation. So, that is why c matrix will be matrix of 0 0 0. And your d matrix will be equal to your a R I d inverse, where this a I R a R I D matrix is basically this matrix here. So, what a b c d parameters for closed delta connected regulator; One more regulator they use, which is called as open delta connected regulator.

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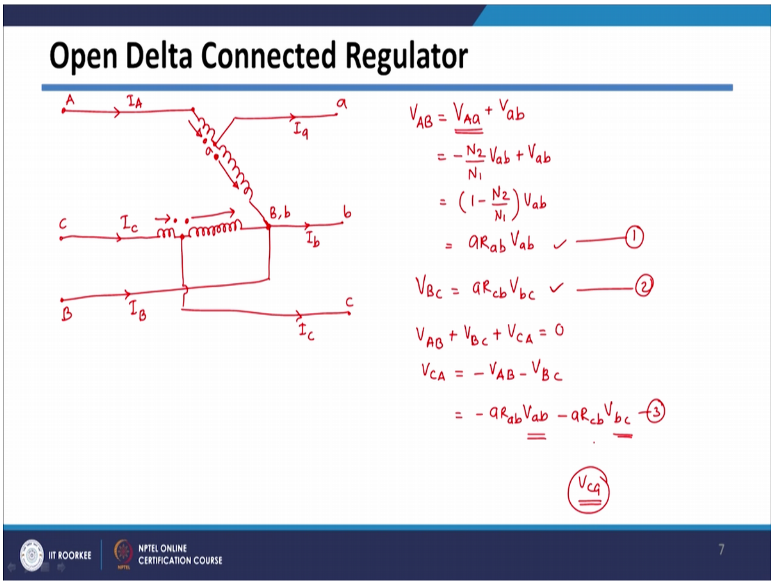

And in this case, there are two regulators, which are connected in open delta, instead of making it closed delta. So, we can use it only using two regulators. First let us see, how they are connected. So, in this case, as I told you there are only two regulators, so one regulator say, this is regulating winding, and this is main winding, it is connected like this. Another regulator is say connected like this, so this is regulating winding, and say this is your main winding.

So, in this case what they do, this will be connected to terminal A, this will be connected to terminal B, and your this it will be connected to terminal capital C. And regulator terminal will take will be taken out, so this will be taken out, and this will become your small a terminal, this will be taken out, and this will become small b terminal, and this regulator terminal will be taken it out, and it will become c terminal. So, by controlling only two regulators, we can control the voltages at a b c phases

So, in this case, you can say this current will be I a, this current will be I small b, this will be I small c, this will be I A, this will be I capital C, and this will be I capital D. So, in this case again I am considering this, in raise position that is why, dots will be at the load terminals, both the dots have same. So, in this case current, which is flowing like this I A, then current I 1 will be through this regulator. And in this case also, I c is coming towards dot, so this current will be going away from the dot.

And now, this terminal is actually both, it is capital B, as well as your small b. Now, to get a and b parameters, as I told you, we need to write voltage equations. So, we can write voltage equation for V A B, so if you write voltage equation V A B will be just this voltage drop plus, the voltage drop across this regulating winding. So, it will be this terminal is small a. So, it will be V A small a plus your V a b, because this is actually both the terminal a small b, as well as capital B. So, I just write as it a small b, because both terminals are same.

So, in this case, we can easily see this V A a, and V a b, they are related, and they are related by turns ratio. And the since the dots are opposite of these direction, your V A a dot will be, this N 1 minus N 2 divided by N 1, and it will be minus N, because these two voltages are in opposite direction, so it is V a b plus your V a b. So, it will be just 1 minus N 2 by N 1 into your V a b ok, this is nothing but your a R.

Now, since this regulator is placed between phases a and b. So, we can say it is a R a b into your V a b. Exactly similar way, we can apply voltage between V B C. So, V B C also we can similarly, write it will be a R c b into V b c. And then V A B, since this is actually three phase three wire connection V A B plus V B C plus V C A, they will be equal to 0.

So, in this case, I can write V C A, because this voltage is not available, which is equal to minus V A B minus V B C. So, in that case, it will be minus a R a b V a b, because we have derived here V a b, and V b c is derived here that is a R c b into V b c. So, we have got three equations here, 1, 2, and 3 if you write them in matrix form, and we will get required your a and b parameters.

