Electrical Distribution System Analysis
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Lecture - 21
Modeling of Step Voltage Regulators
Part IV

In the last two lectures, we have seen various models of three-phase voltage regulator; we have seen wye connected regulator, close delta connected regulator and open delta connected regulator. In this particular lecture, we will take few example, so that we will understand this modeling of regulator in better way. Now, let us see one or two examples of your regulator modeling.

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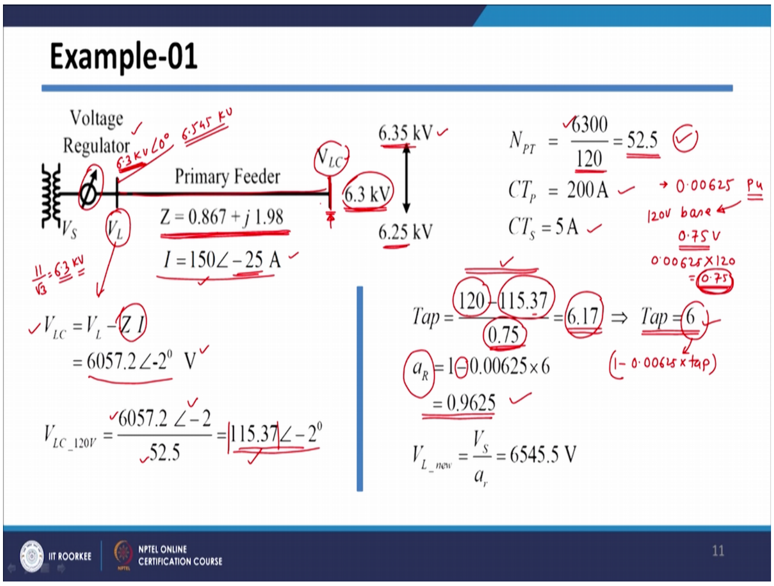

So, in this case, I have consider this example number 1. Let us say you are having primary feeder of voltage 11 kV level. However, I am considering single phase feeder. So, voltage of this will be 11 by root 3 which comes around 6.3 kV.

So, here what I want to do, I want to at the end of the feeder, I want to keep the voltage to be 6.3 kV and range of this voltage level is ranging from say 6.25 to 6.35. And the current carried by this one feeder is say 150 with 0.9 lagging power factor in that case your angle will be minus 25 degree and impedance of the feeder is given here.

So, I want to find out for this particular current that is 150 amperes what should be my tap position of this regulator so that voltage will be maintained at 6.3 in this case. So, I want to find out so basic aim of finding solving this equation to get the tap position of this regulator. This is first objective. And second objective is to get the r c and x c setting of your regulator line drop compensator circuit. So, start with first we will try to get tap position.

So, to get tap position, we should know your PT ratio. So, the potential transformer which is considered for line drop compensator is having say primary voltage line to neutral voltage is 6300 volts. And secondary voltage of regulator say 120 volt. Then your N PT ratio of potential transformer is 52.5; C T primary current is 200 ampere; C T secondary rating is 5 amperes.

Now, first to get the tap position, what I need to calculate if the regulator tap is on normal tap position or if the regulator not at all there, how much voltage I am getting at the secondary means if there is a regulator is not here, in that case I should know how much voltage I am getting it here. Then only I will be able to calculate voltage of or tap position of this particular regulator.

So, without regulator, let us say voltage at this point is 6.3 kV. Now, because of this current flow there will be drop across this impedance here. So, the voltage at this point will not be 6.3 kV it will be 6.3 kV minus whatever drop which is happening across this feeder I will get this voltage. So, I can just write voltage at LC here will be nothing voltage V L here minus Z I which is drop happening across the feeder.

So, if you do that V L is known 6 with reference angle 0 I am considering. And then this impedance of Z Z multiplied by I, I will get voltage V LC at the end. So, we can see that when regulator is not there or where regulator is on normal tap position, I am getting lesser voltage at this end. However, I want to regulate this voltage to say 6.3 kV.

So, what I can do then I can calculate how much voltage I am getting inside the compensator circuit. So, as I explained you compensator circuit line drop compensator basically use to get voltage drop proportional to voltage drop actually happing across your feeder. So, voltage drop inside your line drop compensator circuit will be nothing but this voltage divided by your PT ratio. So, if you this voltage divided by PT ratio I will get your voltage proportional to your LC.

