Electrical Distribution System Analysis
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Lecture - 19
Modeling of Step Voltage Regulators
Part II

Dear students, we are studying the Modeling of Step Voltage Regulator. We are started in the last lecture and in the last lecture, we have seen why we need to regulate the voltage within the limit of say plus minus 10 percent or plus minus 5 percent depending upon standard which were standard you are following. Then in the last class we have seen various techniques which your we can used to control the voltages were distribution system.

So, we have seen we can use on load top changer with transformer, we can use step voltage regulator, we can use voltage booster induction regulator or fixed and switched capacitor. And out of these we are going we are seen step voltage regulators. We have seen single phase step voltage regulators in the last class.

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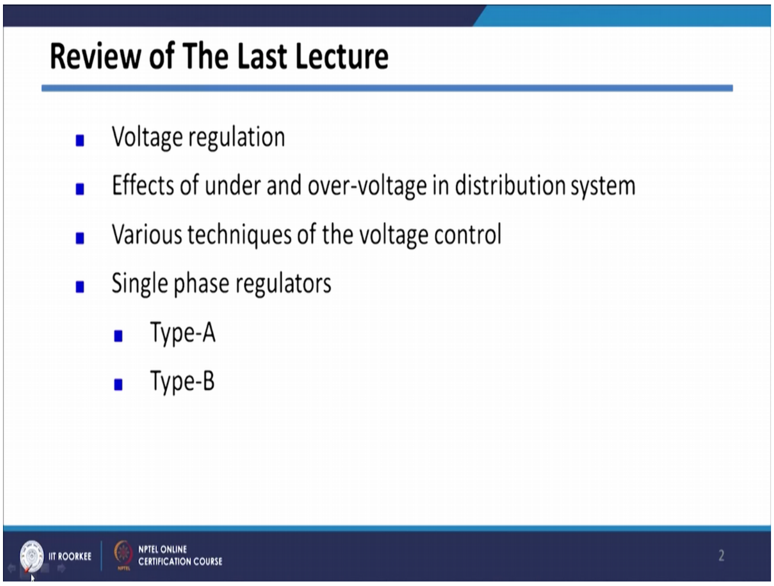

And we are divide this divided this single phase voltage regulator in type A type regulator and type B regulators.

Basically construction of them is similar only the connections are different. So, here I have shown voltage step regulator which is basically B type of regulator, I will show you how A type look afterwards.

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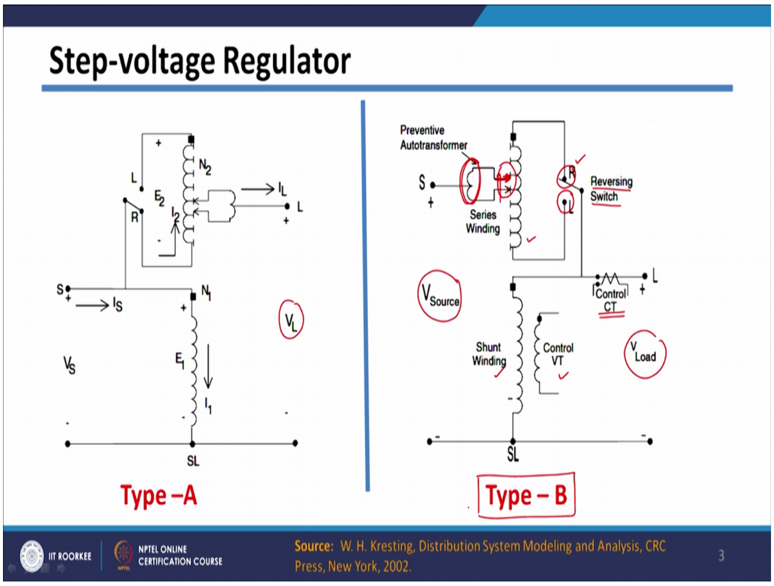

So, in this case as I discussed in the last class, we need to connect this regulator basically in Autotransformer fashions. So, since there is autotransformer there will be one winding which is Series winding; another which is winding which is called as Common winding or Shunt winding. And then, there will be for changing the tap position, we will be having this tap connection here and for that we are using this reactor switching because we do not want to interrupt the current whenever we are changing the tap.

