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

Lecture - 26
Summary of Modeling of Distribution System Components

In the last 12 to 13 lecture, we have seen modeling of various components in the distribution system. Those components like feeders, transformers, regulators, loads, capacitor banks, distributed generation. And in this particular lecture I will try to summarize all those components by taking the important equations, which we have derived. So, we will try to just the revise what we have seen as distribution system component modeling.

So, initially we have started with model of distribution line, and in that distribution line model first we have derived the equation for impedance, and we have derived these equations for the impedance.

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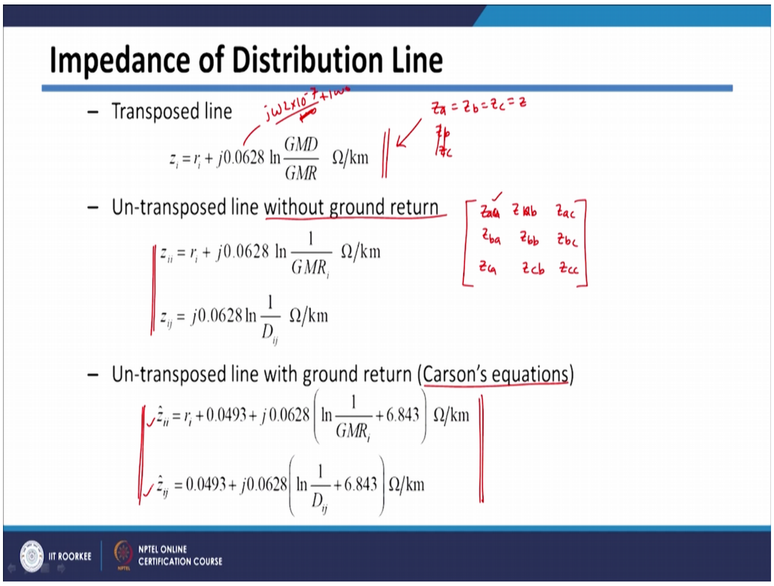

So, we have seen in case of transpose lined your equation for the impedance is this one, where this is nothing but just j omega 2 into 10 raised to minus 7, which is converted into kilometers. So, it should be the multiplied by multiplied by 1000.

So, in this case your Z a Z b and Z c they all will be coming equal. So, Z a will be equal to Z b equal to Z c will be equal to this whatever Z, which we are getting from this formula. However, in case of un transpose line, there will be equation that is Z ab Z; sorry Z aa, Z ab, Z ac, Z ba, Z bb, Z bc, Z ca, Z cb, Z cc. So, it will be full matrix and entries of this matrix, this matrix will be calculated from these two relations.

Then, we have seen in case of distribution system there is possibility that sometimes ground return also be used as return conductor. And, in that case there will be ground currents which are flowing during the unbalance condition and if you want to take that ground return in to account we need to use Carson's equation.

So, in case of ground return the cars Carson's equation will be used and we have derived these two equations, which can be used. So, in this case also we can calculate the impedances between various conductor as well as (Refer Time: 02:57) impedance of that conductor using to this two relations.

So, after that we have calculate this impedance matrix. So, impedance matrix will be calculated based on primitive impedance matrix. And, we have seen that primitive impedance matrix will be number of conductor by a number of conductor size.

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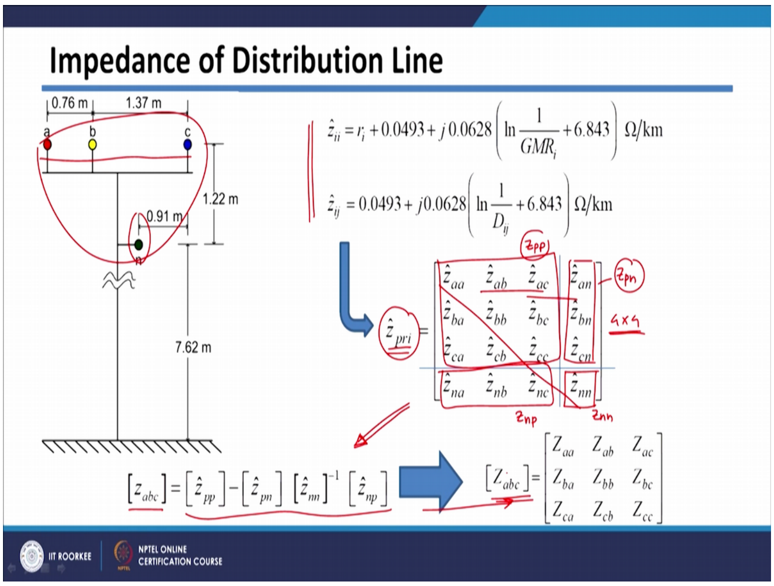

So, if there are 4 number of conductors into system the primitive impedance matrix will be 4 by 4, which will be having entries like this there will be 4 conductor corresponding there will be 4 self-impedances, and then there will be mutual impedance with respect to each of the conductor. So, there will be 4 by 4 matrix in this case because it is there are 4 conductor into the system, if there are more conductor the size will be more. However, for the analysis purpose we need always an a number of phase conductor by number of phase conductor. So, since there is an only three-phase conductor here. So, size of phase conductor matrix will be phase impedance matrix will be 3 by 3.

So, this primitive impedance matrix we have seen that, we need to convert into phase impedance matrix by using what is called as crown reduction? So, for crown reduction we have divided this whole matrix into 4 part, this part we have called at a Z pp because it is relative to phase conductor.

So, that is why Z pp this part is related to Z pn, that is related to phase conductor as well as neutral conductor. This part I am calling it as a Z np because it is again related to phase conductor as well as neutral conductor. And, this part is only related to neutral conductor. So, that is called as Z nn. And, from this 4 parts of this matrix, we can using this crowns reduction technique, we can get phase impedance matrix. So, your final phase impedance matrix will be like this which is basically 3 by 3, because there are 3 main phase conductor 0 circuit, basically we are eliminating this ground or earth conductor using crowns reduction.

