Operation and Planning of Power Distribution Systems
Prof. Dr. Sanjib Ganguly
Department of Electronics and Electrical Engineering
Indian Institute of Technology, Guwahati

Lecture - 20
Forward backward load flow approach for power distribution systems

From my last lecture I started discussion on an important subroutine which we often use in power system planning ok and also in power system operation ok. And this is called load flow or power flow analysis and since, as I said, the distribution networks are mostly operated in as a radial network.

So, we need a special type of load flow or power flow analysis approach ok and that is one of the approaches I will talk about here, and that is a very simple approach, that is basically the applications of Kirchhoff's current law and Kirchhoff's voltage law in a iterative way ok. And this is called forward backward sweep load flow or power flow analysis ok.

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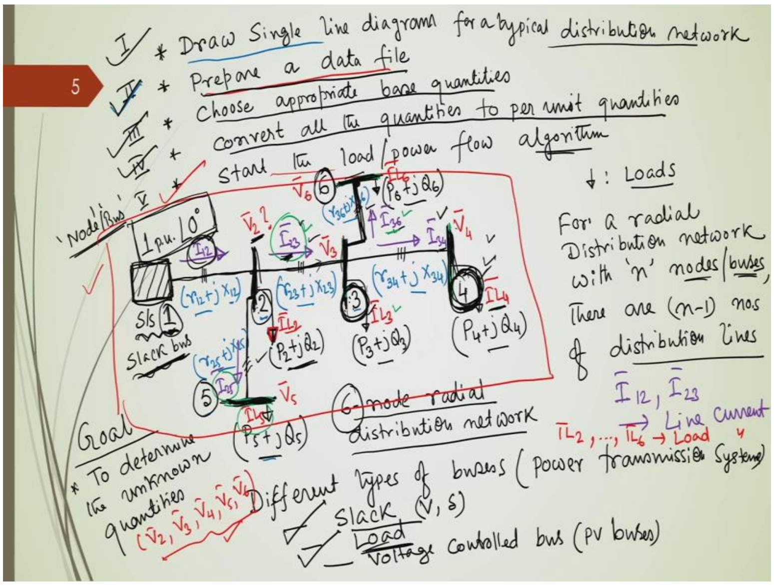

So, in order to discuss this approach, I took an example of a simple 6-bus or 6-node distribution network ok, 6-node distribution network.

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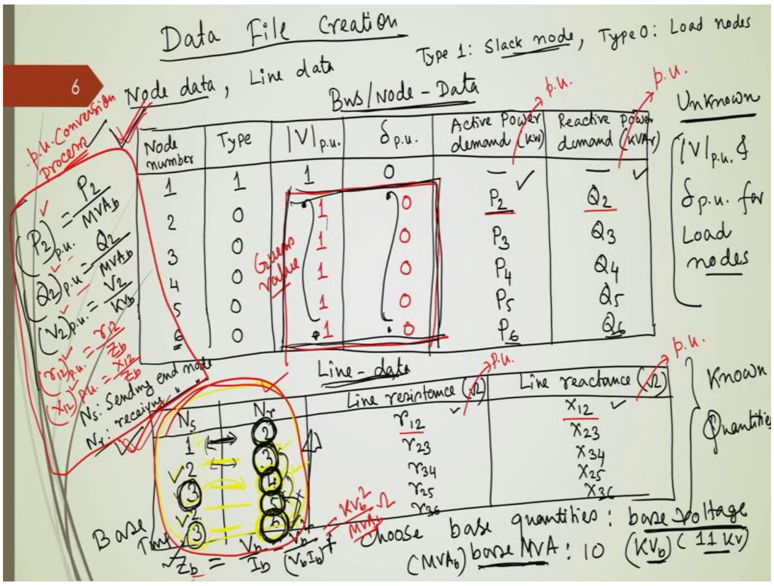

And in my last lecture, I discussed how to prepare these two important data files which are required for this power flow analysis or load flow analysis approach. And this is how we use this node data and this line data information in order to perform this forward backward sweep load flow ok, these are essential.

So, one should know how to compute this data file first. So, I started my discussion with this. And then there are many things like how to convert these quantities to per unit, this I discussed, and how before that, how to choose the base voltage and base volt ampere or base MVA, those things I discussed.