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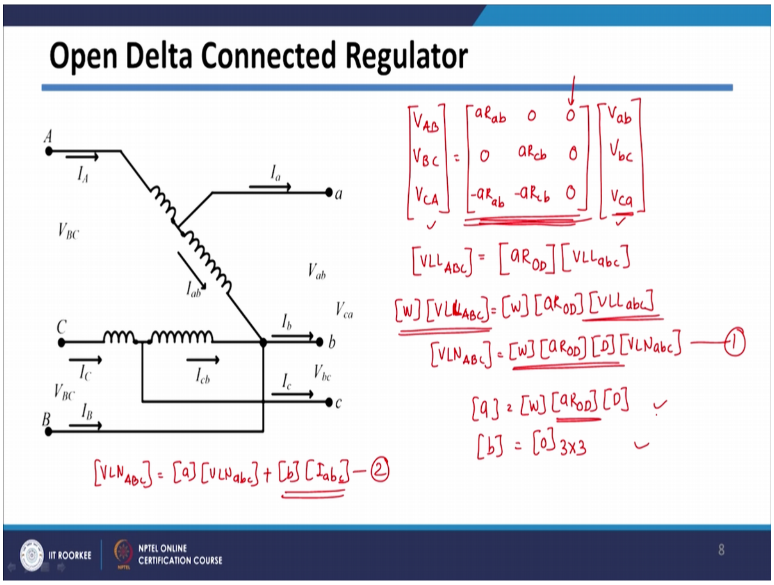

So, let us write them into matrix format. So, from first equation, so we are getting here on this side V A B, V B C, and V C A, which is equal to some matrix multiplied by V small a b. And we have seen that V a b is just related to V A B, V b c is just related to V B C. However, V c is related to both having minus sign. So, in this case, so it will be just a R a b 0 0 0, V B C is related to V b c, so a R c b 0, and here minus a R a b, and a R c b both are minus term here 0, because in all the three equation we are not getting any term, which is related to V small c. So, that that particular term will get multiplied by 0 here so, here we are getting 0 everywhere.

So, I can write it like V L L capital A B C, because these line to line voltages, which will be equal to this matrix I am calling a R. And since it is your open delta connector I can just say O D a R O D multiplied by here also we are getting line to line voltages V L L small a b c.

And then exactly similar way, where we are connect line to neutral voltages. So, this will be converted by multiplying by W matrix V L L is equal to just add a multiplied by W. And this will become line to neutral voltages V L N capital A B C will be equal to W into a R O D into your, so convert this into line to neutral voltages, it will be D matrix conversion V L N small a b c.

So, in this case, if you compare with standard equations, which are basically V L N A B C, which is equal to a parameter into V L N small a b c plus your b parameter into I a b c.

So, if you compare this equation number 1, with respect to equation number 2 there is no term, which is related to currents here. So, your a parameter will be your W multiply by a R O D into your D matrix. And your b will be matrix of 0s having 3 by 3. And this a R O D is nothing but basically this matrix, which you are derived it here. So, the here we have got a and b parameter.

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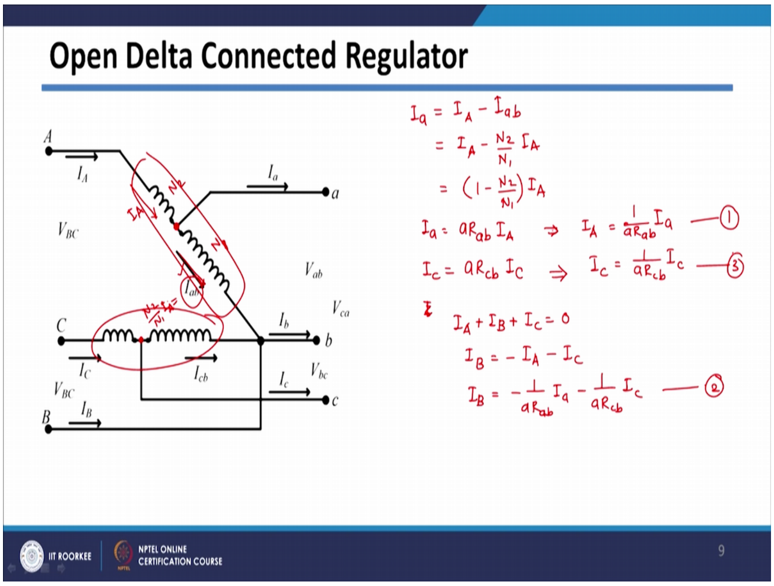

Let us see how we can get c and d parameters. And for c and d parameters, we should write the current relationships. So, currents for writing the current relationships, we can apply kcl at this particular point. So, here the current is I A, and this current I a b, and this I a. So, I can write I a will be equal to I capital A minus your I a b.

And we have seen that this I a, and I a b, they are related by turns ratio. And thus direction of the currents, if this is they are same, it will be I A minus your N 2 by N 1 into I A, because this winding is having N 2 N 1 number of turns, and this winding is having N 2 number of turns. So, this current I a b current will be equal to N 2 by N 1 times your current I A. So, here I can just again it will be 1 minus N 2 by N 1 into I A.

So, your I a will be equal to a R. Now, since this you are considering this regulator between a and b phase, so it will be a R a b into I A. Similarly, I can write for I c also, so I c for this particular current, and this current I c, which is basically flowing from this one. So, by applying kcl at this node I can get similar equation, and this will be a R c b into your I capital C. And third relations, I can get from adding all the three currents, so addition of all the three current should be equal to 0.