So, this is how we can get your phase impedance matrix means using your Carson's relation, you can build this primitive impedance matrix, and after building the primitive impedance matrix get from the crown reduction get phase impedance matrix.

So, once phase impedance matrix available let us see how we can get phase admittance matrix?

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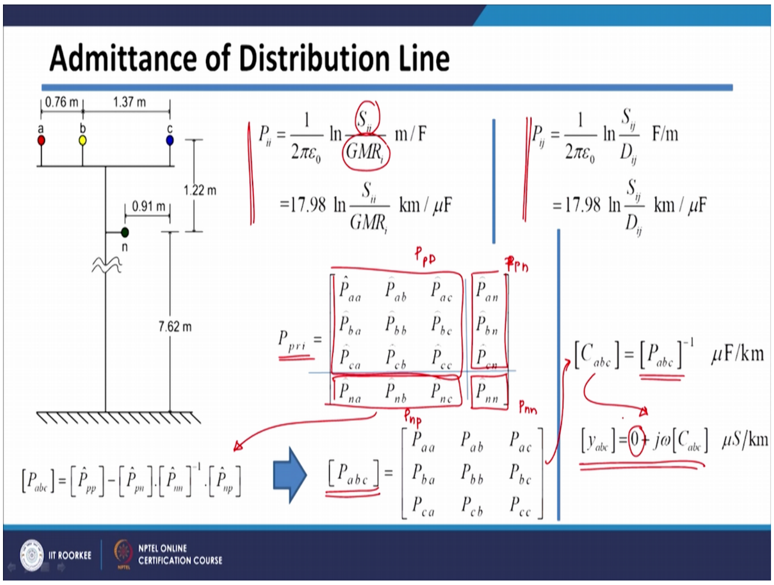

So, phase similar to phase impedance matrix we can get phase impedance matrix by using the potential coefficient. And, the expression which you derived for potential coefficients are like this which again depends upon various distances and your GMRS of the conductor. So, by knowing the GMRS and distance with respect to image, we can get this potential coefficients and potential coefficient matrix will also be number of conductor by number of conductor soil.

So, primitive potential coefficient matrix will be bus of size 4 by 4, because there are 4 conductors here, again this matrix will be divided into 4 parts. So, this is called as PPP, because it is rated to only phase conductor all the mutual and self coefficients of phase conductors. And, these are Z sorry P P n, which is related to phase conductor and neutral conductor, this is again P n P, which is again related to phase and neutral conductor, but this part is only related to neutral conductors.

So, that is we called as P n n and then using this 4 parts using crown reduction, you can get potential coefficient matrix or phase potential coefficient matrix. And, from this potential coefficient matrix we can get the capacitance matrix by taking inverse of it. And, once you the get the capacitance matrix, you can convert into admittance matrix like this it by multiplying by j omega.

So, in this case we have considered conductance of the path is 0. So, we have got impedance matrix we have got admittance matrix.

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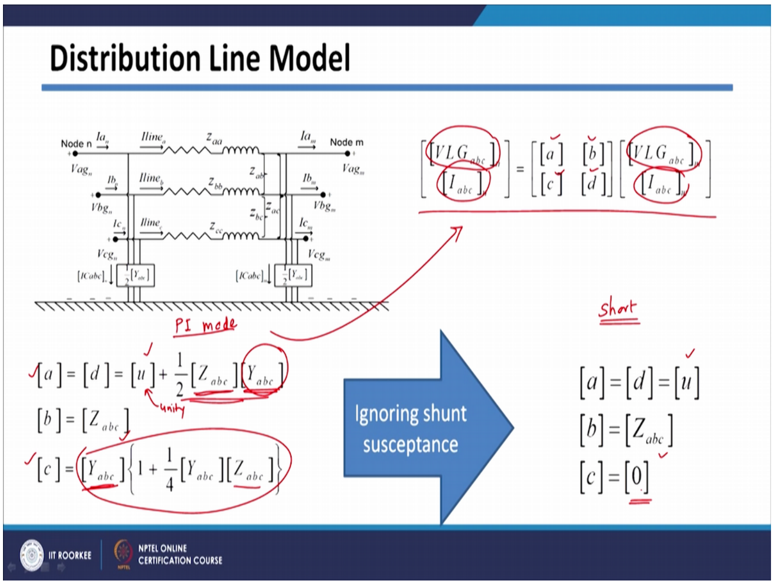

And, then lines can be modeled as pi model or short line model. So, if you are modeling as a pi model, we have seen that your equations for pi model are like this where u is unit matrix. So, of 3 by 3 size and this is your impedance matrix, which I have got this is our admittance matrix, here also this is admittance and impedance matrices.

So, we can write using the pi model you can get the a b c d parameters of these equation, where your sending end quantities like sending end voltage and sending end current is return in terms of receiving end voltages and receiving end currents by this a b c d parameter. So, a b c d parameters of distribution line of pi model will be calculated like this.

So, once you get a b c d parameter with this can be used for any analysis purpose, if you are having short line. We know that admittance of the short line is very small. So, basically this part is almost 0. So, we can neglect this part here. So, in that case in short line model this will become just u, the it will be Z abc and here this will become totally 0, because it is getting multiplied by Y abc which is negligible is 0. So, in this case a b c d parameters for short line model will be unit matrix here, then Z matrix which you have got for using impedances calculated and this is your c parameter.

So, these are the models of distribution line.