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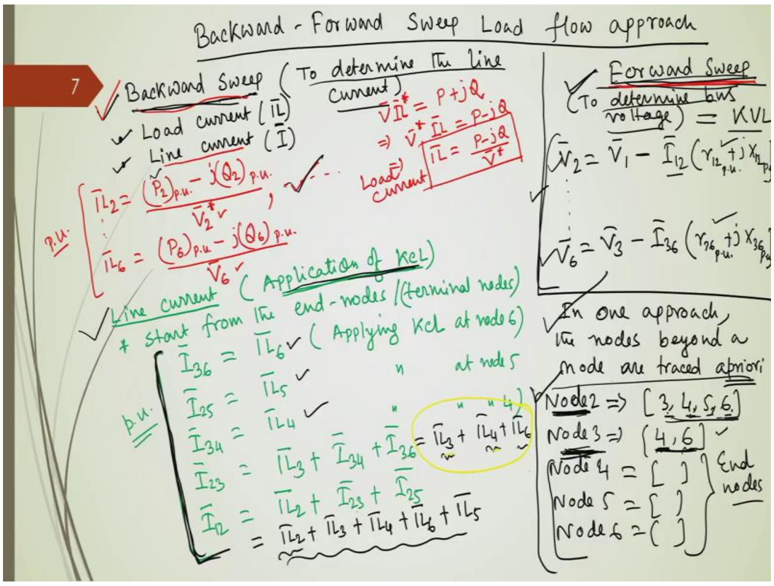

And then in this part I will discuss two important steps, one is called backward step, another is called forward step or one is called backward sweep, another is called forward sweep ok. How to perform these two steps? This I will discuss considering this example, once you understand these steps you can even try to write the program codes on this particular iterative approach in order to solve this power flow for any type of distribution network.

Of course, the condition is to be satisfied that the distribution network needs to be radial ok. So, that is the important consideration here. So, this approach will work for radial networks only ok, and in this particular slide I will discuss how to calculate. In fact, I chalked out how to compute this line current from the load current information in backward sweep.

And then, also I will discuss how to calculate or how to compute the bus voltage of all the buses using this forward sweep ok; and these two steps we need to iteratively use while getting the final solution. Now, if you look at this backward step here firstly, we determine this load current; we firstly, determine this load current from this available information that we have, because most of the nodes in distribution networks they are of load nodes.

So, we know that what is the power demand, power demand means active power demand and reactive power demand of that particular node ok; or rather to be more precise this is the load demand of all the loads that are connected to that particular node. So, this is the aggregated load demand of all the loads or all the customers who are connected to a particular node. So, this P 2 is basically representing the active power demand of node 2; that means, that it is basically active power demand of the aggregated loads who are connected to the node 2.

So, there are, many number of customers may get connected to a particular node ok. And this P 2 or P 3 or P 4 this power demand or active power demand specify the aggregated demand of all the loads who are connected to these nodes, that is node 2, node 3, node 4 respectively ok. So, this, one has to understand and as I said the computation of the line current is the main challenge for writing this generalized program code on this forward backward sweep load flow algorithm.

And one can do either by tracing out this, that how many nodes are beyond a particular node like this, this is one approach ok. So, once you trace down that this node number 3, 4, 5, 6 they are the nodes who are beyond this node 2, because this is very important because if you look at the system from this particular node this power is flowing through this node number 3, 4, then 6 and also 5 ok.

So, if you know that what are the nodes beyond any particular node for example, beyond this node two we have node 5, node 3, node 6, and node 4 then one can find out what is the power actually flowing through this particular node that is node 2. And once you chalk out that ok you can easily compute the line current which is flowing through this node number through the line which is connected to node number 1 to node number 2.

So, this is one way, and another way already I discuss this is how you can find out this line current from this node current to first, you need to first find out the terminal node and that is why let us start the end you know entry of this N r; N r here representing this receiving N nodes ok and of course, this 3 6 means the 6 is the terminal node, beyond that we do not have any load nodes. So, you start with that and then you find whether the 6 is appearing anytime to this N s data.

So obviously, it is not appearing and then you can understand that of course, there is nothing beyond this node 6 ok, there is nothing and node 6 is one of the terminal nodes. So, you start with this line current computation using this available value of P 6 and Q 6.

Once you get that, this will be the line you know load current, load current means the current drawn by all the loads who are connected to node 6 ok.