So, before that actually what I can do this equation, I can say I capital A will be equal to 1 upon a R a b into I small a. And this equation, I can write I C will be equal to 1 upon a R c b into I c. And then, we have seen that I A plus I B plus I C, three currents should be equal to 0. In that case, I can write I B is equal to minus I A and minus I C. So, this will be equal to minus 1 upon a R a b into I small a minus 1 upon a R c b into I C.

So, we have got three equations, this is 1, 2, and 3 ok. So, this equation related to I B. So, equation for I B, I just write instead of 3 I will make this I will write away this as a this will also 2, and this will be 3. So, writing this 1, 2, 3 equations into matrix form.

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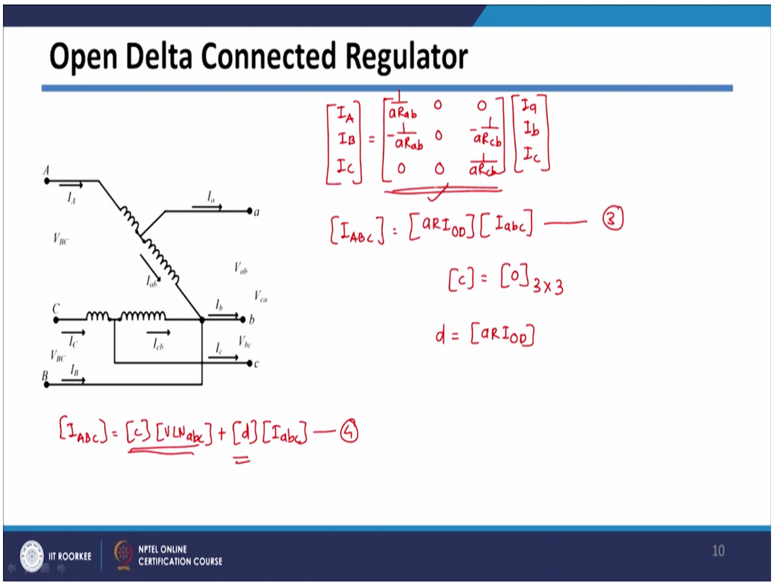

I will get this equation here. So, I A, I B, and I C three currents, which will be equal to some matrix here, multiplied by I small a, small b, and small c, and this will be 1 upon a R a b 0 0. And for D I B equation, we are getting terms related to I A, and I C and both terms are negative. So, I B equation will be one minus 1 upon a R a b 0 minus 1 upon a R c b,.

And here third equation, which is just related to I c so, it is 1 upon a R c b. So, we have got this equation here, and this will be I A B C, which will be equal to I can say this as a a R I open delta calculation into your I a b c. Again we can compare with this standard equation that is I A B C is equal to C into V L N a b c plus your d into I a b c. So, if you compare this is say equation number 3, and equation number 4.

So, if you compare 3 with 4, there is no term related to V L N a b c. So, that is why, your c matrix will be matrix of 0s 3 by 3 size. And your d matrix will be equal to a R I O D matrix, which is basically this matrix. So, for this configuration also we have found out a b c d parameter open delta configuration.

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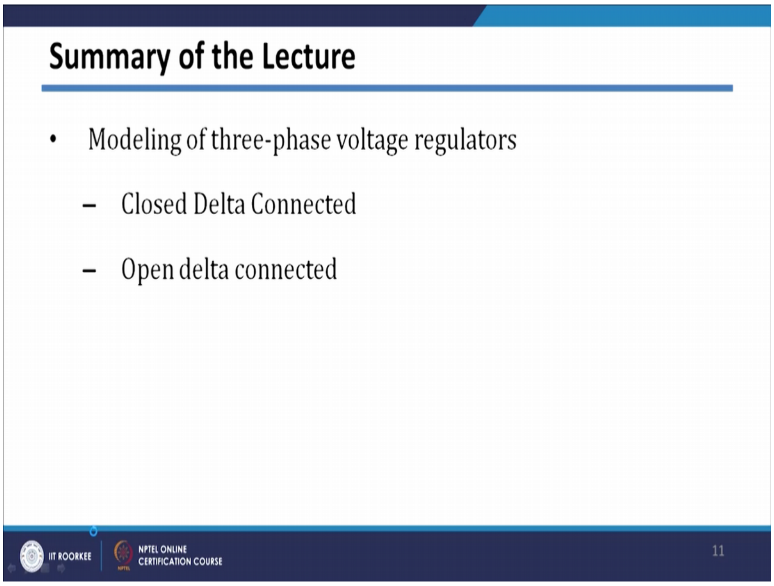

Here we come into the end of this particular lecture. And in this lecture, we have seen modeling of three phase voltage regulator. And basically we have seen two types of configurations here, one is closed delta connected regulators, where the three regulators are connected as a closed delta, and another is open delta connected regulator, where only two regulators are used. And using or controlling this two voltage regulator, we can control the voltage of the three phases at the output side.

So, here we end modeling of three phase regulator. In the next class, we will see few examples, so that we will understand it better.

Thank you.