Power System Engineering
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Lecture - 29
Load flow of radial distribution networks

Now, we will be now starting a new chapter that is Load flow of radial distribution systems. So before starting anything, I have to tell you that try to understand this right. Perhaps book, we will not find all these things but things are very simple. And we will only teach that balanced distribution system not the unbalanced distribution system. And for the distribution load flow, we will talk about two methods only. First all that theories will be given; after that we will see the numericals.

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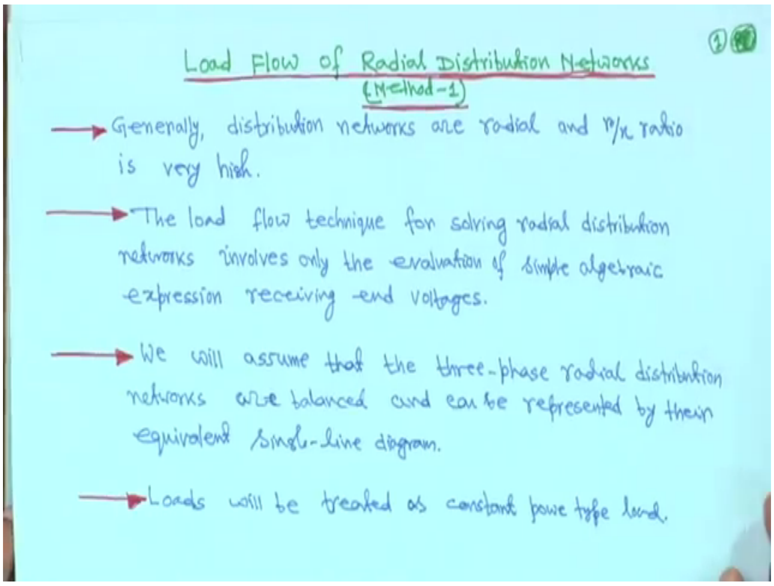

So, question is that, when we talk about that radial distribution network before you are explaining all these things, first certain things let me try to explain. For example, when we studied that your power system analysis course, the structure of power system and your what you call that your substance and few other aspect, there we have seen the transmission line, sub transmission and distribution system.

But actually, how distribution things are for radial and why it is radial. First you have to understand this. Here mathematics are very simple that you have to understand, particularly from the little bit of solving is also very easier. And if you want to write code, then 2 algorithms will be given and it things are very simple. It will not only help you for your what will call for this course, but those who does that BTech project and distribution system, it will help you to write the codes on this to load flow. So, that this is based on that all these things I have tried to simplify and just see how is it before. For example, that whenever we are suppose; any transmission line we are talking, sub transmission sub transmission distribution system.

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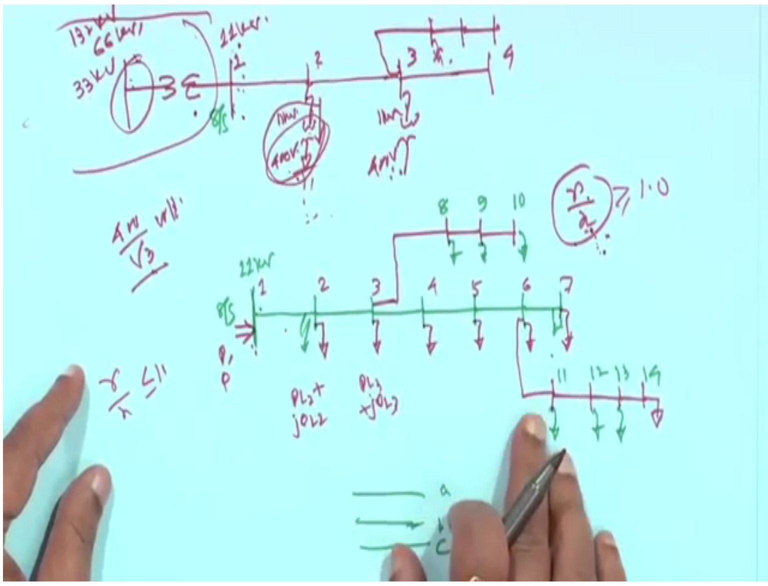