So, once you get that information you store in an array or in some temporary memory. Now, next you go to next node, that is node 5; again, you check whether node 5 is appearing to the sending end node or not. So, it is not appearing, so then you can understand that node 5 is also a terminal node; that means, beyond that we do not have anything, node 5 is also a terminal node.

So, if it is so then, of course, we can calculate this load current and that load current would be the line current which is connecting this node 5 from node 2. Similarly, this from node 6 that load current would be equal to line current which is connecting node 3 to node 6.

So, now, you proceed to the next node you will get node 4, again it is also not appearing in the sending end side. So, it is also a terminal node and you follow the same principle. Then you come to this node 3 and here you can see node 3 is all appearing in the sending end data 2 times; that means, node 3 is not a terminal node. So, it is connected to node 4 as well as node 6.

Now, here you can do one thing that you first determine the load current at node 3 ok. In fact, load current is independent to all these nodes. So, you can compute it, I mean prior to this particular operation and then while determining the current flowing through this you know node 2 to node 3 you have to also consider this load current or node 4 because you know this node number 4 its demand is coming through this line which is connecting node 2 to node 3.

So, whatever current this I 23 it is function of this load current at node 4 as well. So, it is function of load current of node 4 ok. So, that is why we need that ok otherwise if you look at this line current which is connecting this node 3 to node 4, since it is node 4 is a terminal node. So, it is independent of the load current of any other except this node 4.

So, I 34 which is the line current which is flowing from this node 3 to node 4, it is independent of load current of any other node except this node 4. So, it is only equal to the load current of node 4. So, this is something important, one has to understand that is why I am focusing or I am emphasizing this in very detailed manner ok. So, same thing is applicable for other terminal nodes like node 5 and node 6 ok.

So, in node 6 this line current which is flowing from node 3 to node 6, it is independent of any load current except the load current of node 6. So, that is why I 36 is equal to this load current of this node 6 that is I L 6. So, I 36 is equal to I L 6, if you put if you apply KCL at this node you will get this current incoming current is equal to the outgoing current that is I L 6 and so.

So, for terminal nodes there are this line which is connecting to the terminal node. So, the line whose receiving end side is the terminal node it is only equal to the load current of that receiving end node ok.

And that is, one needs to understand and that happens for all this terminal node 6 node 5 and node 4. So, any line which is connecting this terminal node, its line current equal to the load current of the terminal node ok, but this is not applicable for any intermediate node that is at node 3, this line current that is I 23, it not only depends upon the load current at this you know node 3, but it also depends upon the load current of node 6 and node 4 as well.

And that is why you can trace down this, that are there beyond this node 3 and that is done in one of the approaches, that beyond this node 3 we have node 4 and node 6. So, the line which is connecting this node 3, whose receiving end side is terminated at the node 3 or whose receiving end node is node 3. So, it is, line current is equal to its own load current as well as the load current of node 4 and node 6.

So, here one thing is assumed that there are no losses. So, losses are not considered here because in a particular power I mean. So, when this power flows there are some amount losses which I will come later on ok. Now, when you get that so node 3 its line current which is connecting this node 3 at the receiving end side, its line current would be equal to load current of this node 6, node 4 as well as node 3.

So, how to find out this? So, one way as I have already said by tracing down the nodes that are beyond a particular node, prior to this approach starts another way is that you can first see that at node 3 how many times it is appearing in the sending end. So, here, it is appearing in two times, one is this, another is this ok. So, you take the corresponding receiving end side load demand that is, load demand at node 4 and load demand at load 6.

Then again you have to see that whether load 4 and load 6 appearing any times in the sending end side. If it is appearing then again, the corresponding receiving end load should be added so that you can compute the line current for the line which is connecting node 2 to node 3. These things happens when you go to node 2 for example, you see node 2 you have to check first that whether it is appearing in the sending end side or not, yes, it is appearing twice, one is this another is this.

So, corresponding you know load current that is node 3 load current and node 5 load current is to be added, then you have to again check whether these nodes 3 and node 5 they are appearing in the sending end side or not. So, node 5 is not appearing so you can assume that it is a terminal node, but node 3 is appearing ok. So, again you have to perform the operation for node 3, whether who is connected to node 4 node 3 at the receiving end so I got node 4.