Now, based on this voltage, I can get the tap position. So, set position of the regulator compensator circuit is say 120 volts, but however, across that voltage relay I am getting 115.37 volts. So, this is actually I am taking magnitude of this quantity. So, 120 minus this divided by 0.75, 0.75 is actually if you are per unit value 0.00625, it is per unit. Now, for if you calculate this for 120 volt base it comes out to be 0.75 volt. So, this is per unit. And for if you calculate for 120 volt base, it comes 0.75 voltage. This is basically 0.00625 multiplied by base value this is 120 volt will give me 0.75 volt

So, this gives me oneth tap position is particularly inside compensate this line drop compensator corresponding to 0.75 volt. So, if there is difference of 0.75 volt, the regulator will change by one position. So, how by how many position regulator will change that will be calculated by how much voltage difference we are getting divided by per tap position we are getting 0.75 volt change. So, this will give me how many tap position I should move to control the voltage at the line end.

So, it is telling me and should get 6.17. However, tap positions are integer quantities the tap will be said to nearest integer value which is basically 6. So, tap will be set at 6 value. So, once you get this 6, we I can calculate your transformation ratio or your a parameter which is basically 1 minus we have seen that it is 1 minus 0.00625 into your tap position. So, here we need to raise the voltage because voltage is lower here. So, we need for raising as I told you, you need to use minus sign here.

So, basically I will get this is your a parameter which is basically a R is this one. So, in that case new voltage at secondary side of the regulator means at this point. So, at this point earlier voltage without regulator or at in regulator normal position, we are getting 6.3 kV, but when we shifted this tap to tap number 6 this voltage at this position has raised to value of 6.545 kV.

So, once voltage as raised here even though some drop happened into this feeder also you will get required voltage here. Let us see are we getting this required voltage ok. So, new voltage which you have got is 6.45.

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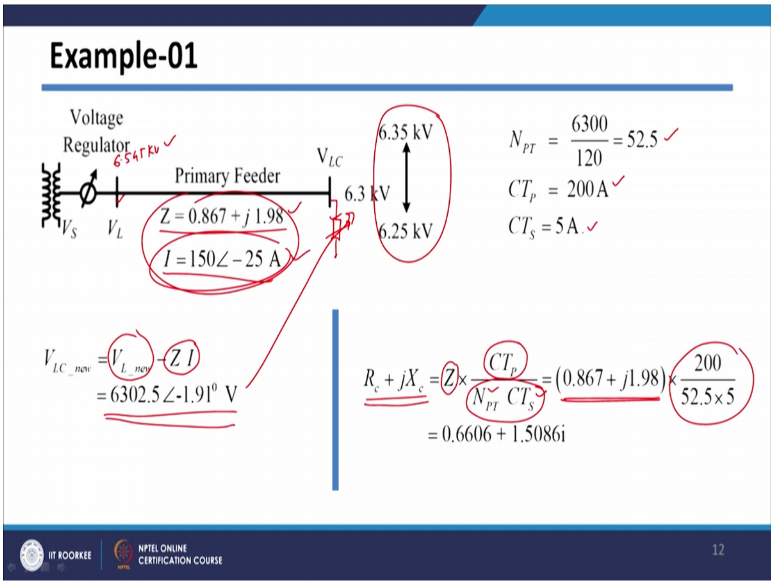

How much it is, 6.545, so 545 kV here and then we need to subtract this drop from this voltage. So, new voltage at this end so new voltage here minus drop which is happening which is Z multiplied by here I am keeping the current constant. So, load to which is connected here deliberately I am considering it is as a constant current load. So, in that case, you can see that new voltage after changing the tap position it is 6.3 kV. So, it is within the range of whatever range we have consider so whatever tap position we have chosen it is correct tap position.

Then as I told you second objective of this example was to calculate impedance settings of your compensators. So, we have derived the formula itself. So, it is actually Z multiplied by C T primary divided by N ratio of pa potential transformer multiplied by CT secondary current. So, this impedance of the line is given and these are the various ratios is 200 CT primary; N T N PT is 52.5, and CT is 5 ampere. So, if you do that, I will get settings of your compensator circuit.

So, in this example, we have seen that how we can calculate tap position based on voltages at the feeder end. And then we have seen how to get the compensator circuit settings. Let us see one more example in this case I have considered three-phase primary feeder let us say it is 11 kV primary feeder. So, all the three-phases are there.