So, whenever one tap is connected to the tap position another then only we can disconnect another tap. So, basically for that we need this reactor here which will be basically used while switching or you can say whenever you are changing the tap positions; so whenever one tap is connected to the next position, then only other tap will get this connected from position. So, current continuity will not get disturbed. And we have seen that depending upon your position of this reversing switch. So, there will be R switch; where actually we can use if you want to raise the voltage beyond this one, beyond normal voltage.

And then, L we can put this reversing switch on real position, if we want to decrease your voltages and then this CT is actually connected on load side to measure the load current which is getting delivered to the load. And then there will be voltage transformer of which will again use to measure the voltage on the secondary side of the regulator.

Similar to this there will be A type regulator which was seen; if you see then they are just mirror images of each other. In this case the tapings will be provided on low voltage side. And in this case tapings will provided on source side and basically this is this configuration is widely used.

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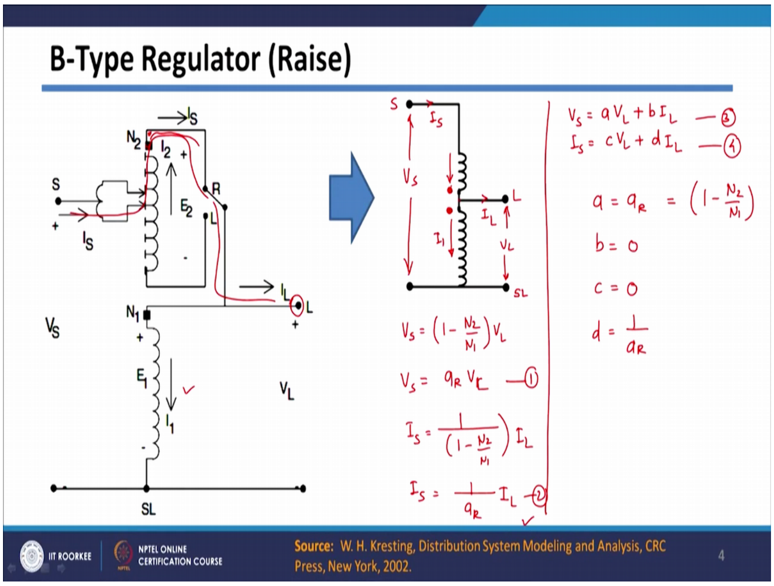

And in the last class we have seen the operation also of A type as well as B type of regulator and what we are seen depending upon your position of yours this reversing switch R or L, we have seen various configurations. So, in this case when your switch is on R position, then the current will flow like this. So, I S will go and then I S will come from this side and then it will from it will get added to your I 1. So, in this case if you see, this dot is connect get is towards your L point.

So, this is your L here; this is common SL. I can say this is your source and you can see that your dot is at L point because if you see here it is this connection is going to L here. So, this is nothing but your L terminal only. So, dot is towards L and for common winding dot is here. So if this current, is your current I S and this current is current I L and this voltage is load, voltage which is basically V L and this voltage is source voltage V S. In this case current direction in the common winding will be decided by dot. So, since I S current is coming to a dot; this current has to go away from the dot.

So, therefore, the direction of current I 1 will be like this. And last class, we have derived the relations also, we have seen that your voltage V S is given by 1 minus N 2 by N 1 into your V L and this 1 minus N 2 by N 1, we call it as a a R which is basically transformation ratio of this one.

Similarly, current relations we have got I S is equal to 1 divided by N 2 minus N 1 into I L. So, basically in this case your is will be equal to 1 divided by a R into your I L and then we compare this with respect to our standard abcd parameter that is V S is equal to a V L plus b into I L and I S will be equal to c into V L plus d into your I L. So, if you compare this equation 1 and equation 2 with respect to this equation 3 and equation 4, we have got your a parameter which is basically a R.

So, a R in this case it is 1 minus N 2 by N 1 and your b parameter is 0 because there is no equation number 1 which is equal to I L. Then this c parameter is an 0 because in equation number 2, we are not having term which is related to V L and your d parameter will be 1 upon a R. So, this is actually parameter when your B type regulator is in raise position. So, here if we want to raise the voltages, your dots will be something like this. So, dots will be towards L both the dots will be at the L terminal.