So, I will add this load current of node 4 with this line current which is connecting 1 and 2 ok. Now, again you have to check whether this 4 is appearing in the sending end side or not. So, it is not appearing. So, I can terminate the process otherwise I have to again perform this operation till I finished it to the terminal node. So, this is something like that at this node 2, you first see that who is connected to this 2. So, 3 and 5 are connected.

Then again 5 is terminal node. So, beyond that there is nothing, but 3 is not terminal node. So, again you have to see that who is connected to 3, who is the receiving end side for the line which is connected to this 3, node 3. So, I got this node 6 and node 4 ok. So, I have to add this, their corresponding load current.

Now, if some other nodes are beyond this 4 and 6, it means, you have to continue the process, till you reach to the terminal node and that is why you know we first compute this terminal load current because they are independent. And then we process these slowly to the substation side ok, because this line current which is connecting this node 2 to node 3 that is I 12 it is function of all the load currents ok because it is near to the substation it is connecting to the substation.

But this line current which is connecting node 3 to node 4 it is independent of load current for all other nodes except this node 4. So, I could calculate it even though I do not know the load current of any other nodes and that is why I start this process from the terminal node ok.

And since the process is started from the terminal node and then we move ahead or we move in a backward we started at the end node and then we perform the whole operation in backward direction and that is why it is called backward sweep ok. Whereas, in forward sweep which is basically used to determine the bus voltage we start from the substation bus because at the substation bus my voltage is specified.

So, I know that what is the voltage at the substation bus ok and in no other nodes, this voltage is specified ok. So, since this substation voltage is specified, we start this we can start the computation of the voltage which is connecting this substation to the other node. So, here connecting node of the substation is node 2. So, I can find out what is the voltage at this node 2, just by subtracting this line drop which is connecting node 1 to node 3 from this node voltage or substation voltage that is specified ok.

So, once you get that, so that will be the updated voltage for node 2 ok, then we go to this next line which is connecting this node 2 to node 3. I know the updated voltage of node 2. So, I can calculate this node 3 voltage simply by subtracting this line drop which is connecting node 2 to node 3, this line drop is I 23 multiplied by j 23 ok.

And I 23 is already computed because line currents are already computed. So, you can compute this voltage; without computation of line current you cannot compute the voltage drop and that is why this line current calculation or line current computation should be done first. So, that is why a backward sweep is to be done and then we can compute the voltage ok.

So, then we move again to the other node which is node 6 or node 4 and we can calculate their corresponding voltage by simply subtracting the line drops and that is how we move. And since we start this operation from the substation bus or substation node and then we move to the other nodes. So, its operation is in forward direction, its calculation or computation is in forward direction and that is why it is called forward sweep ok. So, I hope this is understood.

If it is understood then we will discuss that how long we will do this iterative operation, because as I said, these two steps, that is, backward sweep and forward sweep this we need to iteratively do for several iteration ok so before we stop ok. Now, the question is how long will we do this iterative operation ok?

So, we will operate this iterative operation till we satisfy some condition and that condition is called termination condition, a termination criterion.

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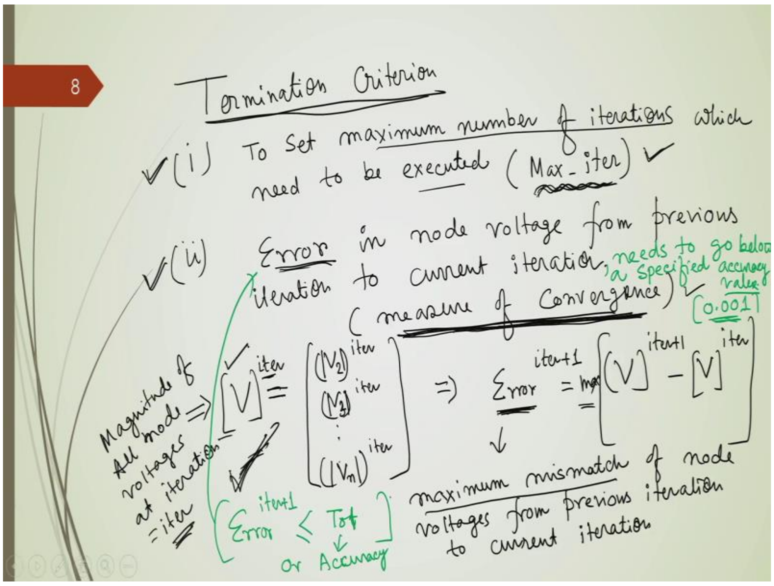

Now, there might be a unique termination criterion or there might be more than one termination criterion ok. So, of course one termination criterion is to set maximum number of iterations, maximum number of iterations which need to be executed ok; which need to be executed.

