Electrical Distribution System Analysis
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Lecture - 23
Load Models in Distributed System
Part II

In the last lecture we have seen various models of Load. In particular, we have seen constant real and reactive power load that is we call it as a constant PQ load. We have seen constant impedance load, constant current loads. And then, we have seen 2 types of combinational loads or mixed type of load; those are called as Polynomial or zip model and other exponential load models. And all these load models, I have described in detail in the last class.

And we also studied their behavior such that we can easily calculate the current injected by those loads and we have seen that behavior of this loads is very different with respect to voltage. In one case with when the voltage is increasing your currents are decreasing; but in other case when voltage is increasing current is also increasing.

So, behaviors of all these loads are very much different. Also I have given some examples of this loads like for constant real and reactive power. Your load models are basically induction motor type or air conditioning kind of load which comes under constant real and reactive power. Basically the behavior of these loads will not be exactly like a constant power.

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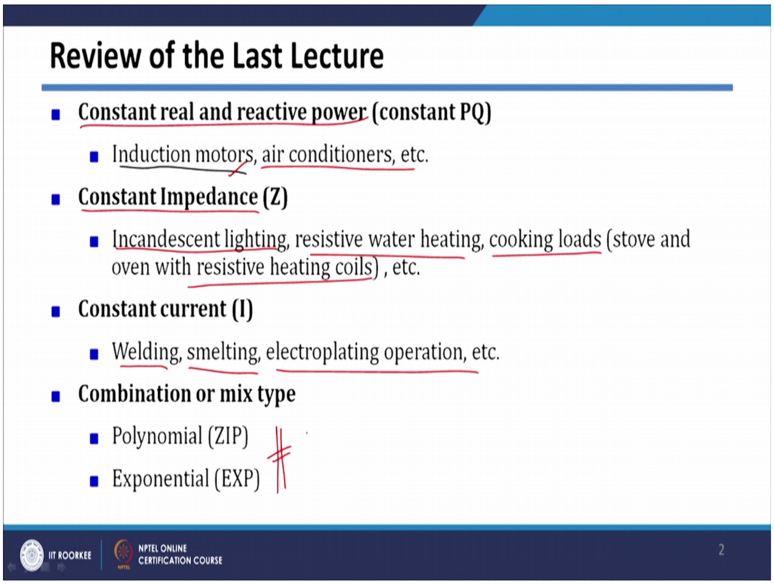

However, approximately we can say that power will remain constant and we can model approximately category of constant real and reactive power. Then, we have seen constant impedance and example of them are incandescent lighting, resistive water heating, cooking loads which are basically based on your resisting heat resistive heating of the coil. And then, constant current basically we will come very small percentage of load those are basically welding or smelting or electroplating kind of load which need constant currents. And as I told you in actual modeling you may need polynomial or exponential model.

So, sometimes as I told you the voltage across the induction motor will not be balanced as well as because of that current through the motor will not be balanced and there will be negative sequence and positive sequence torques as well as negative sequence 6 positive sequence currents and because of that you will be having negative sequence powers also. So, in that case we need to consider those effects also.

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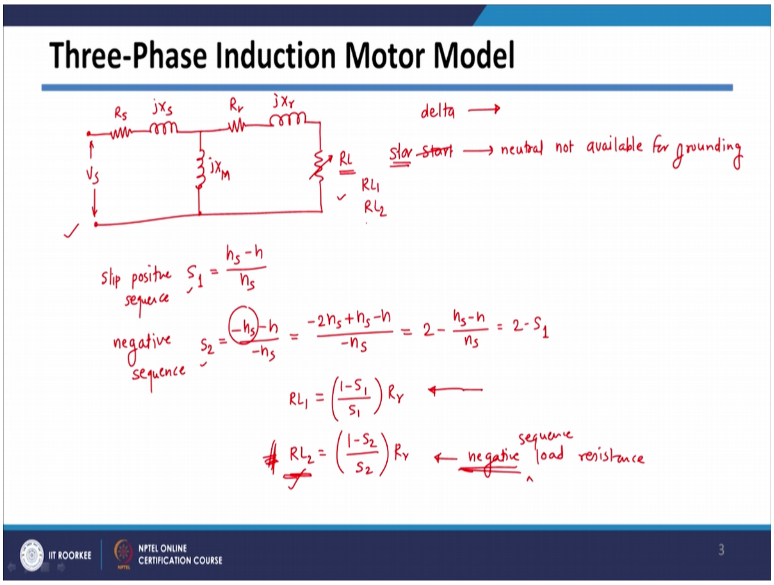