So, suppose when line is coming from somewhere, say this is the transformer is there right, this side transformer is there right. This side transformer is there. So, this side it may be 66 KV, it may be 132 KV right. It may be 33 KV I mean this side right and it may be 220 KV also. But generally it is a 132, 66 or that this side. And this is your step down transformer. And this side actually 11 KV. Also our distribution network, actually in our country, it is most of the overhead distribution networks we will find all overhead you will find 11 KV only right. But in some places, in hill areas, I have seen that distribution your network they have 15 KV or 22 KV and some pieces even less than that 11 KV voltage, 66.6 KV also right. So, even 3.3 KV.

So, question is that, but overhead I mean bulk of the overhead distribution systems, they are of 11 KV. So, when it comes to the distribution side; that means, when substance that which is coming it may be 132 KV line is coming or 66 KV or 33 KV line is coming, then voltage actually is being stepped down. So, when it is step down, it is 11 KV. Now

11 KV figure will be there, for your example, your all are say this thing. And suppose, if I hold it about this side, you forget about this side, if I put suppose this is my say node 1 then, if this is my node 2, suppose load will be tap, here you have that distribution transformer right. This transformer actually this side is 11, this is the 11 KV feeder 11 KV line.

So, this side is 11 KV and this side is say 400 volt. This is a distribution transport, different ratingm, distribution transformer of different rating. It may have 1000kva, it may have 500kva, it may have your, what you call 100kva, 200kva, 75kva, 50kva, 25kva, 16kva and 5kva. Different type of ratings are there, it depends on the your loading condition and that reason. And so this is side actually this is a 11 KV p dot and this side actually is 400 volt. So, whatever residence you get in your these things. Suppose lying to neutral voltage, this will be 400 by root 3 volt; that is whatever we get in your residence or in you or if you stay in the hostel.

In your hostel, this is actually, this will this 400 is line to line. So, this is 400 upon root 3 board, regarding delta star, collection star delta all have been explained in the power system analysis course. But our objective is not this, but this is our, this is actually your distribution transformer and current is you are load is there, here this side load is there distribution side. So, naturally the current is flowing.

Similarly, and another distribution transformer will be there and so on. So, this side also your this is again 11 KV and this side again 400 volt right. So, normally what happened that when you come to the substation here, this voltage may not be 11 KV.

It may be less also. So, generally in our, your what you call, in our load flow analysis, we will assume there 11 KV right. And in that of why it is below 11 KV because when that power is coming to the transmission line, there must be some voltage drop along the line. So, this side voltage may not be 66 or 33 and one time it will be less than that, but transformer they have the tap changer. You can change the tap and you can make it to approximately 11 KV also right.

So, we will assume it is 11 KV, but let me tell you, in rural areas rural areas actually I have observed that is many suppose when distribution feeder such stays at to a very long distance, you will find in this because you can ask me sir this is if 11 KV these are all 11 KV like 400 volt, 11 KV like 400 volt transformer and here you are what you call all the voltage at this, but if it is 11 KV, it will be less than your 11 KV that is true right, but it is the 11 KV feeder. So both, voltage may not be or what you call may not be that your that will be that much variation, but everywhere you can have a transformer tap then you can change the tab setting such that you can get the voltage to approximately 11 KV right.

So, you can find in rural areas particularly in the villages where distribution feeders are too long at the tail end of the feeder, you can find voltage as 7.5, 7.6 KV or 8 KV like that. So, voltage is very poor because of this, if the voltage is very poor naturally that you have a agricultural motor prompts here at rural areas and it will try to draw you are not to call because of low voltage that huge amount of current and because of that the consequent effectives that you are what you call that industry or that agricultural motor pump set that your insulation will burn right. So, that is why you have to maintain the voltage that 11 KV right rather than operating it had very poor voltage.

So, this actually, all these things that 11 KV, 440 volt it will stretch long right, it will be spacing long say 1, 2, this is 3, this is 4 and again there is a possibility that some branch will come here this is lateral branches and it will move.

