Electrical Distribution System Analysis
Dr. Ganesh Kumbhar
Department of Electrical Engineering
Indian Institute of Technology, Roorkee

Lecture - 18
Modeling of Step Voltage Regulators
Part I

Dear students, in the last lecture we have completed Transformer Modeling part and today's lecture we will go with Modeling of Step Voltage Regulators. Before going to the voltage regulator modeling let us see the function of voltage regulator.

So, we know that the voltage along the feeder we will go on decreasing. So, drop along the feeder we will go on increasing as loading increases.

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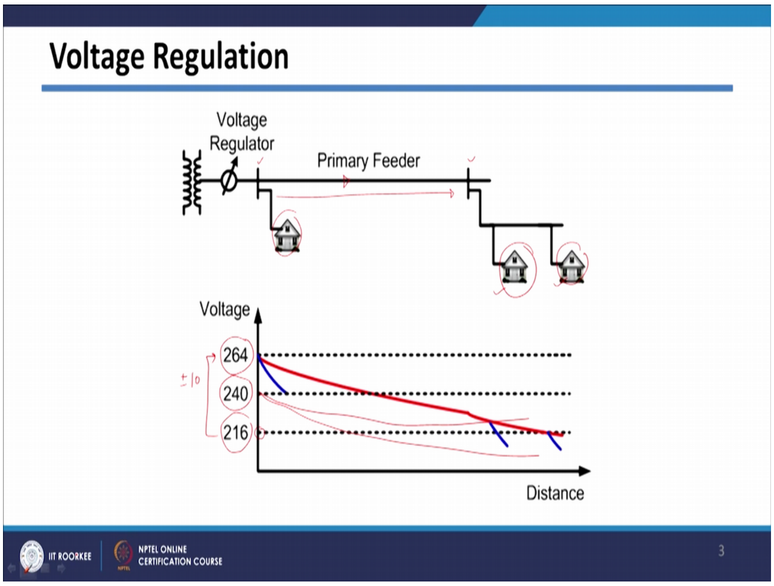

So, whenever there is no load condition if these loads are not there you can see that voltage both the points will be same. However, whenever there is loading on your feeder, there will be current which is fluent through the feeder and which will basically there will be drop across the feeder. So, voltage which is reaching at consumers which are connected at the far end will experience lower voltages.

However, there is limitation on how much voltage can decrease at particular consumer end. So, say in our case if it is there is say 10 percent plus minus variation in voltage if it is allowed, in that case if normal voltage or nominal voltage if it is 240, then voltage variation allowed is from say 264 to 216, 264. So, it voltage all over the system, the voltages should be between 216 to 264. Now, we have during loading condition during no load condition suppose voltage if something like this. So, whenever do in loading condition, the voltage drop will increase and voltage will reach to some lower values.

So, it may cross your limitation that is 216; 216. So, it will be go below that particular level. So, in that case what we can do we can increase the voltage at source point itself and that increment in voltage can be done by using OLTC of the transformer or if the voltage is not available your transformer, you can use extra regulator which basically regulate the voltage at the second this side of the regulator.

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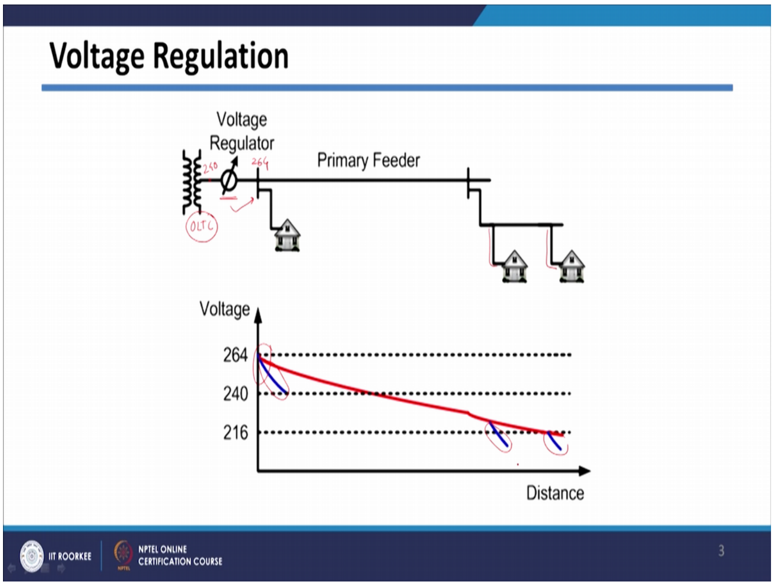

So, if the voltage of the second this side of the transformer say 240, then by using voltage regulator I can make the voltage at the secondary end of the regulator say 264 which you have shown it here. Even though, there is drop across the feeder, we can bring the voltage within the limit ok.