So, to model this induction motor let us consider your equivalent circuit of induction motor which is basically we already studied it; so single phase equivalent circuit of induction motor after ignoring your core loss branch; it will be like this and these are the related to stator winding. So, I can say it will be R s j X S stator this is they are related to stator and this will be R r. This stator is related to rotor j X r and this is your resistance which depends upon your loading condition that is you can say R L and it is j X M, magnetizing branch here and voltage VS is applied across this one.

Now, we know that induction motors are basically generally connected in delta fashion; in that case neutral will not be available. So, since neutral is a not available 0 sequence quantity will not be there. Similarly, even if it is star connected; your neutral will not be available for grounding. So, in that case also your 0 sequence quantities will not be present in case of induction motor. Let us say your; sorry it is star. So, in case of star connected let us say this is your equivalent circuit of 1 phase. So, in that case since I am considering unbalanced voltage across this three-phase induction motor. So, this is single phase equivalent of three-phase induction motor.

And say there will be unbalanced supply across this particular motor and because of this unbalanced supply there will be slip which is in positive direction as well as slip in negative direction. So, there will be positive sequence slip; I can say S 1. So, this is slip in positive sequence will be equal to we know that it is synchronous speed minus actual speed divided by your synchronous speed of motor.

Now, there will be negative sequence slip also; S 2 in that case your synchronous speed will be in negative direction. So, it will be minus ns minus n divided by minus ns. So, this is I can just rewrite. So, I can just write minus 2 ns plus ns minus n divided by minus ns. So, this term minus ns, I just write wrote in terms of minus 2 ns plus ns. So, if you simplify it, it will be 2 minus ns minus n divided by ns. So, it will be nothing but 2 minus S 1. So, negative sequence slip S 2 and S 1.

Now, depending upon your slip your this load resistance will change. So, for positive sequence say R L 1 is this load resistance for positive sequence slip which is basically given by 1 minus S 1 divided by S 1 into your R r and the your R L 2 will be depend on your negative sequence slip. So, it will be 1 minus S 2 divided by your S 2 into R r. So, this is basically negative sequence load resistance component.

Now, there will be 2 sequence circuits; one is positive sequence circuit where I can model it by considering R L 1 and then there will be another circuit basically negative sequence, negative sequence it. So, in case of negative sequence circuit it will be replaced by R L 2.

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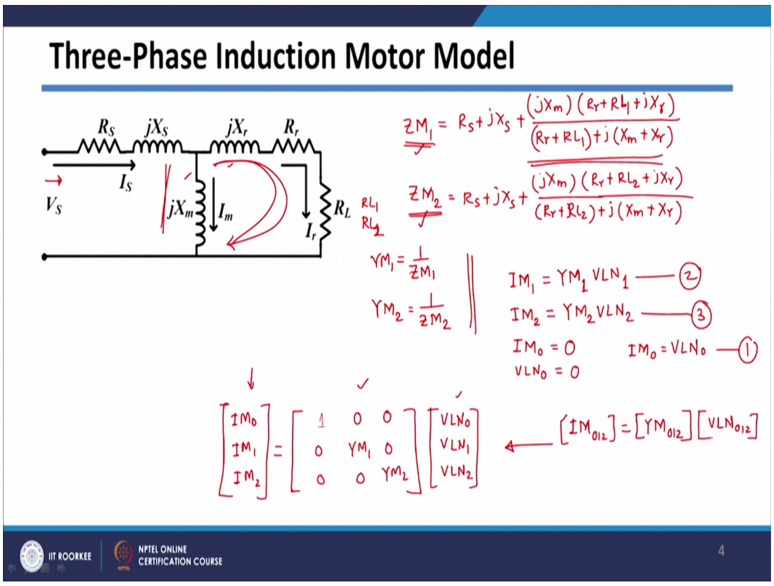

So based on that, I will get equivalent positive sequence network equivalent of this one; so ZM 1 is nothing but positive sequence when I am considering R L 1 resistance here. So, equivalent impedance of this circuit ZM 1 will be equal to R s plus j X s plus there will be this parallel branch.