So, this is one termination criterion, but this is not all, means we will not keep this operation if we get convergence in between. What do you mean by convergence? Convergence means here, if we basically here, our goal as I said is to determine this bus voltages ok, in a iterative way ok. Initially we take a guess value that is a flat voltage guess value we considered initially that all bus all node voltages are equal to 1 per unit ok.

And after performing this forward step I get these voltages are updated. So, voltages will no longer be 1 per unit ok. So, voltages will deviate from 1 per unit and if this deviation from this guess value or to the next iteration voltage is within a given tolerance, then we can consider them ok, we have achieved the convergence criterion and we can terminate the program or we can terminate the iterative process ok.

And that is why the 2nd termination criterion is error in node voltage from previous iteration to current iteration ok. So, this maximum number of iterations let us consider is max iter, max iter and we can set a particular value, let us say, 50 or 100 or 1000 whatever it is. Now, if you use a sole termination criterion for this maximum number of iterations that we will terminate after that many iterations.

Then what will happen if we get convergence much before then; we unnecessarily need to continue ok. So, I will come to that and that is why second termination criterion is very important that if we achieve the convergence. So, this is basically measure of convergence, measure of convergence, this is a measure of convergence, if you achieve convergence much before this, we get this maximum iteration, we can terminate the program ok.

And that is why this is a measure of convergence. Suppose, if we set max iteration or maximum number of iterations is 100 and do we achieve the convergence after you know 3rd iteration or 4th iterations then unnecessarily, we need not to continue till this 100th iteration ok, we can terminate after getting this convergence. But it may so happen that you will never get convergence.

Then you have to terminate after some point and that is why this maximum iteration is set, suppose even after this maximum iteration we do not achieve convergence then also have to terminate it, I have to terminate the program, I have to terminate this iterative process so, that we can conclude that we may not get convergence, the load flow is not converged ok.

Now, how to find out this error, this voltage error? So, these voltages, these bus voltages they will constitute a bus voltage matrix ok or bus voltage vector. For example, V if we represent V iter, V iter it means that it is a matrix which consist of the bus voltages which we get at iteration number iter, that is, iter maybe 1 2 3 and all. So, here we get this bus voltages V 2 iter then V 3 iter.

So, here you can take this absolute values of these voltages because this voltage whatever you are getting this voltage are phasor. So, I will take their magnitude only. So, this V is basically, this V is the magnitude of all node voltages at iteration iter. So, this represents all these node voltages at iteration iter. So, this correspond to error, end of this you know these buses I can say it V n iter ok.

So, this is basically the matrix or the array which consist of all the bus voltages which we get after executing this iteration equal to iter ok, that iter if it is 2; that means, it is the you know bus voltage matrix or it is the node voltage matrix which you get after execution of iteration 2 ok.

Similarly, for any iteration you compute that and then you in order to find out this error at any particular iteration let us say iter is equal to iter plus 1, it is basically equal to this V iter plus 1 minus V iter ok. And then whatever you will get you will take the absolute value and you will take the max of that; you will take the max of that.

So, max, this is basically error, is basically representing the maximum mismatch, maximum mismatch of node voltages from previous iteration to current iteration, previous iteration to current iteration ok. So, it gives maximum mismatch ok or it gives this maximum value, maximum absolute value of, maximum absolute difference of all the bus voltages among all these bus voltages which we get from one iteration to other iteration ok.

So, this is the main convergence criterion, if this criterion is satisfied, we can terminate the iterative process. Now, even if after execution of maximum number of iterations, if we see that convergence criterion is not achieved then we have to also terminate and that termination will lead to the fact that this load flow is not converged ok.

So, there might be some conditions that this load flow may not converge ok. So, for this condition we will keep this second termination criterion.

Now, we will try to make the whole thing in a common form, so that one can understand how he or she will write this program code for this forward, for executing this forward backward sweep load flow algorithm. And this can be represented, the whole process can be represented in a flowchart form or by writing pseudo codes.