And everywhere you have 11 KV, what you call 11 KV by 400 volt or 430 volt and 440 volt, whatever transformers available according to the your rating of those things apparatus. So, all the every higher you have the distribution transformer, everywhere because it is step down. So, what we will do? We will not consider this distribution side because 400 volt side, we will not consider; I mean low tension side of the distribution transformer that will not consider.

We will consider only 11 KV theta and this portion of that we will not consider. This is actually grid side; this one we call as a grid side, that will not consider. So, in the distribution system, what we will do. We will assume this substation that is that 11 KV side is your slag bus right that with from that we will start.

So, how their network will look like in distribution system, it is something like this. It is something like this. Suppose you have this is my 11 KV, I mean this one; 11 KV side. And then we have this radial network, we have this radial network. Suppose you have this kind of radial network this is 11 KV aside and this is actually substation because this is actually, this whole thing is at substation. So, this is actually substation, this 11 KV get to the substation. And this one will treat as a slag bus, this one will treat as a slag bus. This is say 1, 2, 3, 4 say 5, 6, 7 right!

The radial network, the radial in this sense, it is radial means geometrically radial as an the elliptically radial because power flow is unidirectional; because power flow is unidirectional, because it is it is input is here in the substation right p and q input is there and everywhere. So, this distribution transformer whatever you have, what we will take this one we represent as a load say, load at node 2, load at node 3, load at node 4, load at node 5, it is node 6 and this is node 7; these are the load this whole 11 KV by 44 whatever it is drawing power from the 11 KV, this whole thing we represent it as a load. For example, if it is L 2, we will right it is p L 2 plus j q L 2, similarly here p L 3 plus j q L 3 and so on.

And this is actually the load right. Generally it is a lagging load. So, similarly for p L 4 plus j q L 4 and so on; these are the load. So, all 11 KV transformer by 400 volt, it is considered as a load. So, these are the load now another thing is that, it is not only this is only main feeder, there is no lateral branch, but that is not the reality you will find in India that several lot lateral branches are there. For example, if it is say from node 3, something is emerging out say another lateral branches is emerging out. So, this your what to call this is 7, this may be node number 8, node number 9, node number 10; here also node is there. Everywhere load is there, everywhere load is there; similarly several other laterals may be there.

Say from example here, some lateral branches will be there right. So, let some lateral branches with; here also loads are there, loads are there, loads are there right. So, everywhere loads are there. So, it is 8, 9, 10. So, this is 11, this is 12, this is 13, this is 14, this is node number in the arbitrary right. The where you want, you can put. So, this will be actually structure.

Now question is that why it is radial; for the better protective coordination right. Suppose if your actually, if fault occurs very close to the substation somewhere here right, it will, if suppose some fault has occurred somewhere here right. So, it will actually encounter very small impedance of all current will be here it is a high, but if you move somewhere fault is here then it will actually your from here to here, the total impedance will be higher.

If fault has occur, everything will go to the fault; so if fault impedance from here will be very high and that is why that your fault current will be lower right. So, that is why the for better protective your coordination that generally you will find distribution networks operating in radial manner, but if you try to make a miss distribution network, suppose if I join 5 and 10, suppose some line if I join it will be create, it will be loop. If we make it here and here, it will be another one. So, right and if fault happens somewhere, you will find that fault in that case, what will happen because of the parallel your collection the fault impedance will be your less and the fault current will be more.

Therefore cost of the protective equipment or the substation will be higher. So therefore, all the distribution networks you will find they operate in radial. This is the past thing. Second thing is this, all these things distribution line, it is a 3 phases are there a, b, c right; even neutral may be there.

So, their distribution line generally, if you have 3 phases are there, 3 phases a, b, c; all 3 are there, then what will happen every phase it may not carry the same power current, it is unbalanced actually. If it is unbalanced then what will happen for example, suppose you have 3 phases, you have 3 phases.