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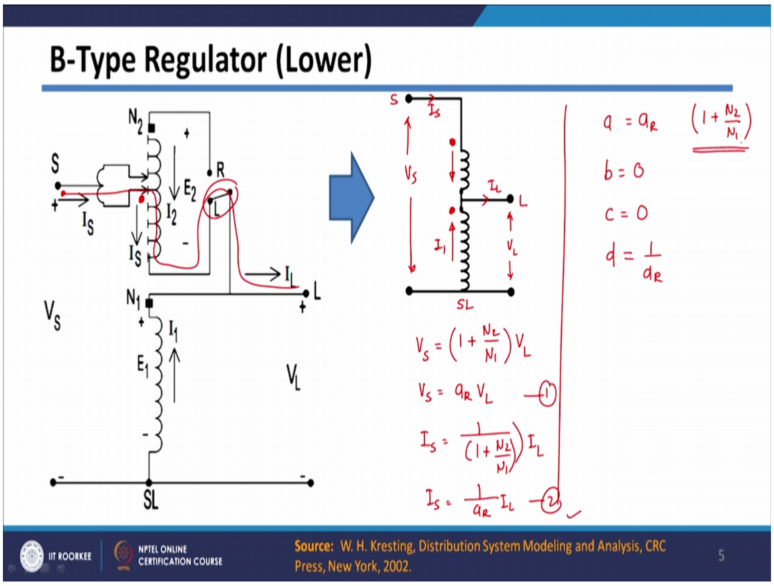

Opposite of this, when your switch is connected to L position, your current path will be something like this. So, in this case current will be coming like this through this winding with regulatory winding, it will go 2 terminal L ok.

So, if you see this dot basically this dot will appear here which is basically at terminal S. So, if this is your terminal S, this is; then this is common SL I can say. So, dot in this case dot is towards terminal S. So, I can put this dot here and this dot of common winding at is same position. So, in this case your, I S current is coming somewhere here.

This is your current I L. This voltage is V S voltage. This voltage is V L and in this case also we have derived in this case the current directions will be something like this. In this case current is going away from dot inside the winding. So, it should towards dot inside the winding. So, current direction will be something like this. So, I 1 current will be something like this.

So, in this case we have derived your V S is actually equal to 1 plus N 2 by N 1 into V L which is equal to V S into a R. In this case a R is having plus sign here into V L. Similarly we have got is which is equal to 1 divided by 1 plus N 2 by N 1 into your I L. So, in this case it will be is will be equal to 1 divided by a R into your I L. So, in this case if you see abcd parameters. So, a parameter will be again a R, but a R is in this case is 1 plus N 2 by N 1; your b parameter will be again 0 because there is no term which is related to I L into equation number say this 1 and these 2.

So, equation number 1, we are not having term which is related to I L which will make b is equal to 0; c will be also equal to 0 because in equation number 2; we are not having term related to V L and your d parameter for this will be equal to 1 upon a R. So, we can see that for B type of regulator we are basically getting this equation.

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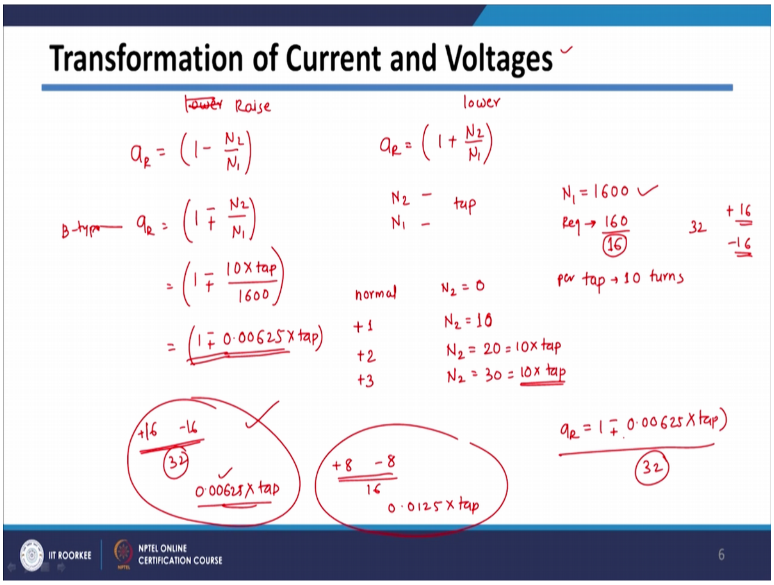

So, basically what we are getting we are getting a R is equal to 1 minus N 2 by N 1 when it is on sorry raise position and we are getting a R is equal to 1 plus N 2 by N 1 which is for the lower. So, basically I can say it a R will be equal to 1 minus plus because I want to write it for raise first and it will be N 2 by N 1. So, this relation is for your B type of regulator. A type regulator, your signs will get opposite. So, in case of A type regulator 1 plus minus N 2 N 2 by N 1; otherwise it will be same.