So, this impedance will come parallel with this one; so you can take the parallel combination of these impedances. So, if you take the parallel combination it will be j X m multiplied by your R r plus now I am considering R L 1. So, R L 1 also will come into series plus j X r. So, these are the multiplication of those and at the denominator will get addition of them. So, it will be R r plus your R L 1 which are basically resistive part plus j X m plus X r. So, this is nothing but this part is nothing but parallel combination of this part of network and this part, this branch of the network.

So, by considering R L 1 I am I have got this ZM 1 n. Now for negative sequence equivalent circuit, we can put R L 2 here instead of RLM. So, for negative sequence I can get ZM 2 which is basically again R s plus j X s which will be mentioned j X m is also not get going to change. So, j X m will remain; R r will remain as it is, only R L will get replaced by R L 2 R L 2 plus j X r divided by R r plus sorry R L 2 plus j X m plus X r. So, this is equivalent negative positive sequence impedance. This is equivalent negative sequence impedance of this particular induction motor.

So, we can get the admittances format. So, ZM 1 or we can say 1 divided by ZM 1 will be equal to YM 1 which is positive sequence admissions and YM 2 will be equal to 1 divided by ZM 2 which are basically add up positive sequence and negative sequence admittances and once you know the admittances, I can write the equations for currents. So, in this case current IM 1 positive sequence current will be equal to YM 1 multiplied by positive sequence line to neutral voltage. So, it will be VLN 1 positive sequence lien to neutral voltage.

Similarly, IM 2 negative sequence current will be equal to YM 2 into VLN 2. So, it will be depending upon negative sequence admittance multiplied by your negative sequence line to neutral voltage. And we know that your; since this motor is we can say star connected with neutral ungrounded in that case your IM 0 will be equal to 0. Similarly VLN 0 will also equal to 0. So, I can say IM of 0 will be equal to your VLN 0.

So, from these 3 equations, we can write the matrix equation. So, I can just write them in matrix form. So, this will be YM 1 or I will start first YM 0 0 0 or it will be 1 here sorry. So, it will be 1 0 0 and 0 YM 1 0 0 0 YM 2 which is getting basically multiplied to; this is getting multiplied to VLN 0; this getting multiplied to VLN 1; this is getting multiplied to VLN 2. And this is basically equal to your IM 0; we are getting from this equation say this equation 1 and this is equal to your IM 1. So, this is say equation number 2 and this is equal to your IM 2. So, this is equation number 3.

Now, we have got this equation of motor currents or induction motor load currents in terms of sequence component. We need to convert them into phase domain. So, this particular matrix I can collectively write.

So, this particular a matrix I can say IM motor currents in sequence domain 0 1 2 which is equal to this matrix I can say YM 0 1 2 and this matrix I can say VLN 0 1 2. So, these are in sequence domain that is why I am writing 0 1 2.

So, let us take this equation on the next slide.

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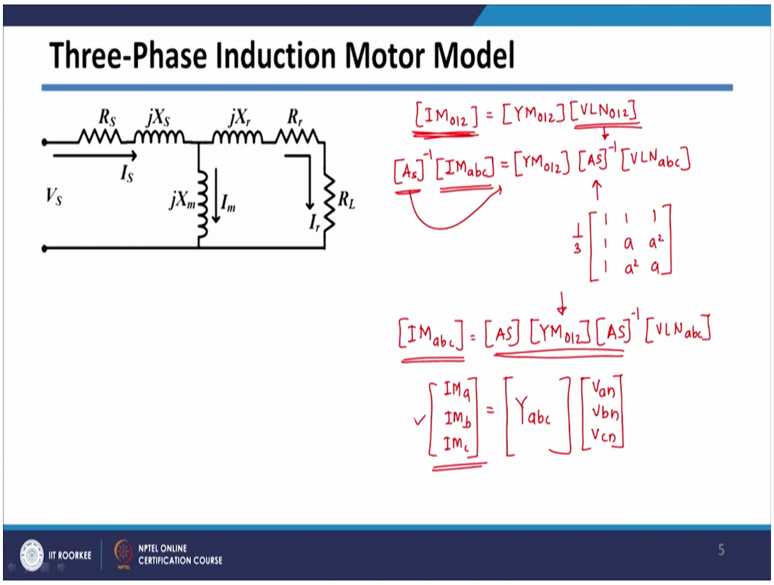