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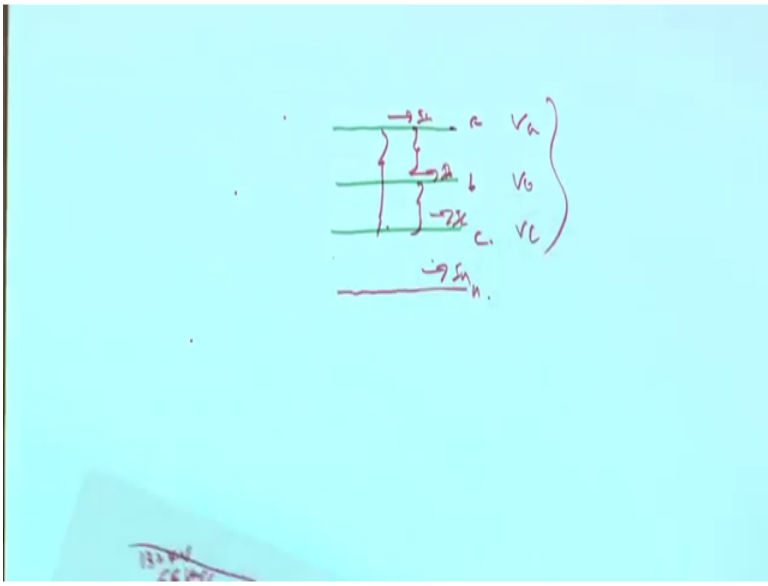

You have 3 because before explaining all these mathematics I have to tell you all these.

Suppose this is phase a, this is phase b, this is phase c and say this is your neutral. So, if every phase is carrying I a, I b, I c current and here if it is unbalance some current will be there in the neutral also; if neutral is there. Therefore, what will happen that mutual coupling will happen between all these phases right ab, bc, ca; same time an, bn, cn that mutual coupling will happen.

That means, you have to consider that neutral your reactors between that your what you call that is phases between each page neutral. So, in that case it will be a 3 phase load flow and you have to consider all the voltage va, vb, vc; all the 3 voltages you have considered and if neutral is there, neutral can be eliminated by some mathematics is there, but that is beyond the scope of this course. We will consider only balanced network.

If network is balanced then we can represent them by a single line right, assuming that all the phases carrying the same amount of current, otherwise the each phase suppose this is your I a, this is your I b, this is your I c, all and since put that is I n, I a, I b, I c could carries different current there is a possibility the neutral also will have some current right.

So, I a, I b, I c different the mutual coupling will happen, but we will not consider that. So, we will assume that distribution network or balanced and therefore, it can be represented by single line diagram; the way we do for transmission system that way we can do and substation actually this will be substation, this is the slag bus we assume this is your 11 KV substation.

That if you take 11 KV base, then it will be actually one per unit and every branch you have impedance r by x. So, the distribution system actually r by x ratio, in distribution system r by x ratio is high because here conductors are off, your what will call small cross sectional area. So, naturally r will be higher than your x value and this r by x ratio is high right.

And generally, whatever from distribution system to transmission system, the reactance of the you are what to call that distribution line and the transmission line for different type of conductors. Somehow I was calculating something that variation of x from these twos and x to your transmission say 220 KV line, generally the reactance actually varies roughly, exactly I cannot tell you the thing, but roughly varies.

I think 0.26 to 7 ohm per kilometer to your that reactance right. It is a you not to ohm per kilometre, this x is values the here what you call the reactants values, it is can tell you in term percentage that will be better; it will be hardly there is a 15, 20 percent right and not more than that exact figure I cannot recall right now, but next class if I come, I will try to see that right. So, generally I have observed that reactants actually compared to the small yours cross section area to higher at the high tensile not very much in terms of percentage, but also varies significantly because distribution such term that raises at it is it actually is a smaller cross sectional area and conductors are of different type for distribution.

It is named from animals are bar like squirrel, then rabbit, then your different type of your weasel, different type of conductors are there for distribution, but that will not discuss; we will take only the r x values. So, every about r by x ratio distribution system will be higher; it may be more it will more than 1, it may be 2 right. It will be more than higher not like transmission system, you will find many cases it will be less than or equal to 10.

But here you will find, it will be greater than equal to 1 for distribution side; that means, what will happen in distribution line and voltage drop will be higher because impedance will be higher. So, there is a voltage drop right. So, these are the certain things, but question is will our assumption is balanced and how we will solve this, this kind of distribution network.