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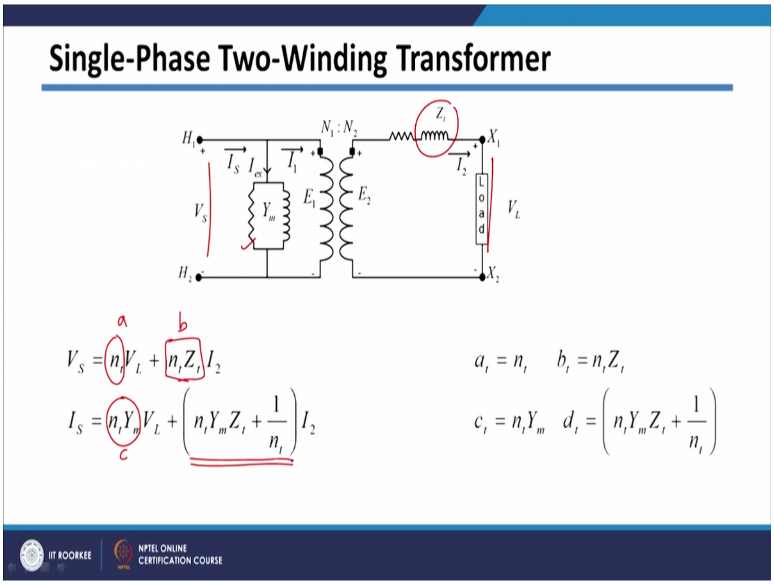

Then, we have seen the models of transformer first we have started with models of single phase transformer. In this case also we have just writ10 the equations of primary quantities and secondary quantities. And, then converted your secondary quantities in terms of primary quantities, and from those relation we have got a b c d parameters of this one. So, this is nothing but your, a b c d parameter which is turns ratio a parameter, turns ratio multiplied by your impedance of this leakage impedance of this matrix which is b parameter. And, then n t multiplied by admittance of this matrix is c parameter and your d parameter is given by this one.

So, these are the a b c d parameters of single phase 2 winding transformer.

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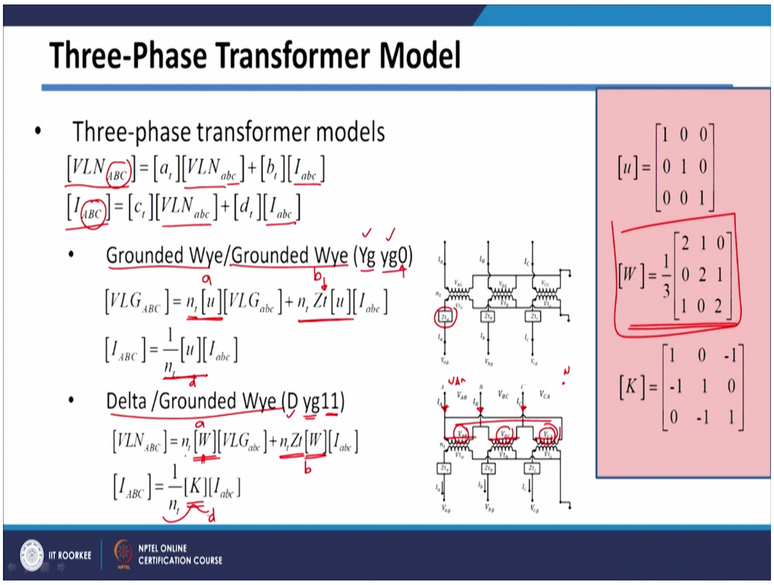

And, then we have gone for three-phase transformer. So, in case of three-phase transformer also we have derived the a b c d parameters of those transformer. So, in this case also we have writ10 primary voltages and currents in terms of secondary voltages and currents. So, these are the primary side voltages to represent added by capital abc.

So, these are primary side quantities and these are secondary side voltages and currents primary side voltages and currents are writ10 in terms of secondary voltages and currents. And, we have derived this model for 4 different types of transformers, first transformer we have considered I simplest one that is ground wye grounded wye by grounded wye transformer, it is called as Yg yg 0. So, since it is grounded on the both side. So, capital Yg is primary side small yg is secondary side and there is no phase difference that is why it is 0.

So, in this case we have got a parameter which is just number of turns multiplied by this unit matrix and b parameter number of turns multiplied by impedance matrix, impedance which is self-impedance or sorry leakage impedance of this transformer. So, this is leakage impedance here and then your c parameter 0 and this is your d parameter.

So this is a, this is b and this is your d parameter c parameter is always we have seen that, it is 0 in case of transformer. Because, we are not considering that shunt branch of this one we are here in case of three-phase model, we have neglected that shunt branch or magnetizing branch of the transformer.

Then, we have seen delta grounded Wye connection, that is D or delta on primary side yg on secondary side and there is 30 degree place displacement that is why 11 here. So, in this case, once we need to convert this W matrix will be used to convert these delta voltages to the star voltages.

So, n t multiplied by w is your a parameter of the matrix again n t multiplied by Z t multiplied by w is b parameter. And, here again this delta currents in this delta winding here, need to be converted into line currents of the transformer.

So, these are the line currents here which are flowing like this. So, this delta currents need to be converted line currents and that is converted by this K matrix here. So, this becomes your d parameter which is K divided by n t.

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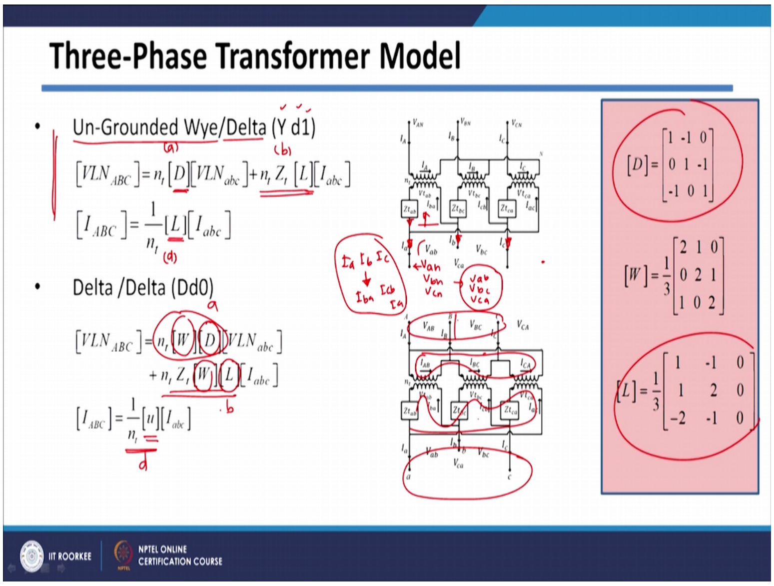

Then, we have seen third configuration that is ungrounded Wye to delta configuration is called as Y d 1 configuration. So, primary Y connected which is ungrounded. So, g is not written here then this is delta and one there is 30 degree phase shift.