So, in this case, we have got IM 0 1 2 which is equal to YM 0 1 2 into VLN 0 1 2. Now, we know that there is sequence conversion matrix which is basically if you multiply this matrix by As inverse or we can say this is equivalent to As inverse multiplied by IM abc. So, if you want to convert phase quantities into sequence component, we know that we have to multiplied by As inverse. So, equivalently this IM 0 1 2; I can write in terms of phase quantities IM abc by multiplying a inverse.

So, in this case YM 0 1 2 as it is and this sequence also I can write in phase domain by writing it like this. Basically what I did? I converted this into your phase domain and we know that this matrix here which is basically as inverse is nothing but 1 by 3rd 1 1 1 1 1 a a square a square a. Now, we can take this as inverse on right hand side. So, I can write this equation as IM abc will be equal to your As if you take on right hand side, inverse will go. Then, YM 0 1 2 multiplied by as inverse into VLN abc.

So, we can see that these currents are nothing but phase currents in the motor that is IM a IM b and IM c. These are nothing but induction motor current in all three-phases which will be equal to this matrix; I can say Y abc which will basically I am getting from this conversion here after calculating your YM 0 2 0 1 2 matrix which I explained you how to get it. And then, multiplied by it will be Van Vbn and Vcn. So, to calculate equivalent injections of the induction motor, those can be calculated by using this equation here. So, this is nothing but your induction motor model which is more accurate as compare to constant power model which you are considered.

Now, let us we will take some examples to understand these models better. This we have already studied your constant power, constant impedance, constant current and mixed type of model. Let us understand it them better by taking some example.

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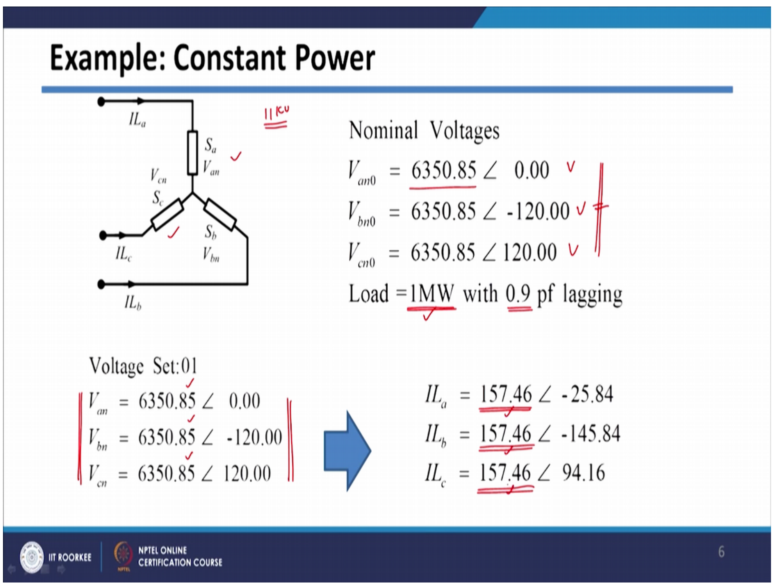

So, in this case I have taken this example of load which is connected in star fashion and the nominal voltages means rated voltages of this load since I am considering say eleven Kv system. So, per price voltage will be eleven by root 3. So, basically they are in volts and loads in all the three-phases I am considering same load that is 1 megavolt of load is connected in all the three-phases; means each phases I am taking 1 megavolt of load and the power factor of this load is say 0.9.

So, in case of constant power loads; obviously, if there is there is balance apply of exactly equal to your rated voltage and if you consider balance apply. So, same voltages nominal voltages say are appearing across your loads in that case you will get rated currents. So, rated currents into this load will be these values and since they are loads are basically voltage across them load terminal since they are constant you are getting same currents.