So, there will be this blue color line which I have shown these are nothing but your service drop. So, there will be some drop which is happening in service connections, though drops are shown it in blue. So, we need to regulate these voltages within the band.

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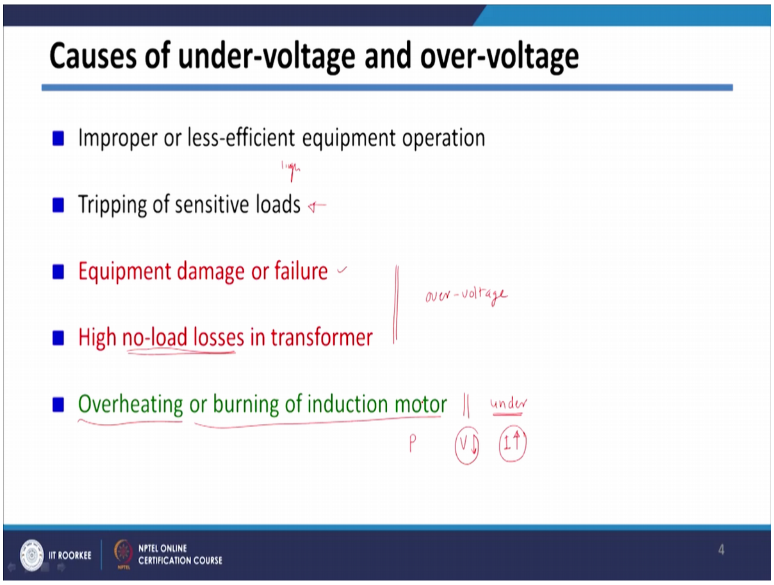

So, we should know why we need keep these voltages with in that particular limit. Because if the voltage variation is allowed say under voltage or upper voltage there will be in pro proper or less efficient behavior of your equipments. So, basically what will happen is whatever your lighting load is there, it will not eliminate properly as well as if there are motors connected they may slow or run slow or they may run fast during under over voltage conditions.

So, operation of your equipment will be improper as well as there will be some losses which are happening into the feeders they may increase or decrease. So, if the here this will be actually less efficient operation. Also we know that many sensitive loads, they are basically connected by your ups systems. So, UPS system is basically consist of inverter and these inverters are designers that during the under voltage or over voltage they will cut off from the supply side.

So, during that condition your sensitive loads will be getting from battery and it will they will keep on draining the battery sometime battery will get exhaust of the charge and in that case your sensitive equipments will be out of power. So, this can happen if prolonged over voltage or prolonged under voltage across your sensitive load and in that case inverters will be cut off from the supply because of under voltage or lower voltage conditions. So, tripping of sensitive load may happen during under voltage and lower voltage.

Let see what are the problems with over voltage? So, these are two which are shown in red dots; basically problems of overvoltage conditions. So, during the over voltage condition, your equipment will get stress more. So, there is possibility that equipment failure may happen and it will damage the equipment. Also during the over voltage condition your transformers the they will be taking more magnetizing currents and your no load losses will be increasing.

So, these are the transformer will show or take more magnetizing current which will leading more no load lasses losses, because of under voltage. So, this is the problem which under voltage. So, under voltage will affect the load which are basically constant power kinds of load say induction motor which will be consider can some kind of constant power load. In that case, if to keep power constant if voltage is decreased in motor has to increase the currents and if the voltage is decreased, you have more in that case current to the motor will increase or basically it will increases the copper losses into the motor and there are many chances that motor will get burnt.

So, there is over writing the motor because of more copper losses or burning of induction motor may happen due to under voltage conditions. So, these are various effects of under voltage or over voltage on your equipments. So, because of that we need to keep your voltages under the strict limits of plus minus 10 percent or in some state the your plus minus 6 percent or some state the plus minus 5 percent. So, depending upon the requirement, we need to keep these voltages within those bands.

Now, let us see what are the options available or what are the techniques available using which we can regulate these voltages your distribution system.