So, in this case we need to convert this delta volt this star voltages into delta voltages. So, here this Van is there with respect to ground whatever it is. So, Van is converted into V ab means Van V bn and V cn will be converted into V ab V bc and V ca, to convert this Van V bn V cn into V ab V bc, we need actually this d matrix here.

And, so, that is why the your this is a parameter is actually n t multiplied by D, where this is your D matrix we already derive it and your b parameter is basically this one.

So, here also this line currents here, this line currents here on the secondary side need to converted into delta current that is I a I b and I c need to be converted into I b a I c b and I a c. So, to do that we need this one matrix here which is basically given by this matrix here, which is b parameter and this is your d parameter again here l matrix will be used, because this of conversion again needed in case of currents also.

In case of delta-delta 2 types of conversion is required, in this case first this line quantities will be converted into delta quantities here, an then this delta quantities again need to be converted into line quantities here. So, here both this matrices will come that is W as well as D, here only in earlier cases there only 1 matrix.

So, here to convert the currents also we need W and l here. However, the conversion of current will get cancel out the each other. So, it is just u here. So, this is your d matrix of the delta-delta conversion a this is your a and this is your b matrix. So, these are actually models of three-phase transformers.

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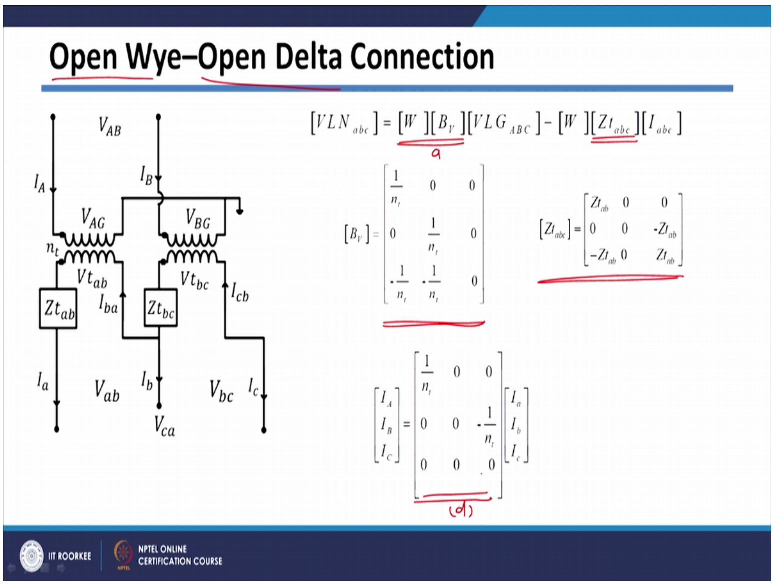

And, then we have seen one model with open wye and open delta connection also this also you have seen that which can pref we can prefer it because it saves you one transformer here. So, from only 2 transformer you can give three-phase supplier to any consumers. So, that is why sometimes open wye and open delta connection is used and we have derived a b c d parameters for this also.

So, in this case this is your a your B v is given by this one, we have derived this 3 W same as earlier Zt abc is basically this matrix here and your d matrix is given by this part. So, this is your model of open wye and open delta connection.

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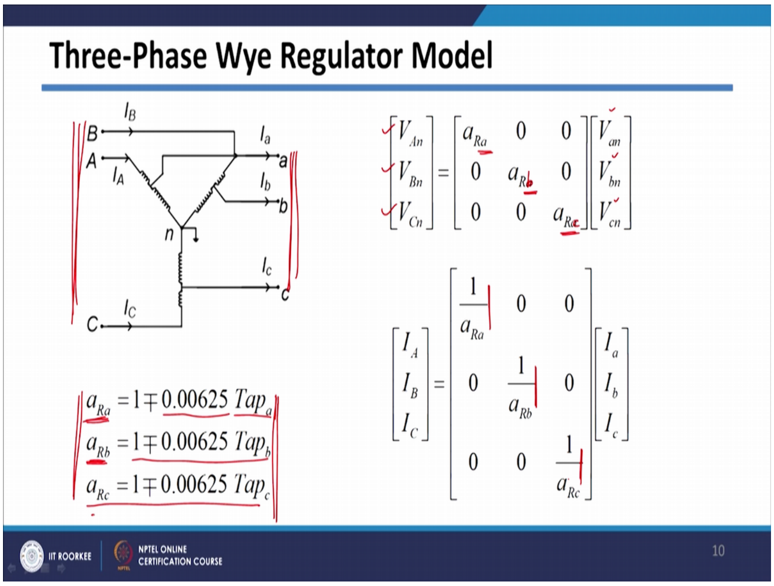

After, transformer we have gone for three-phase regulator model. And we have seen that a regulator model your depends upon your tap ratio, and the transformation of voltage will be decided by your regulator setting. And, this regulator setting is given by one minus plus 0.00625 into Tap of a a Rb. So, setting of b or ratio of b will be given by one minus plus 0.00625 to Tap of b similarly you can get for third.

So, this is our Taps based on Tap your transformation ratio will be calculated. So, if you know the voltages on the secondary side of the regulator, we can get the voltages on primary side of the regulator. So, these are the voltages on the primary side of the regulator, based on voltages on secondary and this will depend on a, your tap position of your regulator depend upon tap of a phase tap of b phase. So, here it should be b and this is should be c.

And, similarly for current also we can calculate currents on primary side of the regulator using currents on the secondary side of the regulator. In this case it will be just opposite of this. So, it will be ratio one by a Ra it is one by a Rb and 1 by a Rc.

So, this is three-phase model of Wye regulator.