Now as I explained in the last class this relation between N 2 and N 1 is actually decided by your tap position and total number of turns in regulating winding was seen, we need around 10 percent turns in regulating winding. So, for example, if you consider the turns N 1 will be say 1600 example, it is not a exact 1 depending upon design they may change; then in regulating winding the turns will be 160 because when want here 10 percent variation in regulating winding.

So, the turns will be 10 percent turns will be in the regulating winding maximum turns and if there are say 16 tap plus 16 and minus 16 total 32 taps. So, for 32 taps there will be plus taps which are 16 and minus 16 taps; so in the divisions which we are making the 160 by 16. So, per tap will be having 10 turns per tap will be having 10 turns. So, if your regulator is on normal tap, it will be your N 2 number of turns N 2 will be equal to 0. When it is on plus 1 that is in raise position your you need to add N 2 is equal to 10 turns 1 tap change means 10 turns will need to be added in regulating winding, then you will get particular change. So, for 1 tap you are having 10 turns; for second tap it will be again 10 turns.

So, N 2 in that case will be 20 turns in the regulating winding. So, it will be nothing but 10 into your tap position which is 2; for plus 3 tap your N 2 turns will be 30 which is basically 10 into again your tap position in this case. So, I can just write it will be 1 minus plus in this case 10 multiplied by your tap position divided by primary turns are say 1600 which you assumed here. So, in this case if you observe it will be 1 minus plus into 0.00625. This 10 divided by 1600 will be 0.00625 into your tap position.

So, for if there are 16 plus and 16 minus tap mean though total 32 taps in your regulating winding, your N 2 by N 1 ratio will be 0.00625 into tap. This is this configuration is only possible for this 1; if there are plus 8 and minus 8 taps means there will be total 16 taps. In that case it will be 0.0. It is double of this it will be 125 into your tap position. So, this configuration I have taken 0.0125. It is possible if there are 32 taps into the your regulating winding. So, this is how we can calculate your, a R for any type of your regulator. So, a R will be nothing but 1 minus plus into 0.00625 into tap and as I told you, this is only possible if there are 32 taps into your system; now, line drop compensator circuit.

Yesterday, I just given brief introduction about line drop compensator circuit. As I told you it is basically used to control the regulator tap positions and this regulator tap positions are controlled based on voltage at end of the feeder or wherever location which want to control the voltage.

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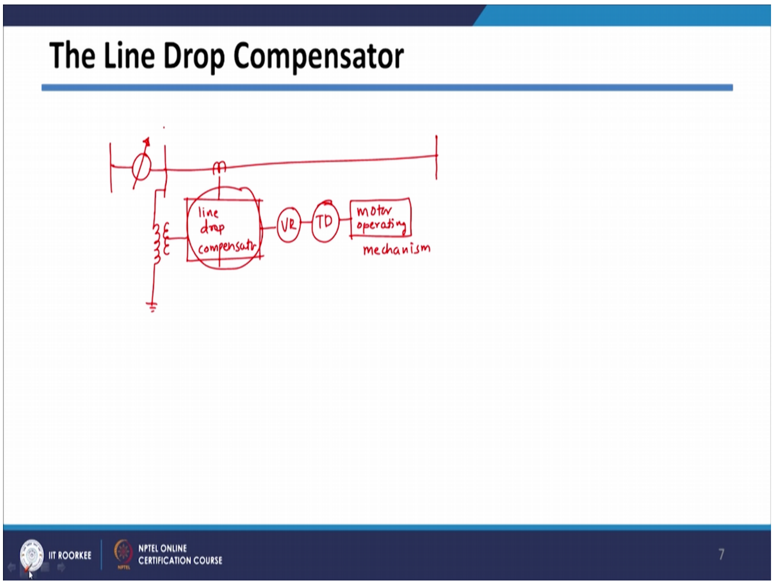

So, in this case say this is your feeder and your interested the control the voltages at the far end of the feeder and then say to control the voltage of this particular bus, you are connecting regulator here and then, here actually the voltage which is given and to control the regulator positions, we use this line drop compensator circuit.