So, in case of constant current constant power load, we have seen that when voltage increases to keep the power constant current has to decrease. So, if you consider that particular case. So, in this case nominal voltages are as it is. However, during say operation of it voltages across this terminal; this is Van Vbn with respect to n terminal and voltage across this is say Vcn with respect to n. So, these are not now nominal voltages. So, here we can say the voltage is nominal voltage across the 1 phase that is A phase; but other 2 phases in B phase voltage as increased and in C phase voltages has going down.

So, because of that we have seen that when the loads are constant power load.

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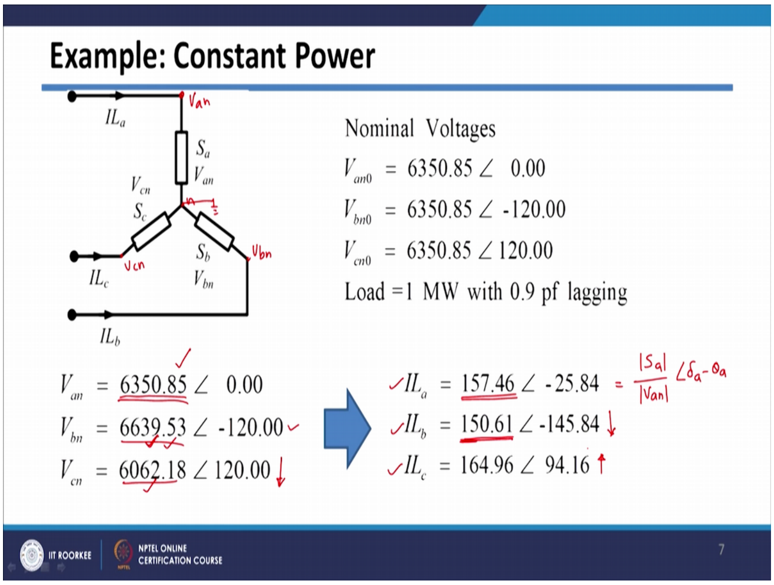

So, we can calculate this load just by we have seen that it will be S a magnitude divided by Van magnitude and its angle will be delta a minus theta a. So, by knowing this, we can calculate these currents here. So, all the 3 currents can be calculated and since they are constant power loads whenever voltage is increased, you can say voltage is increased your current is going down from nominal value. Nominal value of the current is rated value of the current is 157 because rated voltages appearing across that particular node and that is why in this case I am considering this is grounded ok.

So, in that case when the voltage is increased, your current has to goes down. So, you can say it is going down when voltage is decreased. So, in third phase voltage is less, in that case this current is going up right.

So, this is how we calculate currents injected in case of constant power load. In case of constant impedance load, we have seen that we have to first calculate your impedances.

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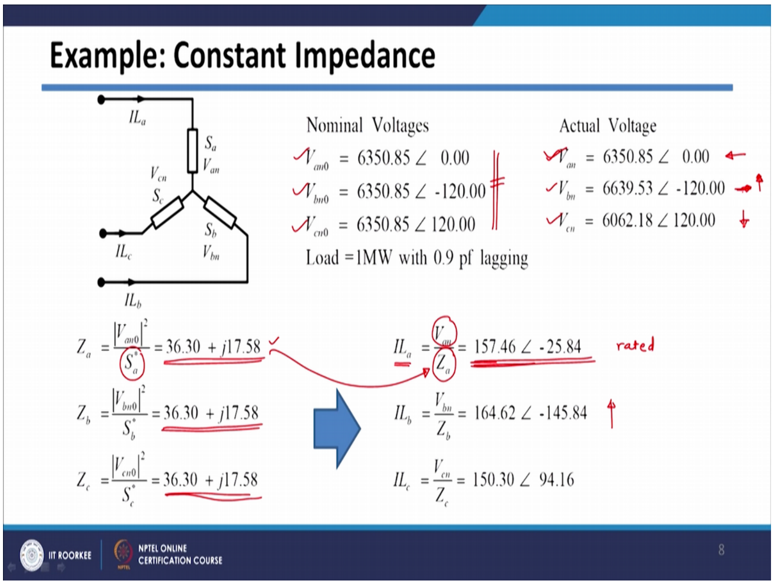

And we know that impedances can be calculated from the rated values of currents sorry rated voltage of values of voltages which are basically given here. So, these are rated values of voltages and rated values of powers. So, by knowing this we can easily get impedances which will remain constant throughout calculation and if there are any other voltages apart from your nominal voltages if they appear. So, in this case these are the nominal voltages; however, during the operation the voltages are changed. So, in this case first phase is getting nominal voltages; however, this phase voltage is increased and this for this phase, voltages are voltage is decreased.