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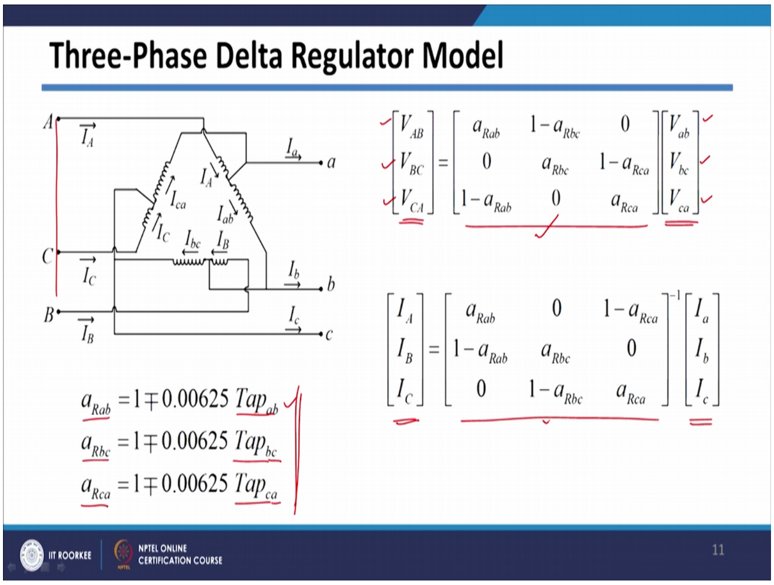

In case of delta regulator primary side voltages those are actually basically delta connected. So, that is why Vab Vbc and Vca can be calculated from the v small ab v small bc and v small ca where the regulator settings, that is a Rab a Rbc and a Rca they will be again similar way we can calculate based on. The regulator which are connected in a and b phase regulator which is connected in b and c phase regulator, which is connected in c and a phase. So, once you get these parameters we can easily transfer your secondary side voltages to the primary side voltages.

Similarly, currents on a secondary side will be converted in the currents on a primary side and these are the conversion matrices. So, to convert the voltages this is your matrix and you convert the current this is your matrix.

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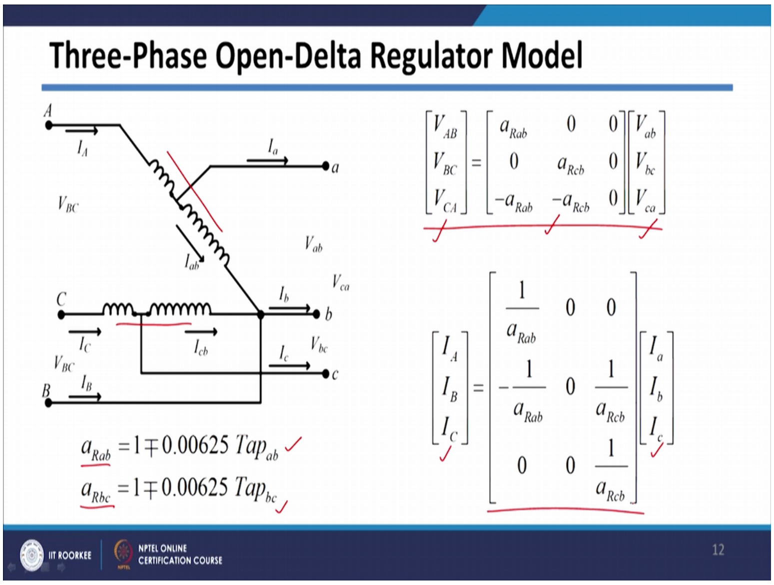

We also seen if there is open delta regulator so, many time to say one regulator we can use open delta, because output three-phase voltage can only be can be controlled by only using only 2 regulator. So, in that case it is used as open delta regulator and these 2 regulators can be used control three-phase voltages at output. So, in that case also we have derived.

So, these are the settings of 2 regulators, because there are 2 regulators. So, regulator connected ab will be having this setting and the regulator which is connected between b and c this is setting, and then transformer ratio we have derived is secondary side voltages will be converted into primary side voltages using this relation. And then secondary side current will be converted into primary side current using this relation.

Then we have gone for three-phase load models various types of load models we have seen first is constant real and reactive power model.

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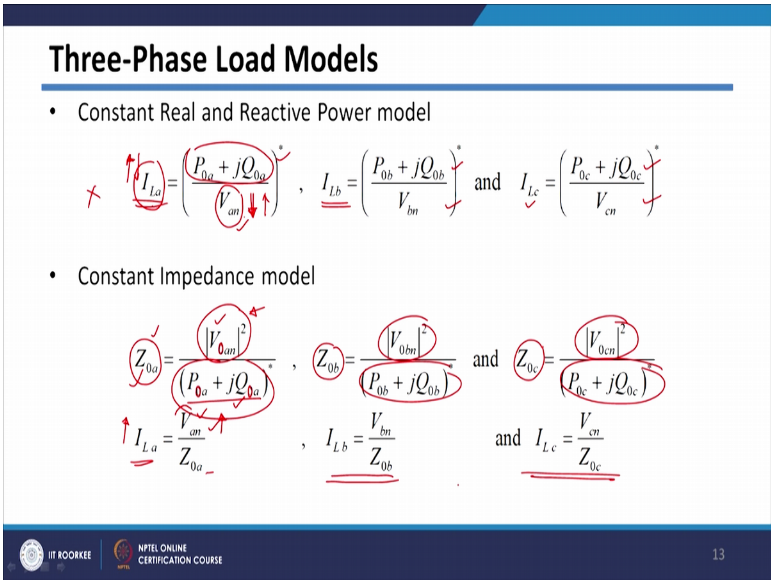

In this it is simplest one in this case your load is kept constant during the load flow iteration means load will not change depending on your applied voltage, in this case your load is remaining constant. So, whenever voltage is changing your new current will be calculated based on voltage. So, if the voltage is decreasing your current will increase in this case. So, in case of constant real and reactive power model, whenever voltage is changing your current will change, but this part power will remain constant.

So, you can calculate all the three-phase currents by considering load in a phase and voltage of a phase, we can get the current in a phase then from b phase load and b phase voltage we can get b phase current and c phase load and c phase voltage we can get c phase current.