And I explained in the last class, Line Drop Compensator circuit is basically taking the feedback from your current transformer and then your potential transformer which is connected here. And this is your line drop compensator and we have seen that then is connected to voltage relay I am writing it a VR. Then it is connected to the time delay circuit because we do not to frequent operation of your regulator and then it is connected to the motor operating circuit, motor operating mechanism.

Now, let us see how this line drop compensator works. So, for that I will just draw the inside view of line drop compensator circuits. So, if you see inside this line drop compensator circuit, it will be having this current transformer.

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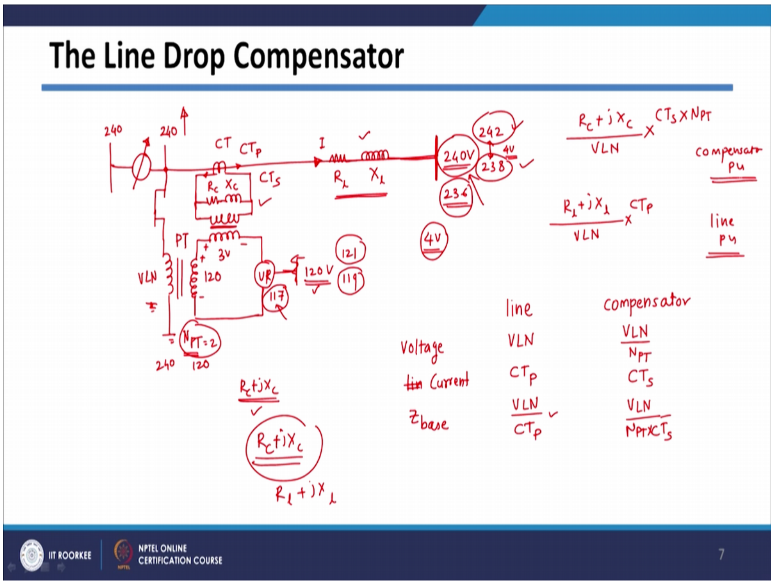

Across this current transformer, some impedance will be connected and then there will be 1 transformer which is having ratio 1 has to 1. So, your having this transformer which is having ratio 1 has to 1 and then you are having this voltage transformer here and then this signal is actually connected to your voltage relay circuit. So, basically this signal is coming from your voltage transformer.

So, this is your PT, potential transformer; this is your CT and then current which is flowing through this is say I and impedance of this feeder is R L is a resistance of this feeder and X L say your reactance of the feeder. And then this CT ratio says CT P is primary rating of CT and CT S say your secondary rating of the CT and the turns ratio of PT will be say N PT. We want to regulate the voltage at this figure at say 240 volt level. I am just considering L T feeder single phase feeder say I want to keep this voltage say 240 volts.

However, we cannot exactly put 240 volt always we need to specify some range. So, say range of the voltage is say 242 to 238. So, variation allowed is 4 volts. So, I can just keep this voltage within this particular limit. Now, whenever current is flowing through this feeder suppose this regulator is not there and in if the regulator is not there and the voltage at this end say 240; then without regulator will be 240 and there will be some drop here. So, in that case voltage here will get drop say to say 236.

So, in this case what will happen is in this line drop compensator circuit, we want to simulate whatever drop which is happening. So, in this case though the 4 volt drop is happening and because of that your voltage is not getting regulated at 240 volts or you can say from 2 it should be above always about 238.

So, we need to simulate this drop or we need to model this drop whatever happening along this feeder inside your line drop compensator circuit and that is why we are putting this impedance here which is I am calling at is R C and X C and that should be proportional to your line drop. So, whatever drop which is happening across your R C plus j X C should be proportional to your drop which is happening across your feeder. So, it should actually simulate or model the actual feeder inside your line drop compensator circuit.

So, in that case what will happen if there is say 236 volt here and suppose 240 volt here. So, N PT ratio is 1 has to 2 say. So, say here if this voltage is 240 because of the ratio is 2 N PT is equal to 2; then voltage at the secondary operative will be 120 volt. So, here it will be 120 volt and the current direction here is like this means inside CT is a current direction will be like this and it will create drop along this one. So, this drop will be just opposite of this voltage here. So, because of that what will happen is suppose some current is flowing and here we are getting some kind of say 3 volts drop because of this 4 this voltage here.