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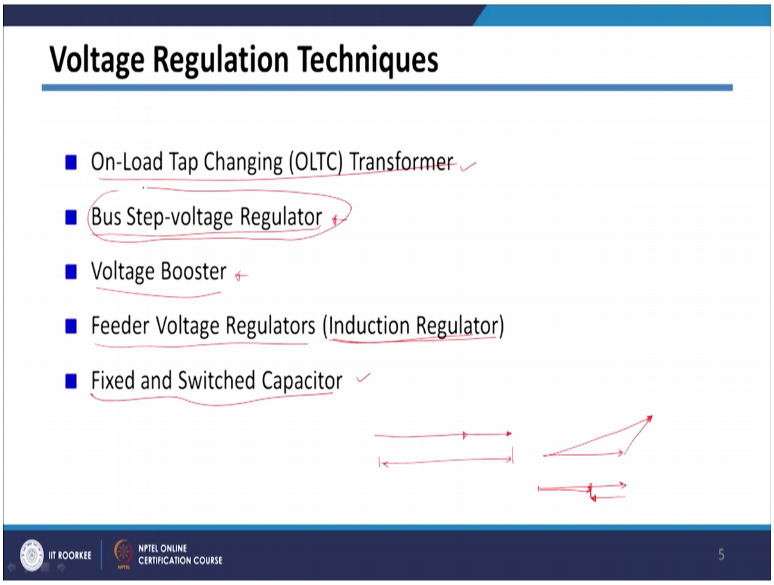

So, one important voltage regulated component is actually your On-Load Tap Changing Transformer. So, we know that then generally your taps will be provided on high voltage side of your transformer and by increasing and decreasing the taps, we can change the voltage at the secondary side and depending upon the voltage requirement at other end of the feeder, we can increase or decrease the tap and regulate the voltage at secondary end.

So, we already seen the modeling of transformer. Then there are actually Bus Step-voltage Regulator which are basically connected at the bus. These are noting but auto transformer or transformer which are connected in auto transformer fashion, we will see how we can model and what how they regulate the voltages in next flew slides. Then there is Voltage Boosters; these are nothing basically two transformers; one is connected in serious another connected in shunt fashion. So, two different two winding transformers which are connected one is connected in serious another is connected in shunt fashion and by regulating the voltage is across series winding, we can control the voltage.

So, this is actually Voltage Booster, then there are actually Feeder Voltage Regulator basically they are called has Induction Regulator and these are nothing but induction motor where your stator winding and rotor winding these induction motor, they will be connected in series and the induction motor will basically in study state position (Refer Time: 09:17) law; it do not be running.

However, depending upon the phase or you can say angle of the voltage requirement, we can change the position of your rotor. So, in this case the voltage across the stator and say this is voltage across the rotor. So, total voltage which is getting regulated which is given by this one. So, by then by changing the angle we can of by rotating or rotor little bit we can change the angle and then in that case your voltage will be this one; so by changing angles.

So, we can again decrease also. So, in this case if this is your stator voltage and rotor voltage may we can may by rotating 180 degree; we can make it in opposite direction which will basically decrease the voltage across (Refer Time: 10:15). So, we can increase or decrease voltage at the along the feeder by using this induction regulators. And then, there are actually to regulate the voltages along the feeder fixed or switched capacitors are also use. So, this switched or fixed capacitor, we will see in next few lectures.

Now, in this case we will most concentrate on what is called as Bus Step Voltage Regulator. So, let us see how they work. As I told you main function of your step voltage regulator is to regulated the voltages at the feeder end.

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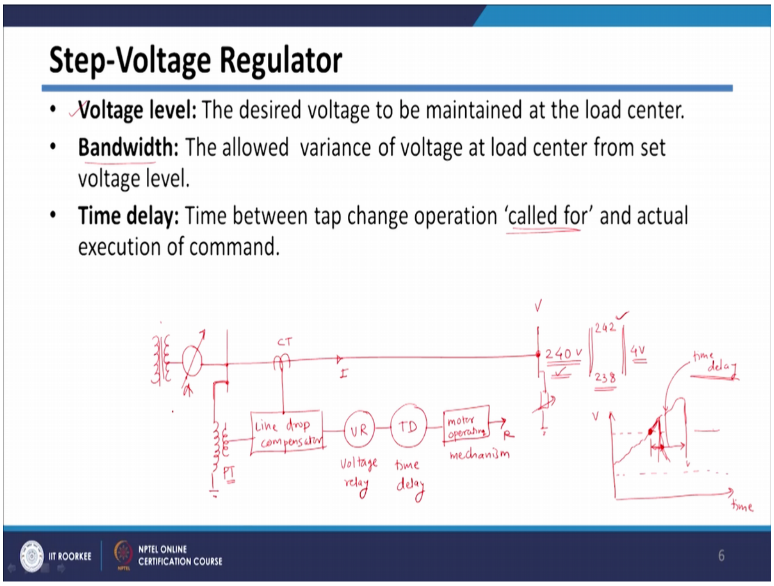

So, if this say the your feeder end, this is start of the feeder and which is basically connected by say regulator and say there is transformer here and we want to regulated the voltages at this, once function of this one we want to regulate at this ok.