But in the classroom purpose, will hardly take as it is a radial network, hardly 4 bus problem or 5 bus problem that we can manage; rest we have to do it in computer generally, but we will see from the classroom exercise point of view. So, this is some basic thing for distribution system. Now we will come that your distribution load flow. So, load flow, we will see that 2 methods, we will see that two methods, but you have to try to understand actually each and everything.

So, things are easy but you try to understand. So, generally distribution networks are radial and r by x is very high; I told you just now right. And second thing is that the load flow technique for solving radial distribution network involve only the evolution of simple either a expression wither a expression of it is of receiving in voltage right.

And this is actually before coming to that it will be power receiving end voltages. So, we will see that we will not use any Newton Raphson method or Gauss Seidel method. We will use we will exploit the radial nature of the distribution system right. So, we just now I told you we will assume that the 3 phase radial distribution network will absolute is balanced and can be represented by their equivalent single line diagram.

This I told you already. A loads will be treated as a constant power type load; we will treat that a constant power load, but composite load also can be incorporated in this algorithm but I will not in that case, we will not come to that, but in that case that every iteration you have to compute the load because for composite load, load will be function of the voltage magnitude.

So, that we will not be considered, but if you have any if you write any code or anything or if you are interested, you can put the question in the forum then we will put the answer but here, I will not I will not do that right. So, now second thing is, for example, just now I showed you first what we will do? We will consider the Main Feeder Case.

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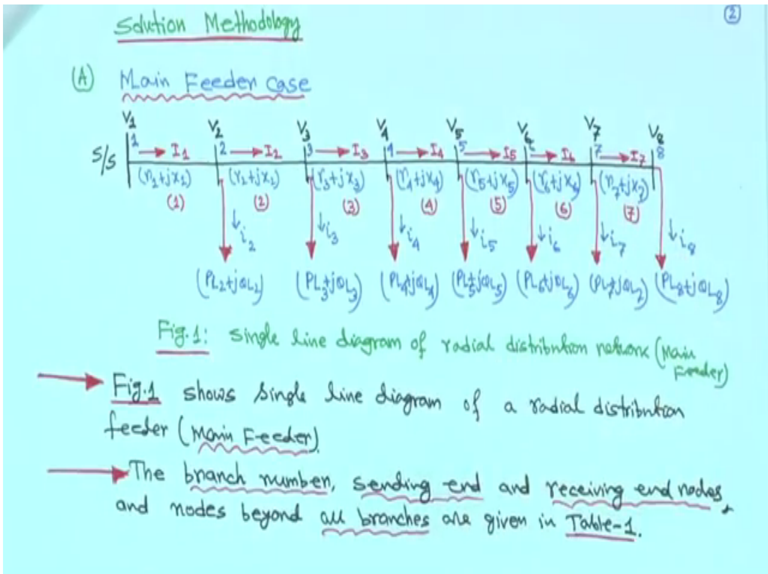

Look at this right; this is the solution methodology; first we will consider the main figure case; that means there is no lateral branches right. So, what will happen that we have taken 8 node problem, if node 1 is a substation, this is your slag bus, this is node 1, this is node 2, node 3, node 4, node 5, node 6, node 7, node 8; the blue ink one right; this is node 8 now.

Every branch it is the voltage is v 1, v 2, v 3 as complex voltages v 3, v 4, v 5, v 6, v 7, v 8. These are complex voltage and substation voltage v 1 we are taking as a stag bus so that means, v 1 will be known to you. That is if we assume 1 angle 0 it will be 1 angle 0 right. Now each branch as it is as it is a radial network there are 8 branches there. So, therefore, as such there are 8 nodes; that means, you have 8 minus 1, 7 number of branches it is a radial network. So, this is branch 1, branch 2, branch 3, branch 4, branch 5, branch 6, branch 7, this bracket the red ink with bracket is actually branch number; this is 1, 2, 3, branch 4, branch 5, branch 6 across this red one right. Now every branch is carrying current.