So, as I told you constant impedance load behaves differently. In case of constant impedance load whenever voltage is increased, your current also has to increased; whenever voltage is decreased current also has to be decreased, ok. So, in that case this currents are calculated the Van divided by Za.

So, Van is actual voltage which are coming across the terminal divided by this constant impedance which you are calculated from the nominal values which we can put it here, which will give me value of the current. So, this will be actually nominal current because in this case the voltages also coming nominal and this is also nominal. So, this is nominal or rated value we are getting here, here.

However, as I told you whenever voltage is increased your current also has to increase. So, in this case voltage current has increased than nominal value and when voltage is decreased your current also has to decrease from your nominal. So, in this case current is decreasing. It is exactly opposite like we have seen in case of constant power load. So, constant power load you can see that when voltages are more, your current is going less and when voltages are less, your currents are going up, but in case of constant impedance, we have seen exactly oppositely ok.

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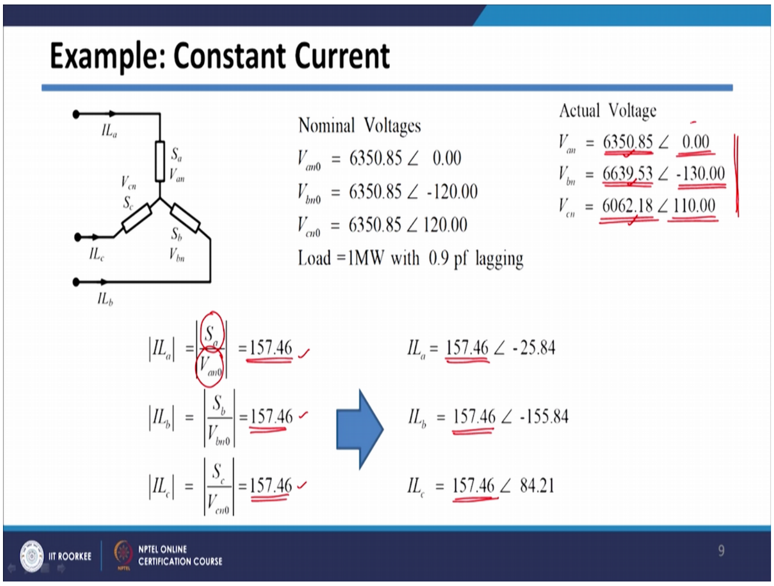

And then, in case of constant current loads currents are constant. So, first from the nominal values of voltages and nominal values of powers we should get your constant current value. So, constant current magnitude we can get from nominal value of load and nominal values of voltage and as I told you it will remain constant.

So, in this case you can see that these are all nominal or we can say constant values of the current for all the three-phases. However, the angles of these currents may change and as I told you these angles will depend your angles of voltages. So, in this case I what I did? I have changed the voltages of all the three-phases and I had changed the angles.

So, for constant current loads the voltage will not effect on the magnitudes of the currents. So, that is why you can see that your current magnitudes are remaining same; even though I have given different voltages for these particular loads.

However, because of your this deltas they are not we can say 120 degree exactly 120 degree phase shifted which we have already considered in earlier cases they were actually 120 degree phase shifted. However, I have considered here little bit different phase angles and because of this phase angles your angels are going to change; this angle will change. So, in case of constant current your currents will remain constant; even though voltage magnitudes change here. However, your angles will be different they depend upon your voltage angles. So, this is behavior of your constant current load.

Now, let us consider one more case of mixed load.