So, let us say we want to regulate voltage at this sense and is say 240 volt; but exact 240 ok, being exact 240 volt will not always possible because there will be some bandwidth of the regulator. So, say we want to keep the voltages of this particular bus within the limit of say 242 by 238 range. So, lower I can go up to 238 and higher I can go up to 242. So, whenever voltages going beyond that I need to regulate using this particular regulator.

So, to do that they use what is called has line drop compensator circuit; before going to line that compensator, we will see the various terms. Voltage level is basically this voltage level which is 240 volts; then, Bandwidth the allowed variance of voltage at load center from set voltage level. So, this voltage set voltage level is 240 and allowed voltage level is 230 to 238 to 242. So, in that case bandwidth is actually your 4 volt bandwidth; then, Time Delay.

So, when voltage is changing here, it will change with respect to time. Let say voltage is changing like this. So, this is your voltage and this is your say time and this is your lower bandwidth to unvoltage same; say this is your upper bond (Refer Time: 12:56) voltage. So, because say decrement in the load at this end. So, this load is connected at this place which is say decreasing and because of decrement in the load, the voltage at this bus is say increasing.

So, let us say voltage is increasing like this it is within the band. So, we do not have to worry; now, at the voltage as gone beyond the limit which you have specified. So, we need to operate the regulator at this point ok. However, what will happen is there will be some time delay and then, they will it will. So, here the voltage has gone up; however, the regulator as operated at this particular point.

So, the time difference between these 2 point where the tap change operation is called for because we need to call for tap change operation at this point. However, your actually execution of command is happened at this particular. So, this is called as Time delay and this time is delay is required; however, because we do not want frequent operation of your regulator. Because there will be always small changes in the current which will basically change the voltage at the feeder end and for those at each transient change in the current we do not want your regulate to operate; means I can say that here the voltage this current is decreasing and voltage was going up. However, suddenly suppose some load has come then what will happen is here the voltage will stop start dropping.

So, since this drop is happening or it is voltage is coming within limit before your time delay set time delay here the your operation of regulator will not happen because this is this change in the voltage is basically happen due to transient change in the current. So, for that we do not want to operate your regulator. So, there should be always some time delay specified with regulator operation.

So, as I told you this operation is carried out using what is called as line drop compensator. So, this is your line drop compensator circuit. We will see what is inside this and we are taking signal corresponding to current using ct and fed to this one and similarly we are getting signal proportional to your voltage using pt and it is given to line drop compensator circuit.

So, this is your potential transformer; this is your current transformer and signal correspondent your load current will be taken by ct and voltages at regulator other end will be taken it by pt and this line drop compensator will this side voltage need to be increased or decreased and then, it will given to the voltage relay.

So, it will given to the voltage relay and this voltage relay will be given time delay because as I told you time delay is required to avoid the frequent operations of the regulator or chartering of regulator. So, this is your voltage relay which gives signal. There will be some time delay circuit and after that this signal will be given to what is called has motor operating mechanism and this will give signal to your regulator. So, this will we actually given signal to the regulator and this regulator will operate or its step will be change depending upon the voltage step down or step up is required.

So, there are 2 types of regulator they are called it as type A and type B regulator; all most they are similar; however, they just differ in their connections. So, as I told you; these step voltage regulators are basically auto transformer and they are having load tap changing mechanism.