So, this is capital I 1, capital I 1 the current of branch 1, capital I 2 is current of branch 2, capital I 3 is current of branch 3, capital I 4 is current of branch 4, similarly this current of branch 5, I 5; current of branch 6, I 6 and current of I 7, capital I 7 is your what you call branch 7 right. But it is a last bunch, later we will see the same current actually going to the load. So, basically I 7 is going to I 8; that is load current. Now as I told you everywhere that distribution transformer is there; that means, current will be flowing through this right.

And actually these are the, these are the current that is I 2, I 3 actually I mean these are the current. This is the current going to this for example, in node 2, I 2; it is I 3 these are the current going to the distribution transformer that is from the that is to the distribution load right. So, if it is so, then this as the current going to them your load distribution side rather than we will distribution transformer or we will consider that distribution side load that is 11 KV say 11 KV right. 400 volt transformer and after that all the residential, commercial loads are connected right.

So, this is I 2 for node 2, I 3 this is the load current for node 3. This is the load current for node 4, this is a load current for node 5, this is the load current for node 6, this is the load current for node 7 and load current for node 8 right. The blue one is I your that node number, blue one. Now this is also you have a load, lacking load.

So, for node 2 it is p L 2 plus j q L 2, a writing this is known this will be given data this is known right. This will be p L 3 plus j q L 3. This will be p L 4 plus j q L 4, this is for node 5 p L 5 plus j q L 5. This will be p L 6 plus j q L 6, this is p L 7 plus j q L 7 and this one p L 8 plus j q L 8 right. So, this figure 1 actually single line diagram of radial distribution network this is for main feeder.

One thing before proceeding further, I would like to tell such that there should not be any confusion..

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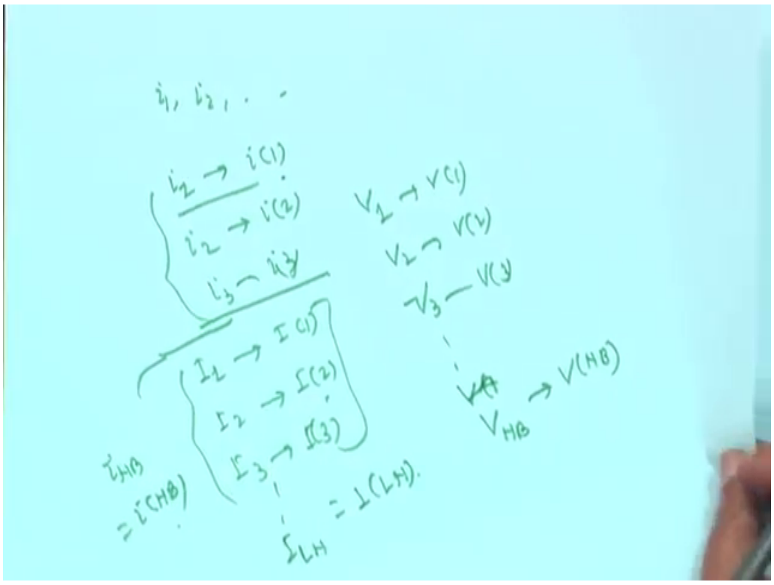

When I write current say if I write current I 1, I 2 like this, actually from the whatever algorithm I am given it from the coding point of view, when I write I 1, actually here I have writing I bracket 1, they are same thing. When I is suffix 2 it is I 2 right it is. When it is I 3 means it is I 3 right same thing.

So, there should not be any confusion. Similarly when I write I 1, actually this will be your, you can write I 1, capital I 1, branch current when I write I 2, it will be I 2 and so on. When I write I 3, it will be or I 3. I put in bracket from the coding point of view I have written this all this thing, here in a diagram it will be in suffix, but I like the mathematics, I will use this one.

But identical thing similarly for voltage; if it is voltage v 1, it will be v 1; if it is v 2 actually it is v 2. So, if it is v 3 actually it is v 3 and so on right. So, all if it is coming to your total number of branches say total number of branches L n it will be your I L n right. If you come to total number of node, if it is your if it is V NB, it will be actually V NB if total number of node.