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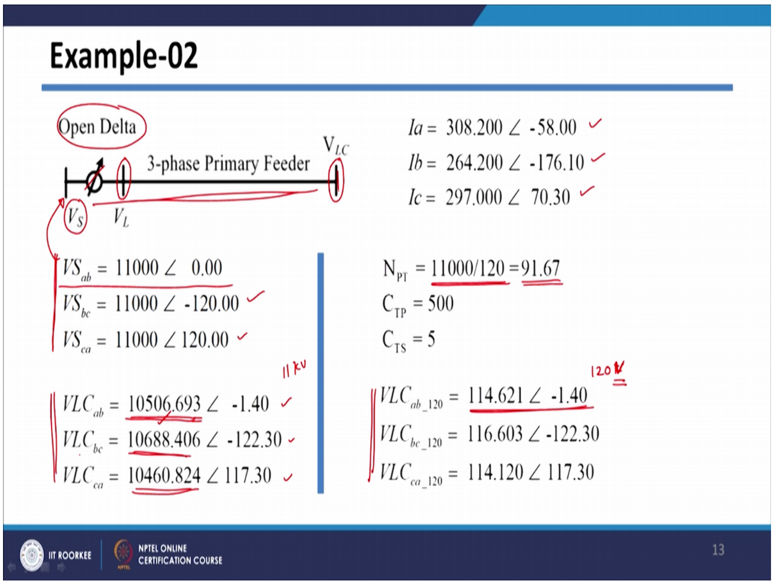

So, we are having and it is open delta connected means system is basically delta connected system I am considering. So, phase to phase voltage or line to line voltage is V ab is 11 kV and they are actually 120 degree shifted. So, basically voltage at this position actually these three voltages with 120 degree exact 120 degree phase shift, because they are actually source voltages and we need to keep them constant at 11 kV.

Now, depending upon the tap position, the voltage here will vary and depending upon load currents the voltage at this bus they will vary. And the drop across all the three-phases they will be different. And many times what happens these three-phase feeders will be having 3 by 3 matrix of impedances. So, while calculating the settings of your regulator which basically need the impedances of three feeders; however, here we are having three-phase matrix. So, in case of three-phase, what we can do to calculate the settings of your regulator, we need to do load flow studies first without regulator. So, without regulator calculate the voltages at this feeder end by keeping this voltages V s at this end.

So, if you do the load flow study in this case, it is simple one what we have to do is V s minus whatever drop which is happening at in this feeder because of this three currents in three different currents in three different phases I a and I b and I c you will get the voltages at secondary side. So, these are basically voltages at this secondary side; and from this I can get the settings.

In this case, these voltages first I need to convert on 120 base. So, to convert these voltages into 120 base, what we can do your PT ratio is 11 kV by 120 volts which comes around 91.67. So, if you divide this quantity by a 91.67, I will get these three quantities. So, this is on 11 kV base and these are the voltages which are based on 120 volts. So, just I have change the base of these three quantities here.

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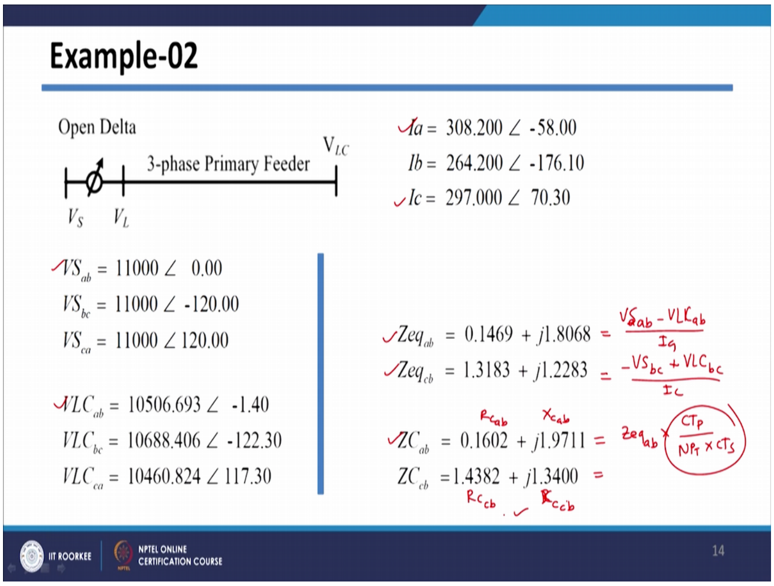

Now, let us calculate equivalent impedances. Since I am considering open delta here to calculate equivalent ab and cb, because if you see these delta connected regulator, they will be something like this.