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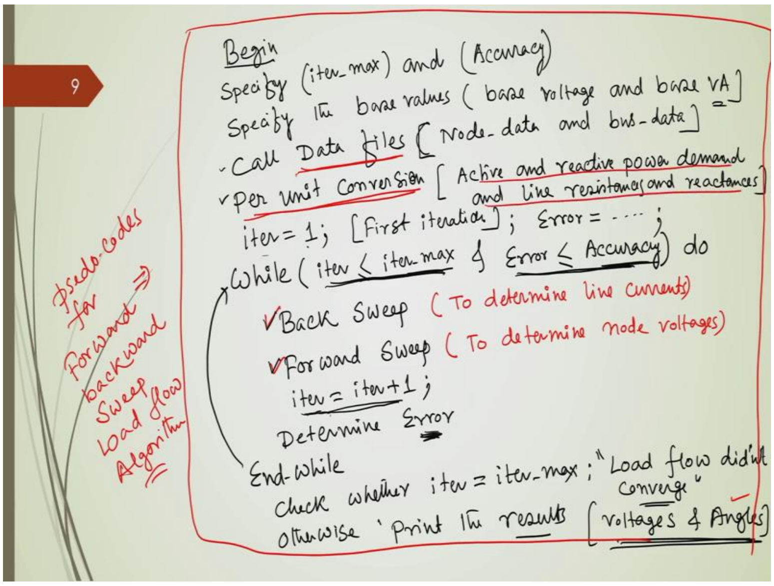

So, here I will write pseudo codes for that ok. So, in order to write pseudo codes, we will begin this program. Then the first thing that you have to specify is, you specify this iter max, that is, how many number of maximum iterations you will execute and here you can see, there is one thing I missed here that this is how we can compute this error ok. And this convergence criterion is that if this error of one particular iteration let us say iter plus 1 ok.

If it goes below a given value of tolerance or given value of accuracy, this tolerance or accuracy then we can consider that we can terminate the program and that is basically this criterion. So, it this error in the node voltage from previous iteration to current iteration needs to go below a specified accuracy value.

This accuracy value you can set as 0.001 or 0.301 or 0.201 that is up to you which gives that if this maximum error from this node voltages, from current iteration and previous iteration goes below this value 0.001. That means, maximum changes, maximum mismatch of this voltage value goes equal to or below this value accuracy, then will terminate the program ok. We will terminate this program ok.

So, that is why, this is the main convergence measure. Now, first to specify this iter max, that is, what is the maximum iteration up to which we will do this computation and we will also specify and, we will also specify this accuracy that what value of accuracy or tolerance you are to get ok.

What is the desirable value of accuracy or tolerance? So, first to specify that and then the second thing we have to specify base values that is base voltage and base volt ampere, this volt ampere can be in kVA or MVA as per your choice, then you need to call two data files, call data files. So, what are the data we required to compute this load flow analysis?

We have two important data files, one is called node data or bus data, another is called line data. So, we will call this node data and bus data ok. So, after these data files are called the data files. So, after these data files are called, you have to do this per unit conversion. So, next step is per unit conversion. So, we have several parameters which need to be converted to per unit.

Since we know this their values as well as we know their base value, we can convert them to per unit. So, what are the quantities normally we need to convert to per unit? We need to convert per unit active and reactive power demand, active and reactive power demand and line resistance and in reactance, line resistances and reactances; ok.

So, this we can do prior to our iterative operation starts and this will be, this will remain same throughout this iterative process because active and reactive power demand will obviously not change and line parameters are line resistance and reactance will not change. Now, how to convert this active and you know how to convert this to per unit, means one quantity to per unit quantity, this is mentioned over here.

So, this is the process by which we can convert this, is per unit conversion process, this already I discussed in my last lecture; first you convert this active power demand, and the active power demand to their corresponding per unit values, voltage is already in per unit ok, voltage is already in per unit.

And then you compute this resistance and reactance of the line into per unit ok, by dividing to the corresponding base values ok. Now after doing so, we will start this iterative process. So, we specify the first iteration as iter equal to 1. So, that is basically first iteration ok, and in order to start this iterative process we have to call a loop ok.

And you can, there are several ways to call the loop, either it can be a for loop or it can be a do while loop or whatever. So, here basically we will call do while loop. So, what we will do, we will check two convergence or two termination criteria, one is convergence criterion another is this maximum iteration criterion.