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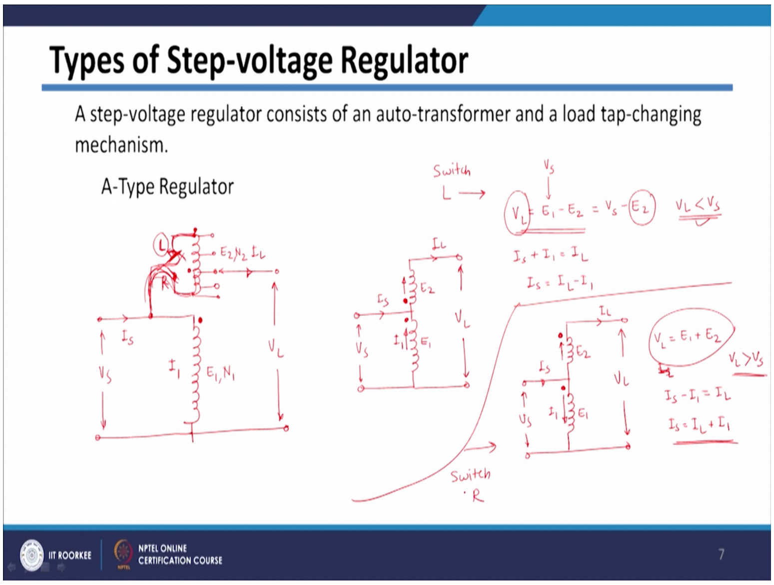

So, in case of type A regulator you are having this circuit here something like this. So, as I told you it is auto transformer which are basically it two windings; one is called as common winding and one is called as regulator winding. So, these are two windings. So, basically this is your regulating winding where we need to use taps.

So, these are various tap positions on this one and here, this is common winding and then there will be selective switch which is connected here and then there will be secondary side. So, this will be your V L load voltage this will be your V S, primary voltage. The current which is coming I S. I S current which is going to load say I L voltage across this winding is say E 1; voltage across the regulating tons which are coming into circuit is say E 2, tons say N 1 tons of this say N 2 and current through this winding it will say I 1; directions will decide how they varied and say this windings are connected such that the dots are at the top.

So, the dot connection: if the because they depend upon how windings are bound. So, windings are bound so that dots are say here. So, in this case suppose this connection is connected this terminal or this is selective switch is connected to this terminals. So, in this case what will happen is simplified diagram of this will be something like this? So, here we are having sorry. So, this is again your V L this is your V S and this is your I S current which is going on and if you see where the dots are coming for this winding dot is coming somewhere here and for this winding the current will be going like this and this like this; so initially if for this winding is coming dot as the top.

So, basically when your current is entering the dot is coming somewhere here and then it is going. So, start of the winding where you getting dot and then it is connected to V L terminal. So, dot is coming somewhere here. So, this dot is here and this dot is here and your current I L will be here.

So, we know that always if the current is entering to some dot it should leave to the other dot. So, here seen the direction of current is something like this I L which is going out of the dot ok, then this current should come to ours dot. So, I L directions of I 1 will be something like this. So, this is your E 1, this is your E 2. So, I can easily right your V S or V L will be equal to your E 1 minus E 2 right. And then your, I S will be I S plus I 1 will be equal to your I L. So, in that case we can write is will be equal to your I L minus I 1.

Now, when so, what will happen is in this case your V L lower voltage will be lower than supply voltage because supply voltage is corresponding to your V S and E 1 they will be equal because that they are connected same. So, in this case your this will be equal to V S minus E 2. So, E 2 will get voltage will get subtracted. So, therefore, in this case your V L will be lesser than your V S right.

Since V L is less than V S, we can call this terminal as V L terminal. Because when we are putting switch on this particular terminal, it is actually lowering your voltage. Now if you see if switch is connected to this particular terminal in that case your circuit will be like this. So, when this other terminal I can call it has R because it will be use for S. I will fill how it is coming today.

So, this is when the switch is connected to L L is this L position and when it is connected to say R position. So, when this terminal here in that case again I am just drawing your regulating winding and then, this is common winding and this is your V L here and this is your V S here; directions of I S and I L; they will be as specified.

However, if you see here this dot will be here only if for this winding ; however, dot of this winding. So, is starting and then this dot will come here. So, dot will be at the end of this winding. So, dot will come somewhere here in this case. So, in this case it is E 1, this is E 2. Current direction if you see in this case current is entering to the dot. So, in this case current has to leave the dot.

So, current direction will be this one. So, I 1 direction will be something like this I L direction which is entering the dot. So, I can easily write in this case V L will be equal to addition of because there in same direction. So, E 1 plus E 2 and your I L will be equal to or you can say I S minus I 1 will be equal to your I L. So, in that case your is will be equal to I L plus I 1. So, by connecting of your regulator to R terminal, we can increase the voltages as second. So, here you can see that your V L will be more than V S.