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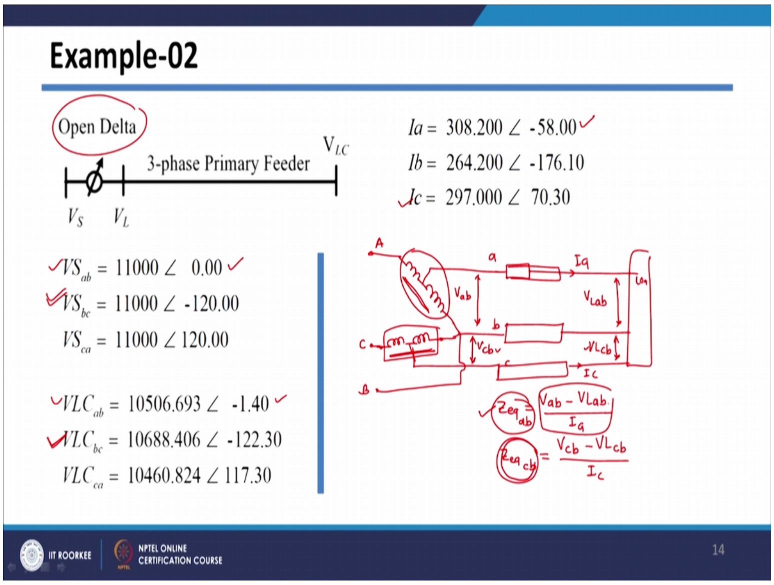

You are having this three two regulators which are basically place like this. And this is your a phase, this is your b phase and this is your c phase which is coming out. We have seen that. And there this is basically going to capital A phase, this is going to capital B phase, and this is going to capital C phase.

Now, if the load is connected here. So, this is your load and then there are transmission line impedances and then say loads are connected here. Now, since there are only two regulators, we need two settings only. And to get those two settings, we need to know equivalent impedances of these three-phases. So, we need only two equivalent impedances and based on those two equivalent impedances, we can get the compensator setting for these two regulators.

To get the compensator setting of this regulator, so Z equivalent will be equal to in this case this voltage we can say it is V ab and this voltage so this I am calling V ab. And this voltage at the load end I am calling V L ab. So, V ab minus V L ab divided by your current this current is I a which will give me one setting. So, this setting is for Z ab

Similarly, I will get another setting Z equivalent for regulator which is connected between c and b. So, it is actually between c and b will be equal to V cb minus V L cb basically cb is nothing, but this voltage here vcb this voltage here V L cb I am calling. So, this voltage minus this voltage divided by your this I c current will give me another setting.

So, based on this setting, I will set my rec regulator between a and c and based on this impedance I will set my another regulator which is between c and b. So, that is why I am doing it here. So, this equation you remember vab because V ab already we know. So, this is V ab and V Ls load center voltages V a this we know. So, this voltage minus this voltage divided by I a current give major equivalent ab similarly V cb means negative of this voltage minus sorry this voltage minus negative of negative of this voltage minus negative of this voltage divided by your I c current will give me second.

So, basically ok, so I got these two equivalent settings. So, this I have got as I told you this I have got v V S ab minus V LC ab divided by your current I a. So, I a current in this three quantities are known. In this quantity I have got minus V S bc plus VLC bc divided by your current I C here. So, this two quantities I got by doing this operation.

And as we have seen that settings are obtained by it will be Z equivalent into ab multiplied by your CT p divided by N P T multiplied by your CT s. So, all this things are I have just explained in last slide it is given. So, this all this quantities are given here. And we can calculate Z C ab. So, these are nothing but R c in ab circuit and this is X c in ab circuit. So, these are the settings of regulators in ab phase. And this is R c in cb and X c in cb circuit. So, these are the settings of the regulator in cb circuit.

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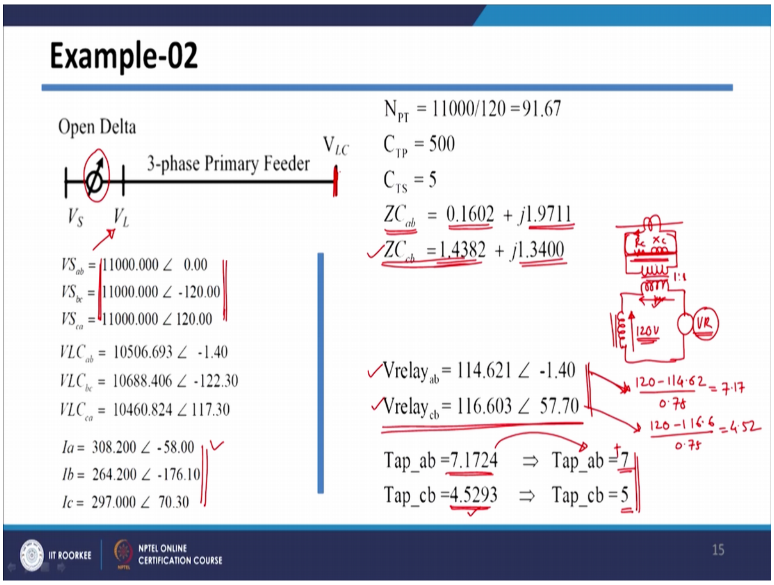

And once you get that, I can get the voltage across the relay because we have seen that in line drop compensator circuit, it is basically something like this you are connecting this impedance here. And then we are having this one as to one transformer. And here we are having put input from potential transformer. And here it is voltage relay we are putting. So, this is actually one as one transformer.