So, in that case the voltage across your relay is 117 and the set voltage corresponding to this. So, set voltage here is 240 means set voltage we need here across voltage relay which should be 120 volt and bandwidth is then 121 to 119 corresponding to this I have taken by considering N PT ratio is equal to 2. So, set value of voltage inside your line compensator circuit is 120 volt which is corresponding to 240 volts and corresponding 240 volt maximum voltage allowed is 121 and minimum voltage allowed is 119.

But you can see that this voltage is going below 119 in that case this VR voltage level get operated; it will give signal to time delay circuit, after some time delay your motor operating mechanism will operate and it will change the tap such that the voltage at this bus will get raised such that will get again 240 volts at this position. So, this how your line drop compensator circuit work.

Now, question is how to get this impedance values? So, as I told you this impedance inside your line drop compensator that is nothing, but your R C plus j X C is basically need to be proportional to your R L X L. So, how to get these values, we can just see for that what we can do we will just see; what are the base quantities in the various circuits.

So, there are 2 circuits; one is actually line circuit which is basically transmission line or distribution line circuit, another circuit is compensator. So, circuit which is inside compensator I am calling compensator circuit. Let us say how much voltage we are getting? So, line voltage is actually nothing but your VLN line to neutral voltage; basically here will get this line to neutral voltage across the PT primary coil or at the output of your regulator and in inside the compensator will get voltage which is equal to VLN divided by your N PT. So, this voltage will get dropped or step down to your potential transformer ratio level.

So, inside compensator your base voltage will be VLN divided by N PT. Then this current; so current, so, current in the line circuit is nothing but CT primary, whatever CT primary rating is there it is actually base current for primary circuit and then base current for secondary circuit will be just C TS because it is rating of secondary side of the this CT which is inside the your compensator circuit; and, if you calculate Z base Z impedance base.

So, in this impedance base will be VLN divided by C TP and in this case it will be VLN divide by N PT and it should be divided by C TS. So, C TS also will come down. So, it will be multiplied by this one. So, for compensating circuit your base impedance will be VLN divided by N PT into C TS. Now, let us see how we can get the values of this R C plus j X C. Now if you consider the per unit values of R C plus j X C and per unit value of R L plus j X L should be equal because I want actual them to be proportional.

So, if we are considering particular bases inside line circuits and compensator circuit and if we calculate per unit values of this and per unit values of this it should come equal. Because they are if they are proportional and if we are considering particular base quantities particular circuit per unit values should be equal.

So, what will be the per unit value in your primary circuit? So, per unit value will be primary circuit will be or your sorry compensator circuit will be R C plus j X C divided by your base value. So, base value we are getting VLN and this denominator will go up it will be C TS multiplied by N PT. So, this is actually base value sorry per unit value in compensator circuit. So, this is actually compensator per unit value and then line per unit value can be calculated like this.

So, it will be R L plus j X L divided by its base value which is basically this which is VLN and these denominator will go up which is basically C TP. So, this is actually per unit value of line impedance and this is per unit value of compensator impedance; so that those should be equal. So, on the next slide I will just take them.

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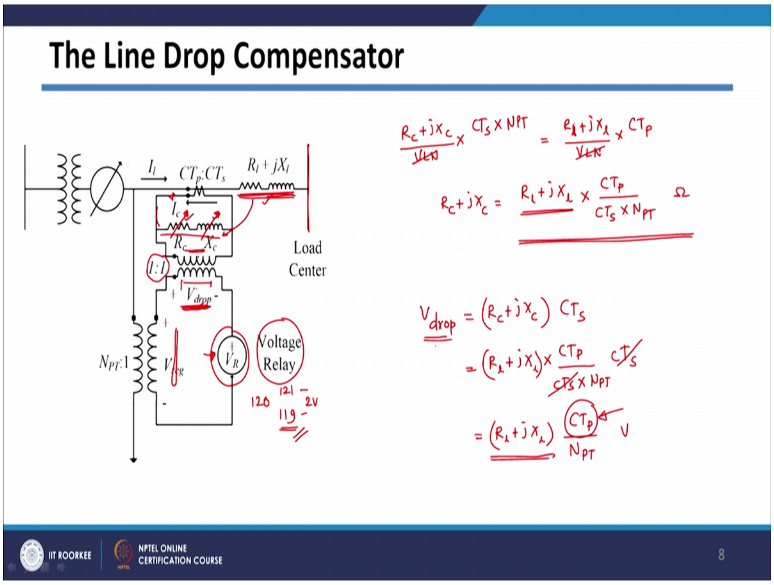

So, in this case we have got R C plus j X C divided by VLN into C TS into your N PT which is equal to R L plus j X L divided by your VLN multiplied by your CT primary ratio.