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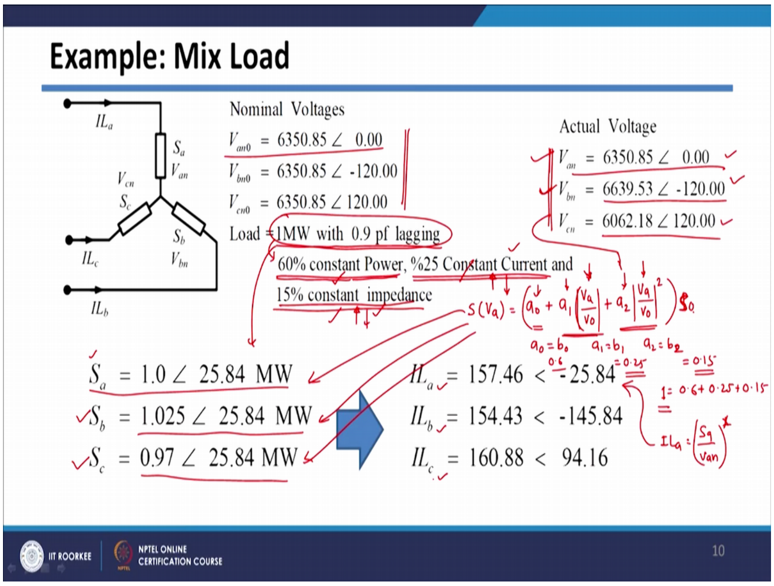

So, in this case again similar problem I have considered, your voltage nominal voltage I kept same; your total power of the load I have kept same, but I am considering out of this, 1 megawatt 60 percent load is constant power; 25 percent load is constant current; and 15 percent load is constant impedance. Now, by knowing this configuration, what we have to do is first we have to get your actual loads for actual voltages, because as I told you since some part is constant power. So, whenever. So, for this particular position, your power will remain constant. However, for these 2 cases with respect to voltage, the power of the constant current load will change; similarly power of constant impedance will change.

So, in this case whenever voltage is increasing power of constant current and constant impedance will actually increase and whenever voltages are decreasing powers of them will actually decrease. So, overall by knowing this, we can calculate the powers we have seen that the mixed load model which you are considering here is zip model.

So, we have seen that S Va is actually equal to a 0 plus your; a 1 V a divided by V 0; its magnitude plus a 2 into Va divided by V 0, its square and it is to be multiplied by your P 0 sorry here it will be S 0. You have to calculate separately because the constant may be different in this case I am considering same constant. So, that is why you can say S 0 also here. I am here considering even though I have we have separate constant for both p and q component in this case I am considering a 0 equal to b 0 and a 1 equal to b 1 and a 2 equal to b 2.

So, this will be 0.6. This two's will be equal to 0.25 and this 2 will be equal to 0.15 and we know that addition of them is actually 0.6 plus 0.25 plus 0.15 that should be equal to 1 total per 1 per unit load.

So, in this case a 0 is 0.6; a 1 is 0.25; a 2 is 0.15 because this is actually this part we have seen that it is behaves as a constant impedance; this part behaves as a constant current and this part behaves as a constant power load. So, this is 60 percent 0.6; this is 25 percent 0.25 and this is 15 percent that is 0.15 and by knowing this an S 0, we already given the power. So, we can get the S 0 from this particular value; 1 megawatt with lagging power factor you can get the S 0.

And by knowing the voltages of different phases; so, voltage actual voltage of A phase if we need to put it here. Then for calculating power of B phase you have to put actual voltage of b phase here in this equation and to get power of C phase you have to put actual voltage in this equation of actually C phase. And from that I can get all the 3 powers of all the three-phases. So, power of A phase will not change because voltage is nominal value means voltage of nominal value and actual voltage is same here. So, it will be just 1 megawatt and same angle.

However, in case of second load, your voltage is increasing means power has to increase. So, in this case power has increased because both this powers increases and when voltage is less than nominal both the powers will be less than your nominal power. So, it will be less than and then we have got the power and then come power we can get the current. So, this current will be your IL a will be equal to Sa divided by Van and we have to take the star of it with respect to angle. So, if you do that, I will give this is; so for you can calculate for all the three-phases. So, this is current in a phase, b phase and c phase. So, I have given the example of all the 3 types of load as well as 1 type of mixed load.

So, in summary of today's lectures, we have seen the model of three-phase induction motor. So, that we can accurately model the induction motor to get the injected current whenever there is unbalance supply across the induction motor and for that we have derived the equation for injected currents using the Sequence Component Theory. And then we have considered one example where we have seen the effect of various different load models constant power, constant current and constant impedance as well as one type of next load model.

Thank you.