Similarly here also, if total number of node is N B, it will be I NB is equal to this one. If it is it will be I NB is equal to I NB. So, means, there should not be any confusion I will use this when mathematics part. And mathematics is very simple here, but I will use this notation, but from the when I am explaining in the figure.

It will be suffix this because it looks good also set some place and easily understandable right. Therefore, what do your first mean feeder the lateral branches, how we will do this? So, figure 1 shows the single line diagram. They say that every branch you have the impedance also, r 1 plus j x 1, r 2 plus j x 2 the blue colour, r 3 plus j x 3, r 4 plus j x 4, r 5 plus j x 5, r 6 plus j x 6, r 7 plus j x 7. This all the resistance and reactance will be given in ohmic values and this p L 2, p L 2 q L 2, p L 3 q L 3 and so on. All this will be given in kilowatt and kilowatt you have to convert it to per unit, but later we will see right. When we will take the numerical side, at that time we will see.

Right and I told you all this bracket red in mark is their branch number right. Now the what we will do now, branch number sending in node, receiving in node and nodes beyond all branches you have to make a table first right because you have to write the you have to understand first.

So, the first the your sending a sending a node and receiving a node right, all things you have to write you have to write branch number also there are 7 branches here right and how many branch as there between here you have a beyond each branch. For example, how many nodes are therefore, suppose this is your branch 1, beyond these bands how many nodes are there 2, 3, 4, 5, 6, 7, 8 right.

So, how many 7 nodes are there. This for main figure only. Beyond this branch, how many nodes are there? 3, 4, 5, 6, 7, 8; 6 nodes are there. Beyond this branch, how many nodes are there? 4, 5, 6, 7, 8; 5 nodes are there and so on. This way, you have to make a table. So, first table I am given then I will explain that how things are right. So, in this table actually.

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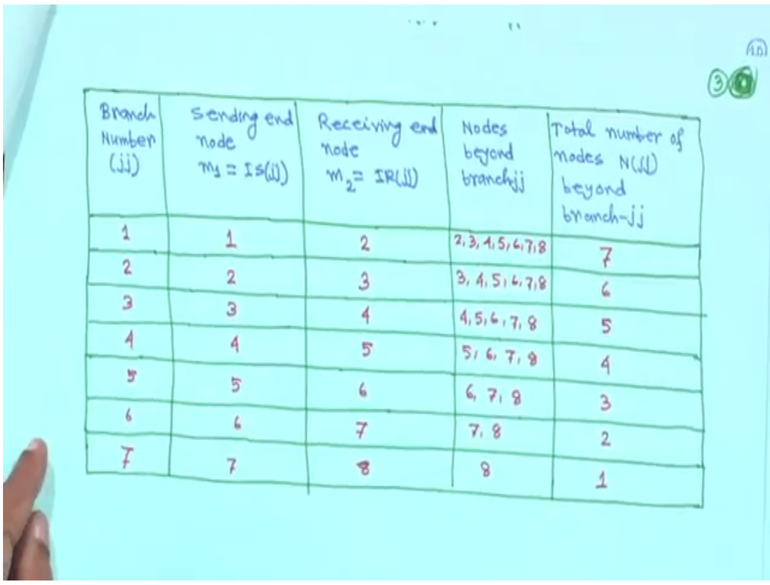

Branch Number (jj)	Sending end node $m_1 = IS(jj)$	Receiving end node $m_2 = IR(jj)$	Nodes beyond branch jj	Total number of nodes N(jj) beyond branch-jj
1	1	2	2, 3, 4, 5, 6, 7, 8	7
2	2	3	3, 4, 5, 6, 7, 8	6
3	3	4	4, 5, 6, 7, 8	5
4	4	5	5, 6, 7, 8	4
5	5	6	6, 7, 8	3
6	6	7	7, 8	2
7	7	8	8	1

It is your branch number, we represent by jj right. Here I maybe jj because j we are using as a complex operator. So, that is why jj branch number say branch 1; branch 1 is sending a node is m 1 is equal to IS jj, m 2 is equal to IR jj right; that means, for your understanding, for your understanding because you have to your what you call you have to make circuit.

Suppose when branch number is jj 1, we are making m 1 is jj, m 2 is IR j.