So, in this case this VLN VLN will get cancelled out and if you get R C plus j X C will be equal to R L plus j X L multiplied by your CT primary divided by CT secondary multiply your N PT in Ohms. So, basically we are as I told you we are interested in getting this compensator parameter which are R C plus j X C this is nothing but we can get R C plus j X C it is called as compensator setting because these are R C and this X C they will be variable. So, depending upon your impedance of your feeder you need to set these values.

So, depending upon impedance of your feeder we need to set the values of R C and X C such that these voltage at this bus will get regulator basically what is it is doing; it is simulating the drop proportional to drop which is actually happening in the line proportional drop will be getting created here and that drop is getting created here. And this drop is getting subtracted from this our secondary voltage of the PT and depending upon this difference voltage is getting applied across the voltage relay.

So, at that should be in the range, as I mentioned for this particular problem as I mentioned if it is set values 120 and bandwidth; bandwidth generally depends on compensator circuit. If the bandwidth is say for 2 volt that is voltage variation allowed is 2 volt here. So, this is your bandwidth for your compensator circuit and if the voltage across this voltage relay getting beyond this 121 and below 119 the relay will operate; otherwise it will keep on it will not operate many times.

So, voltage across or we can we calculate this voltage drop. So, voltage drop as I told you; so, V drop will be equal to this impedance multiplied by your secondary current. So, it will be just R C plus j X C multiplied by your current C TS which is basically flowing in the secondary side of this one. So, this current multiplied by this impedance same drop will come here and since this is 1 has to 1 transformer, this drop will appear here. So, this drop which is happening across this driving I am calling V drop will be equal to R C plus j X C multiplied by your C TS.

And then, we have seen that C TS we have got it here in terms of R L plus j X L into your C TP C TS multiplied by N PT multiplied by this C TS I am just writing as it is. In this case this C TS they will get cancelled out. So, R L plus j X L multiplied by CT primary ratio divided by your turns ratio.

It will give the drop across this one. So, depending upon this drop which is happening here which will be which as I told you this drop is actually proportional to your drop or proportional to your impedance of this particular feeder. So, that drop we are considering it here. So, depending upon current in the CT primary, the drop will change. So, as the CT primary current changes, this drop will change. So, this how your line drop compensator work.

So, we have seen till now single phase regulator lets go for three-phase regulator. So, three-phase regulator first will see simply simple configuration that is wye connected regulator. So, the wye connected regulators in this case also as I told you generally B type of regulators are used.

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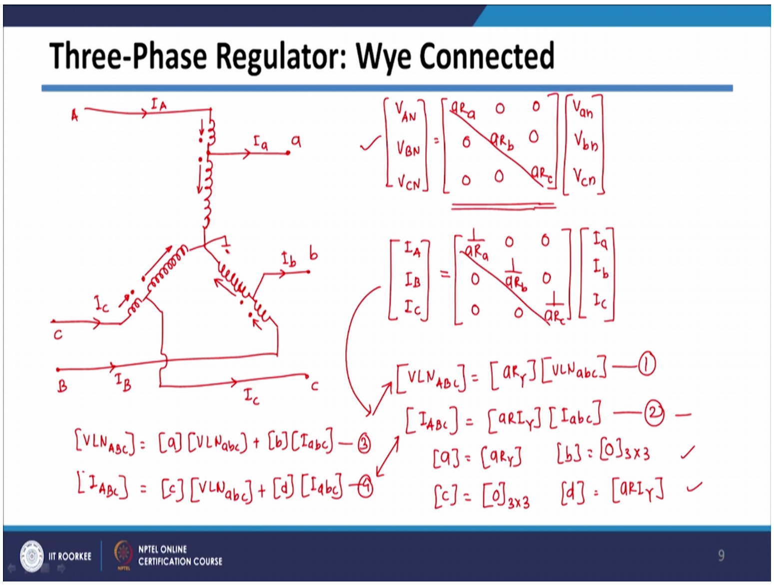

So, I am just taking your B type regulators which are connecting in. So, it will be having 2 winding. So, this is a phase A; one is one winding is this. This basically winding is regulator winding and then one winding is your common winding or series shunt winding. Then similarly, we can plot another phase. We will also having 2 windings and then, there will be third phase. So, this is regulating winding and this is your shunt or common winding.