Opposite of that, in case of constant impedance model, first you have to get the rated impedance of the device. And, that rated impedance of the device will be calculated from rated voltage and rated load value. So, from rated load value here this 0 0 terminology I am using it to represent the nominal values or rated values of that load.

So, this is rated voltage of this load this is rated power of the load and from this rated voltage and rated power of the load we can get the rated impedance. And, this rated impedance will remain constant throughout the iteration of any load flow or other analysis pure doing this part this impedance will remain same.

So, similarly we can calculate for base phi phase b voltages and power value phase c voltages and power value we can get the. And, then if you want to calculate the current because and load flow studies generally injected current is required and to calculate that injected current, we can use this relation here that is V so, actual voltage which is coming.

So, here we have used in this case we have used rated voltage and here you are using actual voltage. So, actual voltage divided by rated impedance here we have got rated impedance. So, actual voltage divided by rated impedance will give me the current. So, in this case when the voltage is increasing since the rated this impedance is constant when the voltage is increasing current also will increase so, exactly opposite of this. So, in this case when voltage is increasing or voltage is decreasing current was increasing, when the voltage is increasing current was decreasing exactly opposite, but here with respect to voltage when voltage increasing current is increasing.

Similarly, we can calculate for other 2 phases also and this will be used during the load flow studies.

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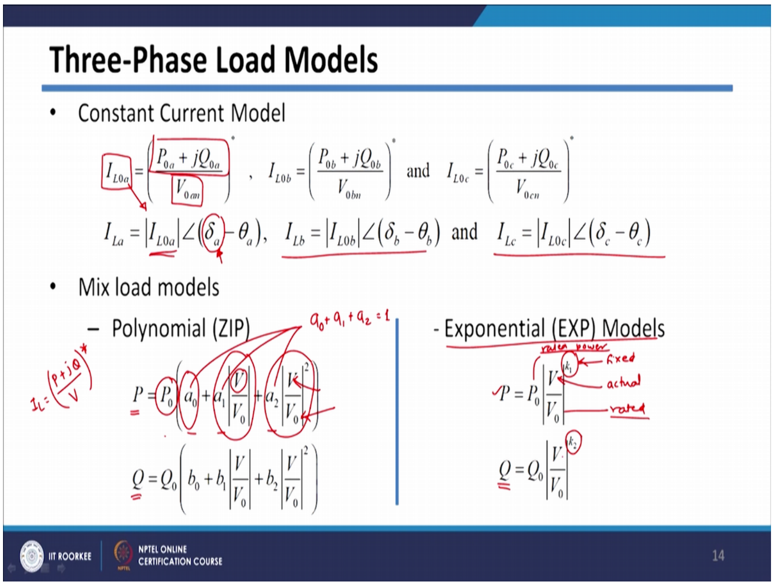

In case of constant model that is next model here first you have to get the rated current value. So, that rated current value will be calculated based on rated power, which is this divided by rated voltage. So, from the rated voltage and rated power first get rated current.

And, this rated current will remain constant throughput iterations only thing is it is angle will change, because this angle will depend on angle of voltage where the load is connected. So, this angle is nothing but angle of voltage where the load is connected.

So, this will change in iteration. However, this part will remain equal to this part only. So, we need to just change the angle of voltage do not you have to change the other things. So, similarly we can get for other phases and then we have seen mixed load models, because we have seen that in case of distribution system. The loads are generally mixed type means there will not be on the constant power loads or constant impedance load or constant current load, there will be always mix of these loads.

So, if the loads are mixed then you can use Polynomial ZIP or Polynomial or ZIP model or Exponential model EXP model. So, in case of polynomial or zip model all the 3 types of loads are considered and overall load can be calculated that is overload load P or overload reactive load Q can be calculated, based on this 3 coefficients. And, this 3 coefficient adds we have seen that this coefficient adds to one we means total per unit load. And, this particular portion represent your constant power proportion, this part represent your constant current proportion and this represent constant impedance proportion.

And, this is how then by knowing the actual voltage and rated voltage, we can and knowing this parameters a a one a 2 and a 0 and rated voltages and rated power we can get P n Q. So, it iteration this V will basically change. So, whenever V changing your power will be changing depending upon the coefficient of a 1 and a 2.

So, once you get P and Q from this one. So, current will be calculated. So, IL will be just P plus j Q divided by V star or sorry overall star overall star. And, in exponential load models, you we use a 2 exponential factors here k 1 and k 2.

So, in this case this is actual voltage this is rated voltage which is known and this is rated power. So, by knowing rate so, this rated power is known rated voltage is known. So, by knowing so, this k 1 is also fixed before during the iteration. So, k one is also fixed. So, when your actual voltage is changing your power of this load will change.

Similarly, in this reactive power also will change depend upon value of V here, then we have gone for modeling of distributed generation and we have seen that distributed generation will be modeling.

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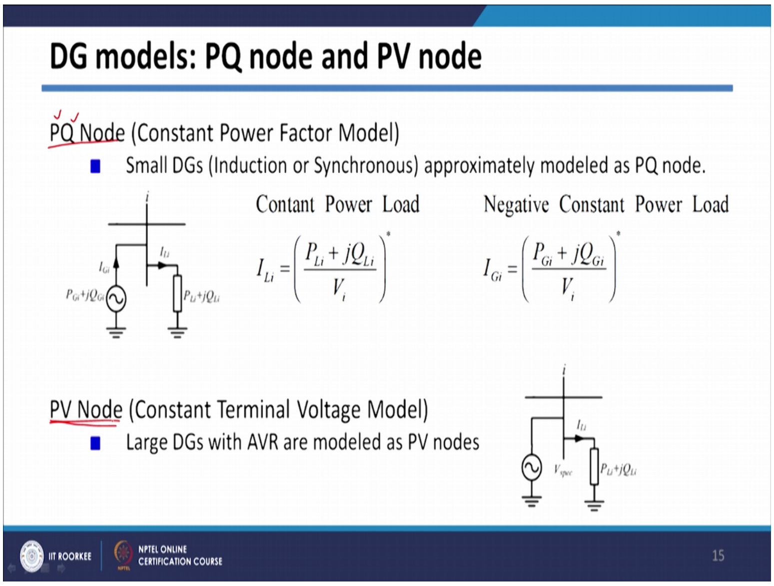

As PQ node or PY node where P and Q specified and from that your injected current will be calculated. However, in case of PV node your power is specified and voltage of that node is kept constant.