So, what we can do this voltage plus this voltage both can be calculated because this voltage is nothing but whatever voltage we are getting you on the secondary side of the transformer. Here we are calculating first we are calculating to get this tap setting, we are calculating without considering the regulator or regulator on normal tap position, so that is why voltages V L will also be equal to this voltages and the voltages here it will be 120 volts. So, this voltage will be 120 volt. And then based on these settings of two regulators we already calculated. So, this as I told you this gives me R c and X c. So, this is R c and X c for ab phase. And this is R c and X c for cb phase regulator

So, and the current is also known. So, we know the current we know this settings here, I can get the voltage drop here because currents here currents are also given. So, when I am considering current in phase a, so I can easily calculate how many drop which is happening across this feeder sorry this compensator circuit; same drop will come here. So, 120 minus that drop will give me voltage across the volt voltage across this voltage relay coil.

So, in this case, in ab phase regulator I am getting this voltage across the relay. And for cb phase by considering these R c and X c values, I am getting voltage across the cb relay which is basically this one. And using this we can get the settings of tap settings of this one. Tap settings we have seen that we are getting 120 minus 114.62 divided by your 0.75 will give me tap setting of relay between sorry voltage regulator between ab phases. And here a 120 minus 116.6 divided by 0.75. If you do I will get tap setting for regulator which is placed between c and b.

So, these values if you calculate, so here I am getting 7.17 and here I am getting 4.52. So, these are basically tap settings I am getting. And as I told you tap should be integer values. So, I am choosing nearest integer value. So, the regulator between ab phase, your tap setting should be 7, plus 7, because you want to increase the voltage. And here we are getting for second 4.5. So, nearest tap position either you can go for 4 or 5, but in this case since it is this is a just more than 4.5 we can choose tap position five nearest integer value.

So, we can see that for open delta connected regulator how we can calculate your tap position. So, how we are calculating first assuming that your regulator is at normal tap position or regulator is not at all there we are getting voltages at here. And then corresponding voltages inside the compensator circuit. And by knowing the difference or voltage across your voltage relay coil, we are deciding your tap position.

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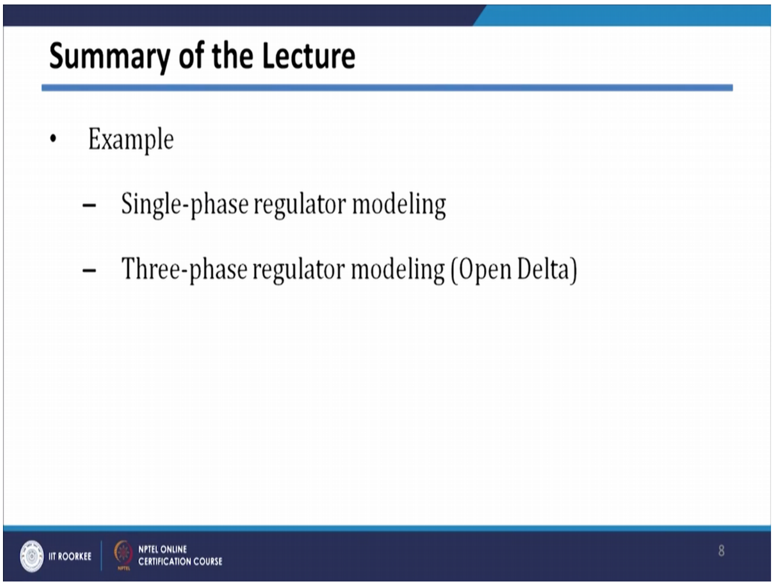

So, in the summary of today's lecture to understand the regulator better. In this particular lecture, we have taken two examples one is on single phase voltage regulator, where we have calculated the settings of single phase voltage regulator, so that voltage at the feeder end will be will get at required bandwidth.

Similarly, we have taken one example of three-phase voltage regulator modeling where we have consider regulators which are connected in open delta fashion. And in this case also, we have calculated tap positions of those two voltage regulators which control voltage at the feeder end.

Next class we will start with load models.

Thank you.