So, your rising the voltage from source voltage that is why if this terminal I am calling at is a raise R terminal and here when it is on this side switch is on this side, we are actually lowering the voltage which you have seen here when V L is becoming less than V S. So, that is why called this switch has switch L.

So, this particular condition which you have shown it here this will be for switch position which is position R.

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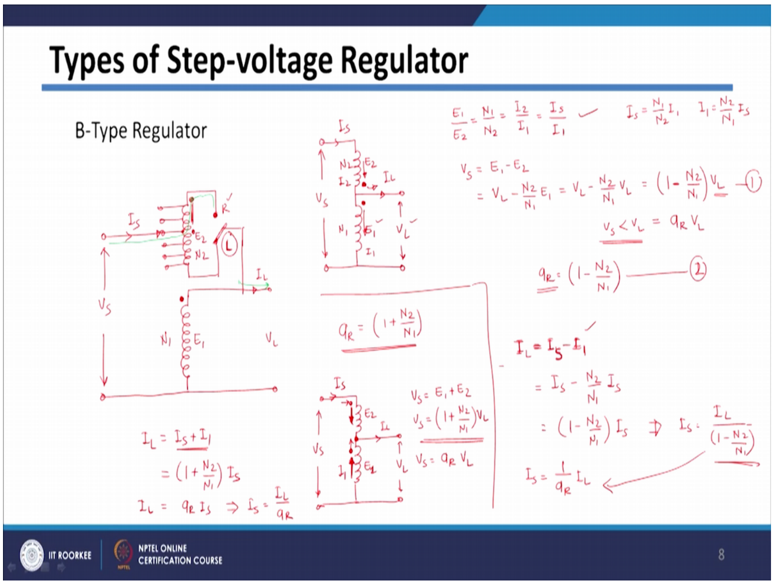

Now, let us see B type regulator. The construction is similar. However, only the connections are different in this case also there are two types of winding; one is again we need regulator winding with tap positions.

And then, one common winding which is same, then this is your V L terminal and here we are taking this and this will be connected to your selector switch. Switch may be connected on this side or it may be connected on this side this terminal. And then, as I told you there will be taps on this regulating winding. So, that we can increase or decrease voltage from set position and your supply is connected to this particular tap. So, it is just opposite of that a tap of regulator. So, this is your V S; this is current I S and the current which is leaving here I am calling it as I L.

Again here this is E 1; this voltage across this regulating winding tons which are coming in circuit, it is E 2 N 1 the tons are N 2 here. Now, in this case also has I told there are two positions possible; one position I am calling it as a position R and L. Let see how I am, why I am calling this position as a position R?

So, in this case also if you dots are something like this; this dot is here and this dot is here. So, let say your position is on R. So, this terminal is connected here. So, just remove this. So, it is connected like this. So, if you draw this diagram here, it will be something like this; where, this is your V S and this is your I S this will be I L V L. So, this voltage is your V L. Now if you observe the dots here. So, when I S is coming from the side, I will just take the different color.

So, will understand say the current is coming here and then going in and then from this side both the current, I will getting hidden and then it is going like this. So, dot if you of this drop it is coming opposite side of the winding. So, in that case drop is coming somewhere here and this drop is sorry if dot is here. So, this is your voltage E 1, this is voltage across this is E 2; number of transfer N 2; here the number transfer N 1.

Now, you can easily see that your E 1 by E 2 will be equal to your N 1 by N 2 which will be equal to your I 2 by I 1; basically this current time calling it has I 1 and this current say I 2 which I 2 is equal to I S both currents are same. So, I can say it is I S divided by I 1.

Now, if you see the voltage V S will be equal to E 1 minus E 2; both are in opposite direction. Dots are opposite direction. So, voltage will be E 1 minus E 2. Now, your voltage E 1 will be equal to V L because V L and E 1 voltage, they are same this voltage and this voltage it is same.

So, V L minus and then your voltage E 2 will be your N 2 minus N 1 times E 1 which is basically again V L equal to V L. So, V L minus N 2 by N 1 E 1 E 1 and V L they are same. So, I can say if V L here. So, it will be 1 minus N 2 by N 1 into V L. So, we can see that V S will be lesser than V L. In this case V S will be lesser than here. So, since this particular condition is happening that is why we need to put this connection has raise here.

So, this particular terminal will be raise terminal because you are getting V L per terminal voltage V L which is more than V S and this particular term which has 1 minus N 2 by N 1 I am calling transformation ratio or transformation ratio of the regulator a R multiplied by V L. So, where a R is nothing but 1 minus N 2 by N 1. Now, let see what is the relation of currents here? So, since if you can see here this current I S is actually coming towards dot here. So, this current should go away from dot.