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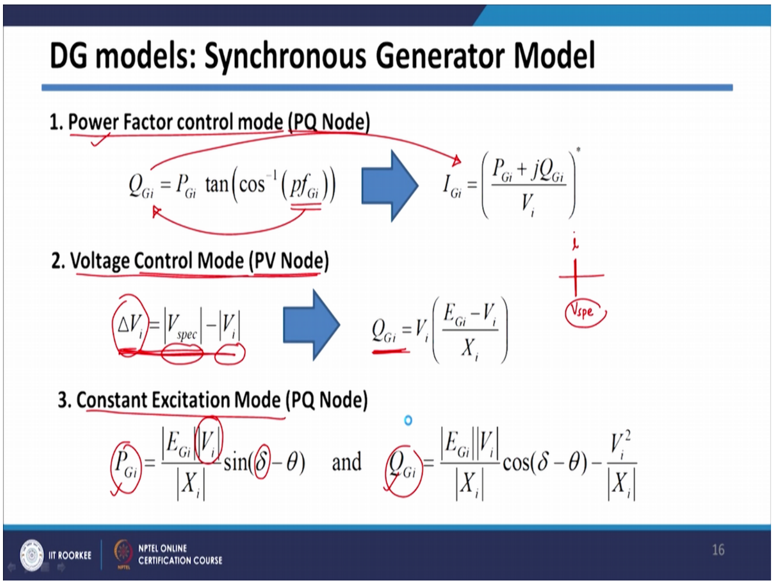

And, then we have seen synchronous generator model we have seen 3 types of model one is when the power factor is controlled, when voltage is controlled and then third is excitation control. And, we have seen that when whenever we are using power factor control mode you have to use PQ node PQ node always considered as negative load applied at that particular bus. So, it will act as a your generator will act as a negative load.

However, in case of PV node your generator will keep the voltage at that particular node constant. So, in this case we have seen that in case of constant power factor control, we from the power factor which is controlled, you can get reactive power and from the reactive power, you can get the current injected and that can be used in load flow studies.

However, in case of voltage control mode we have to keep the voltage of that particular bus constant. So, if it is i-th bus. So, here the voltage will be equal to specified. So, for first what to do how much it iteration how much you diffidence we are getting into this one, and then you need to change reactive power supplied by the generator. So, that the gap between specified voltage and actual voltage of that bus in that particular iteration, we will get minimized or within tolerance. So, we will try to bring this delta V within tolerance, in this case to keep the node i-th node voltage at specified value.

So, in this case first calculate delta V if it is not within the limit change the reactive power depending upon the voltage, if there voltage is less feed the leading reactive power supplied a reactive power, if voltage is higher absorb the reactive power like this.

Then, we have seen constant excitation in this case you can calculate the PG and QG value of that node by knowing the voltage of the bus and angle of the bus. And, then we can get this PG and QGi, which are basically specified values of the for real and reactive power.

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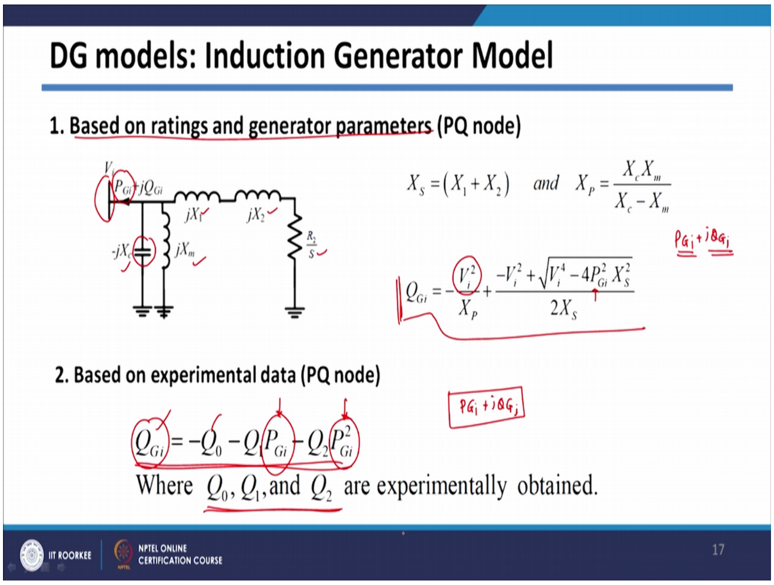

Then in case of induction generator model we have seen 2 models one is based on parameter. So, from the parameters of the generators, we can get of this reactive power absorbed by generator that is QGi including the power factor correcting capacitor.

So, this is how we can calculate specified reactive power and real power will be specified already earlier then we can actually get the P G i plus j Q G i, because this is specified and then for this particular P G i, we can get the respected Q G i by knowing the voltage at this bus. So, from this voltage of this bus and P G i we can get the Q G i values.

Another way of getting Q G i values is actually from the experimental data. So, this curve can be plotted which gives basically for different P G i values the Q G i values. So, this Q 0 Q 1 and Q 2 can be experimentally obtained. And, once this Q 0 Q 1 Q 2 is available for any value of real power you can get the reactive power need needed by that induction generator.

So, for any particular P G i value we can get Q G i values using this equation, and you can get the P G i plus j Q i j j Q G i and you can calculate injected current.