So, while this iter less than equal to this iter max; that means, this is the first, first termination criterion whether iteration, it is a check whether this iteration current iteration number is less than equal to the maximum iteration number that you have set; whether there is another convergence criterion that you have seen that error ok.

So, this error initially, when you start this first iteration, error is equal to, you have to specify a value ok. So, for error you specify a higher value and then before you execute this program the there is no error actually. So, you have to specify error value a high value and then you specify this error goes below certain accuracy value, this is the second termination criterion which is called convergence criterion ok. And if both the conditions are satisfied then you perform this next procedure.

So, what is the next procedure? First procedure is backward sweep, next procedure is forward sweep. So, if these conditions satisfy you do this operation. So, this backward sweep is for determination of line current, to determine the line current and forward sweep is to determine the bus voltages.

So, if we write it here again, this is to determine line current and this is to determine node voltages. So, after performing line currents and node voltages, after performing these two steps you will get the updated voltage, you will get the updated voltage. So, whatever updated voltage we will get let us store this updated voltage within this array.

So, now we have this V now, after doing so we will make a iterative count that is iter is equal to iter plus 1. And then next what we will do? We will compute this V iter. Or here in fact, you can do one thing, instead of this error specified to this iter to iter plus 1, to iter we can also specify it like this iter minus, iter minus 1 ok because we have already added this iteration count by 1. So, if you have done so after execution of this operation then our iter count will be iteration count will be 2, ok. So, then you find out this error, determine error ok.

So, after doing so, you get this error value and this is also something which you iteratively updated which will be iteratively updated. So, now, for example, that when you know first operation of this loop. So, when iter will be 1 you perform this backward sweep and forward sweep after that you make this increment of this iterative count by adding one.

So, we will achieve this iter equal to 2. So, this error will be giving you the error from iteration 2 to iteration 1. In iteration 1 this bus voltages were all these initial guess values which we considered at 1 per unit for all the buses and for this current iteration that iter is equal to 2, these new voltages will be updated voltages of all these buses or all these nodes ok.

So, once you get this determination of error, we will make this end while and again, this will go back to the loop, it will check these two conditions whether this error goes below this accuracy or this iter less than equal to iter max. So, this time iter will be equal to 2. So, 2 will be lesser than iter max because normally we set it to some values say, 100 or 50.

Now, when we go to iteration 2, the first condition will be automatically satisfied and if the second condition is also satisfied, so it will terminate this loop ok. After this termination you check whether iter is equal to iter max, if it happens, if it happens then we will call this load flow did not converge, did not converge; that means, we did not get the convergence ok. Otherwise, you print the result, print the results particularly these voltages node, voltages and angles ok.

So, this will give you the actual value of this node voltages and actual value of node angles. So, this is how this pseudo code works. So, this whole process is called pseudo code, the whole process is pseudo code for forward backward sweep load flow algorithm.

So, this is the pseudo code for forward backward sweep load flow algorithm, this pseudo codes, the student can implement in whatever language they are comfortable with, you can implement it any language, whether it is MATLAB or Python or C, C plus plus, whatever language you are comfortable with. And this code should be written in such a way that these codes will work for any distribution network.

And that is, this need to be generalized ok if we change this data file, if we change this data file from this any node system, 6-node system to 30-node system to 100-node system or 2000-node system, so your program will work and it will finally give the converged value of bus voltages and angles.

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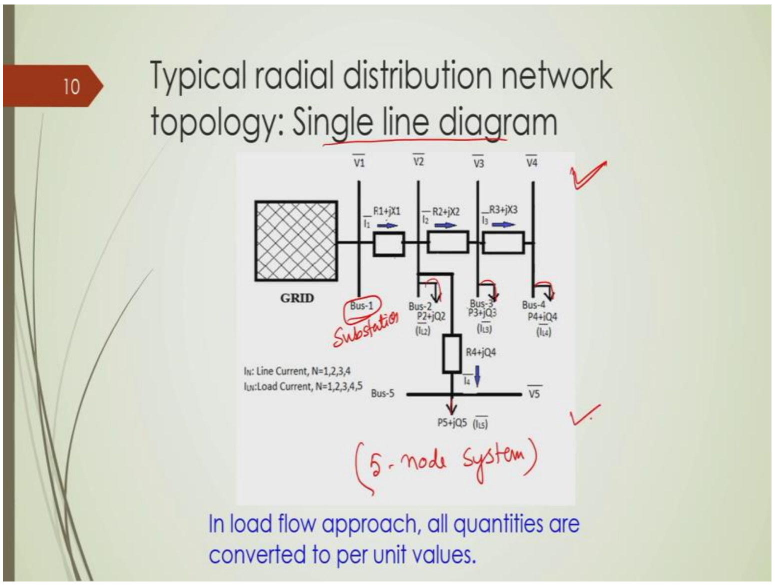