So, this current I shown be like this. So, I 1 direction will be something like this. So, in that case I can write another equation. So, we have got this first equation here from that we have got this term here. So, I can say this 2. So your, I L will be equal to I S minus your I 1.

So, where getting I L will be equal to your I S minus I 1. Now this I 1, we can write in tons of I S. So, in this case I can write I S or you can say will be equal to N 1 by N 2 into I 1 or you can say I 1 will be equal to N 2 by N 1 in to your, I S. So, this I 1, I can just replace by is will be equal to N 2 by N 1 into your, I S. This should be equal to 1 minus N 2 by N 1 into I S. So, I can just write I S will be equal to 1 divided by a R into I L because this will lead to I S will be equal to your I L divided by 1 minus N 2 by N 1 and this we have defined it has a R. So, this term if I write it a R, it will become actually this equation. So, is will be equal to 1 divided by a R multiplied by your I L and when the this terminal is connected to, it will be opposite where we are connecting this two say L. So, I will just erase it.

Now, in this case I am connecting it to L. So, in that case your dot is here, so this dot. So, this in this circuit is not coming into picture this dot will come somewhere here and if you draw equivalent circuit of this, it will be this is regulating winding; then this is your common winding and then where I am this terminal here and dot will appear here.

This dot will appear here l then it is I L voltage V L which I call terminal this is V S and input current is I S. So, in this case since this, this current is entering to the dot; this current should leave the dot. So, the leave the dot means actually it should be direction should like this basically direction this should be. So, we can say in this case this current is leaving the dot towards inside the winding.

So, it should actually inside the winding it should flow towards dot. So, here it is leaving the dot. So, it should flow towards the direction of the current will be something like this. So, I 1 will be directed like this and is will be directed inside winding like this.

So, this is your E 2 sorry E 1 and E 2. So, I can easily write in this case your V S will be equal to E 1 plus E 2 and by using same philosophy, I can just say e V S will be equal to 1 plus N 2 by N 1 into V L. So, we can get these relations. So, which will make V S will be equal to new a R which I am got platting it here multiplied by V L and same relation in this current relation also I can get I L will be equal to I S plus I 1 because if you apply KCL at this node.

Your I L will be equal to because both this currents are coming toward the node. So, I L will be is plus I 1 and if you simplify this it will be 1 plus N 2 by N 1 into is which will make your a R into is I L is equal to N 2 is and this implies is will be equal to I L divided by a R.

So, we have got these relations and depending upon where it is connected low or raise. So, this is your terminal which is basically resist the voltage and depending how which is connecting it will decide how much raise we want. Similarly, when it is connected to, it will low the voltage and depending upon which the dominating is connected; it will lower that much particular voltage.

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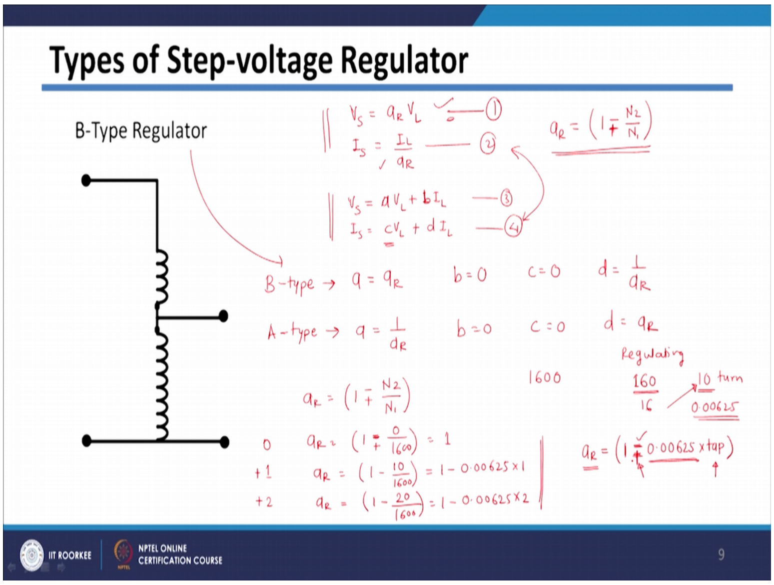

So, basically in this connection we have got two equations which is basically V S will be equal to a R into V L is one equation and another equation which is I S which is equal to I L divided by a R which is second equation and this a R will be equal to 1 minus plus N 2 by N 1. Because when it is raise we are getting minus sign has a we are discussed in side. So, we are getting minus sign when we are sizing it is raise position and in case of lower position, we are getting plus sign here in both the cases. So, it will be that is why I am writing minus plus instead of plus minus and this decides your how much voltages getting increased or decreased.