So, this is your phase B and this is your phase C and as I told you we are taking this terminal out which is between common winding and series winding. This will become your small a; then this I am taking out this will become small b and this if I take it out, this will become small c and then currents this current is I A; this current is I B; this current is I C and this current will be I small a; I small b and I small c.

In this case since I am considering raise position. We have seen that in case of raise position, your dot position will be something like this. Dots are coming at load at both the dots are coming at the load terminal end. So, dots will be something like this. So, when this I a direction is something like this.

So, here also it is towards dot. So, current should leave from this dot this b is also towards I b is towards dot. So, this also lead the dots leave the dot. So, this also I c is towards dot. So, here the current should leave the dot. So, current direction will be something like this. So, in this case we can easily write the equation for the primary side and secondary side voltages of this voltage regulator. So, I can just write V AN, V BN and V CN; 3 voltages just like 3 single phase regulators. So, a R aR a R and this will be V small an (Refer Time: 34:14).

So, here I assumed that actually this is grounded neutral is grounded that is why. So, in this case you can see that there are 3 regulators which are single phase regulator which are connected. So, I just, taken the equation which we are derived for single phase. So, for first phase your V AN voltage will depend on a R multiplied by V AN; V BN a R multiplied by V BN; V CN will be equal to a R multiplied by V CN.

Now here there are 2 possibilities; this if this regulator is completely three-phase regulator and there is possibility it will be gang operated means all the taps of all the three-phases if they are operating simultaneously, then your all the 3 coefficient of this particular matrix they will be same. And sometimes what they do 3 single phase regulators they connect in star fashion and in that case the control circuit of 3 different regulator works differently means there is possibility that 3 regulators will be having or working at different tap positions.

So, in that case you need to consider that. So, this a R a will depend on your tap position of regulator a; this a R b which will depend on tap regulator of b and tap regulator of c. So, specifically you have to mention it, if your regulator is not what is called as gang operated. Similarly, I can write current relationships.

So, current relationship in this case your current I A current I B and current I C capital will be equal to in this case again similar to 3 single phase regulators connected in star fashion and star is grounded. So, independently they operated; it will be 1 divided by a R a 0 0; b will be depend upon your I B current. So, a R b 0 and c will depend upon your just I C current. So, in this case it will be sorry I a I b and I c; 3 current ok.

So, this equation I will just write it like this. So, it will be V line to neutral voltages all the 3 phases is equal to this matrix I am calling a R y matrix because it is wye connected transformer and then this is your again line to neutral voltages of secondary side small abc and this I can write I capital ABC. Again, this matrix I can just another name a R current related. So, I can just aR I multiplied by I abc.

And this if you compare this equation with respect to the equation which we you have seen. So, we have seen that VLN ABC is equal to your a parameter into VLN small abc plus b parameter into I abc and another equation which we have seen I capital ABC will be equal to your c parameter matrix VLN small abc plus your d matrix into I abc.

Now if we can compare this 1 and 2 and 3 and 4. So, if we compare 1 with 3. So, your a parameter will be equal to your aR y matrix and b parameter will be equal to 0 matrix of 3 by 3 size and your c parameter will be again 0 matrix because there is no term related to VLN in equation if we compare 3, 2 and 4; they are in equation number 2, we are not having term related to VLN ABC.

So, in that c also will become 0 of 3 by 3 size and d will be your matrix aRI current related that is why I am writing I term there aR y. So, these are nothing but your abcd parameter for this one. Since, it is wye connected network we are getting very simple parameter. So, here all the 3 regulator they are working independently.

So, in the summary of today's lecture: we have seen line drop compensator circuit in detail and we have seen that line drop compensator circuit is basically required to create the voltage drop which is proportional to drop which is happening across your feeder. So, inside line drop compensator we have seen that there is impedance consisting of R plus j X and the voltage drop which is created across this impedance will be used to operate the relay.

So, relay will be having voltage relay will be having some kind of bandwidth; if this voltage drop across that voltage relay go beyond the specified bandwidth, your voltage relay will operate. After that we have gone for modeling of three-phase voltage regulator and in three-phase voltage regulator we have seen wye connected regulator.

So, next time will see delta connected and open delta connected regulator and will see some examples on voltage regulator.

Thank you.