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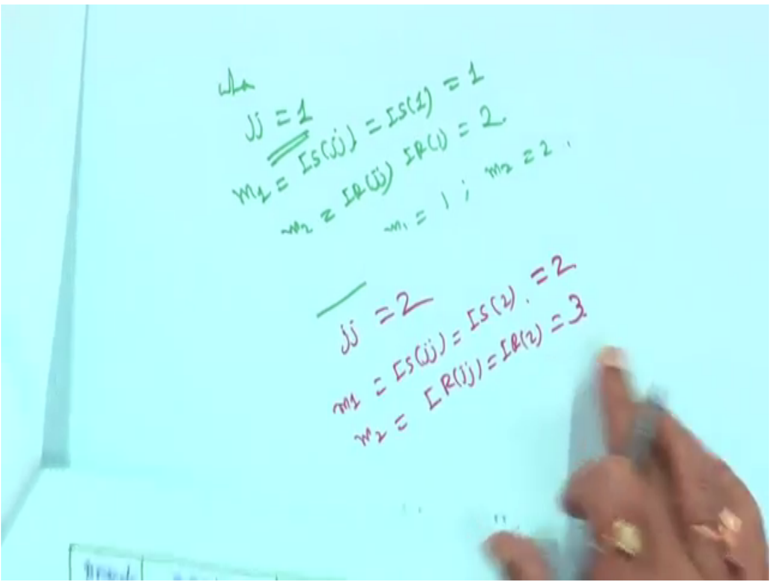

That means, when your when jj equal to 1, when jj is equal to 1 right; this is your m 1, m 1 actually I S jj, jj is equal to 1 is equal to is 1, that is when jj is equal to IS 1 actually is equal to 1 and when m 2 is receiving it m 2 is equal to IR jj, that is your m 2 is equal to IR jj and j is 1, jj is 1. So, it will be your IR 1, that is equal to 2; that means, when branch number jj is equal to 1, that is your sending in node m 1 is equal to 1, receiving a node m 2 is equal to 2, m 1, m 2 will come later right.

For the time being, this is your, for the branch 1; that is why I putting m 1 is equal to IS jj, m 2 is equal to as sending a node that is you are just now I told that m 1 when jj is equal to 1, m 2 is equal to 2; this way you have to put it in an array right. So, nodes beyond branch jj. So, this is branch 1, this is branch 1.

So, how many nodes are there beyond? How many nodes are there; 1, 2, 3; first you count 1, 2, 3, 4, 5, 6, 7; 7 nodes are there because starting from 2 to 8. So, do not count node number 2, 3 do not count. You count first how many nodes are there 1, 2, 3, 4, 5, 6, 7. So, total number here also nodes beyond branch jj, these are the nodes 2, 3, 4, 5, 6, 7, 8 and total count is 7 right.

Similarly when jj is equal to 2, when your jj is equal to 2, just hold on when jj is equal to 2 say jj is equal to 2, your m 1 is IS jj is equal to IS 2; from this table, you can get one branch number jj is equal to 2, when jj is equal to 2, your IS 2 is equal to 2; sending inside is 2. So, it equal to 2 and receiving inside m 2 is equal to your IR jj is equal to IR 2 is equal to when jj is equal to 2 receiving inside; first to make this table of your own, this is 3. So, this is three; that means, from branch, if you look at the diagram for branch 2, this is you are sending a sending in node 2, this is receiving in node 3. That is why I sending in node 2, receiving in node 3.

So, that is why it is 2, 3. And how many nodes are there beyond branch 2, this is branch 2 you count your 1, 2, 3; 1, 2, 3, 4, 5, 6 right. You have total number of node 6 and they are your this 1, branch 2, 3, 4, 5, 6, 7, 8 right. So, you have 3, 4, 5, your 3, 4, 5, 6 to total it is 6; these are the nodes available with this table, you will make up your own right because this data you have to read in the computer, then automatically know Newton Raphson nothing. I will show you how simple it is right; automatically you can develop their algorithm right. But this table you have to make, the connectivity sending in branch numbers sending and receiving in nodes beyond branch jj and total number of node count.

Thank you very much we will be back again.