So, if you can compare these voltages. So, basically we want abcd parameter here. So, we know that V S abcd parameter we want V S voltage supply voltage which is in tons of a V L plus b b parameter into I L and is we want which is equal to c into V L plus d into I L which is 3 and 4 and if you compare this voltage this equation. So, with respect to this equation, I can say your a will be equal to a R. For b type of regulator all these things, we are derived for b type of regulator b parameter because since there is no term which is related to current here into this particular equation.

So, your b parameter will be equal to 0. In this case, there is no term second equation if you compare with respect to this 4 equation term related to c is not there. So, then that case c also I can say 0 and your d will be equal to 1 divided by a R.

Similarly, an I if you do for A type of para regulator will get just opposite because we know that both the type judges they are just oppositely connected. So, for A type of parameter this regulator your a parameter will be 1 by a R; b will be 0; c will be 0 and d will be a R because a just both are oppositely connected. Now, if you see this a R; a R I am saying a 2 is equal to 1 minus plus into N 2 divided by N 1 and this N 2 that is tons on regulator winding they are variable because we know that the tons are changing depending on the tap position and we want voltage variation to be in plus minus 10 percent right.

So, the number of tons in regulating winding will be 10 percent of regular tons in the common winding. So, say if there are say in common winding if there are say 16 1600 turns, then tons in regulating winding regulating winding they will be say 160 because only 10 percent variation we are doing using the regulating winding right and this 160 regulating turns, we are taking sixteen taps out.

So, there will be plus 16 taps minus 16 taps our plus minus we are doing just by raising our lower switch by touch selecting switch. So, there will be a 16 taps we are taking it out from it. So, 16 variation will be available. So, since we are taking 16 tap so per tap number of tons will be 10 turns. So, this should be also because 16 divisions, we are making so per division or per tap there will be 10 tons right.

So, when your regulator on normal tap means 0 tap, then we can see that number of tons of regulating winding will be 0. So, a R will be equal to 1 minus or it will be whatever it is minus plus will. So, both are. So, in that case this way show will be 0 divided by 1600. So, it will be just 1. When tap is say plus 1, in that case your, a R will be equal to 1 minus for tap 1, we are adding 10 tons of N 2 winding. So, there will be 10 here divided by 1600 which comes around 1 minus 0.00625 into since 1 tap is there, so I can say write 1.

Then on it is on tap 2, so a R, in that case it will be equal to 1 minus; now since there are 2 tap position, it will add 20 tons of regulating winding. So, N 2 will be than 20 divided by 1600. So, it will nothing but equal to 1 minus 0.00625 into 2 taps. It is equal; so per 10 tons; the voltage variation which is per unit, voltage variation which is coming which is 0.00625.

When you are considering 16 tap positions. So, in generalize way I can write this a R will be equal to 1 minus plus 0.00625 multiplied by your tap position. So, if you know the tap position where the your regulator is lying we can easily find out this a R. Because it a R will be just tap position multiplied by 0.00625 plus minus it should be added or subtracted from 1.

So, when we want to raise the raise the voltage in case of b tap regulator you need to use minus sign and when we want to reduce the voltage or get to taps you need to use plus sign. So, that is why minus plus. So, minus is used for raising the voltage at the secondary side and plus is used to decrease the voltage on secondary side.

So, in summary of today's lecture: we have seen why voltage regulation is required because this under voltage or over voltage condition will create lot of effects on your equipments of your consumers. So, your voltages of the distribution system should be kept under strict limit of say plus minus 10 percent or some cases is plus minus 6 percent also. And we have seen those effect on various component how under voltage and over voltage effects on various equipments, then we have seen various techniques of voltage control.

So, we also we have seen voltage can be control using on load tap changer; we can we have seen step voltage regulator, voltage booster, induction regulators or switched and fix capacitor. Out of this we are seeing step voltage regulator into this particular section of chapter. And then, we have seen how we can models single phase regulator and we have seen that there are 2 types of regulators; type A regulator and type B regulator and from the first principle of auto transformer connection, we have derived abcd parameters of type B regulator.

Next time, we will see how we can model thing phase connected regulators.

Thank you.