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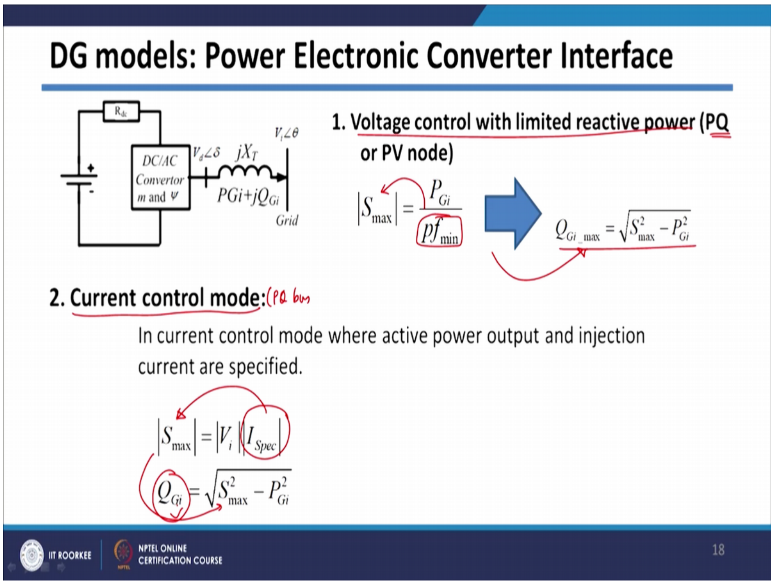

And then finally, we have seen DG models for photonic based converter interface. So, in this case there are again 2 modes of operation one is actually voltage control or reactive power mode limited reactive power mode and then current control mode. So, in this basically the current is control to this specific value from that current we have seen that we can calculate maximum apparent power it can supply, and from this maximum apparent power we can get what will be the Q G i of the generator.

And, in case of control reactive power you can get S S max using P G i divided by minimum power factor, which is assigned to this controller here from that you can get S i max. And, then actually maximum reactive power which can be supplied by this converter will be calculated like this. So, if this reactive power requirement of DG or reactive requirement of that bus is lesser than this limit, which is available. Then, it can be used as a PV bus otherwise it will be always use as a PQ bus.

So, in this case also it will be used as PQ bus, because Q G i will be calculated and P G i is actually specified. And finally, we have gone for capacitor model and we have seen that capacitor model is considered as constant susceptance model. So, from the k V r rating of the capacitor we need to first get susceptance of the capacitor, and from that susceptance get the currents. So, whenever voltage is changing, your currents will be basically changing currents are not constant in this case.

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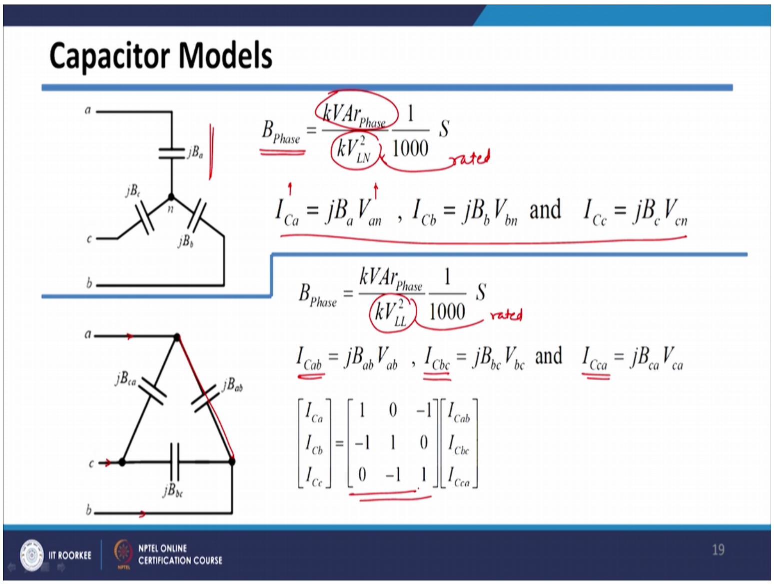

So, so, susceptance we of the capacitor bank or capacitor in phase will be calculated based on rating of that capacitor. And, line to neutral rated voltage. So, this is actually I should say rated voltage. And, once you get the susceptance then we can get the currents in various phases, and delta connected also similar thing will happen only thing is here we have to use line to line rated voltage of the phase because this capacitor getting connected, between line to line.

And, in this case we will get the currents of delta phases and then you are need to converted in convert into line currents, and to convert this line currents we need to actually use this relation here.

So, summary of this lecture: in this lecture I try to summarize whatever models detailed models we have seen which are basically distribution line, transformers, regulators.

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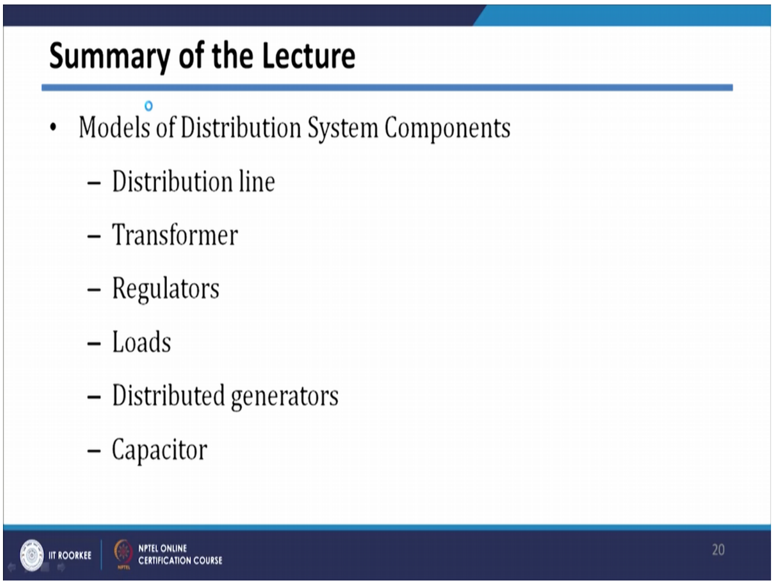

Loads, distributed generation, capacitor. I try to summarize the equations which we have derived for all this kinds of components in the distribution system.

In next lecture we will try to see various analysis methods starting with load flow analysis.

Thank you.