So, whatever I discussed in this lecture, this is basically written in slides form. So, here we took this single line diagram of a typical distribution network to illustrate that. You can see this is a 5-node system. So, this is a 5-node system ok. So, we have this node-1, that is substation and all other nodes are connected to customers or loads ok.

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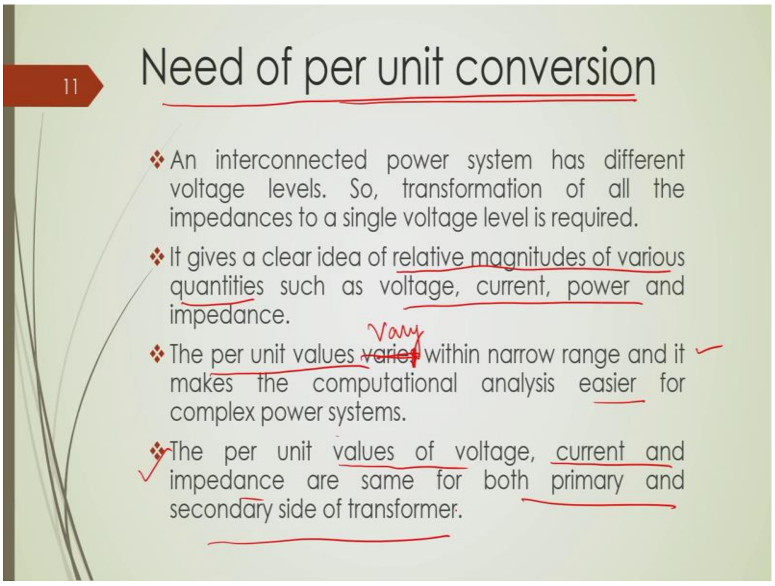

And this is basically illustrated, so that you can understand this whole operation, but already I took this example here and I hope this example is understood and similar kind of example is given in pictorial form in this particular slide. Now, there are some important information that one need to understand, that first of all, why we convert this per unit conversion?

As I said, before your execution of the program we need to convert, we need to follow this per unit conversion of all available information like active and reactive power demand and line in parameters ok. Now, why do we do these things? Now, this is basically followed not only for this particular load flow approach or power flow approach.

This is applicable for any type of load flow approach, whether it is a Newton Raphson, whether it is a Gauss-Seidel or first decoupled, any type of load flow or power flow approach, where we follow this per unit conversion ok. Now, why we give this per unit conversion? Because, it also gives relative magnitude of various quantities. Per unit means we bring down the quantities in between 0 to 1 ok. Now, when I will show you, in fact I have some results for different distribution networks after execution of this forward backward sweep load flow. I will show you how these node voltages are usually represented.

So, since you can, you convert all these quantities into per unit this voltage they change, voltages change within a very narrow band ok and we can get a comparative information. For example, if we consider this substation voltage as 1 per unit and at node 2, I get a voltage of 0.99 per unit. So, this gives a clear idea that there is a 1 percent of voltage drop which take place between the line which is connecting this node 1 or substation to node 2 ok.

So, this means, these quantities they vary from a narrow band. Now, if we say that node substation voltage is 11 KV and this node 2 voltages is 10.998 KV. So, that may not give you the comparative, comparison so easy or so quickly ok. So, we can make relative magnitudes of various quantities, also these values vary, this per unit values vary, per unit values vary within a narrow range and it makes the computation analysis much easier ok and whole things will be much understandable.

Second means, one of the important features is that this per unit values of voltage current and impedance are same for both primary and secondary side of transformer. So, it is independent whether which side of transformer you are considering this ok. So, this you can see and you will understand ok. Now, this is how we convert to per unit quantities, how this calculation or computation to per unit quantities we do.

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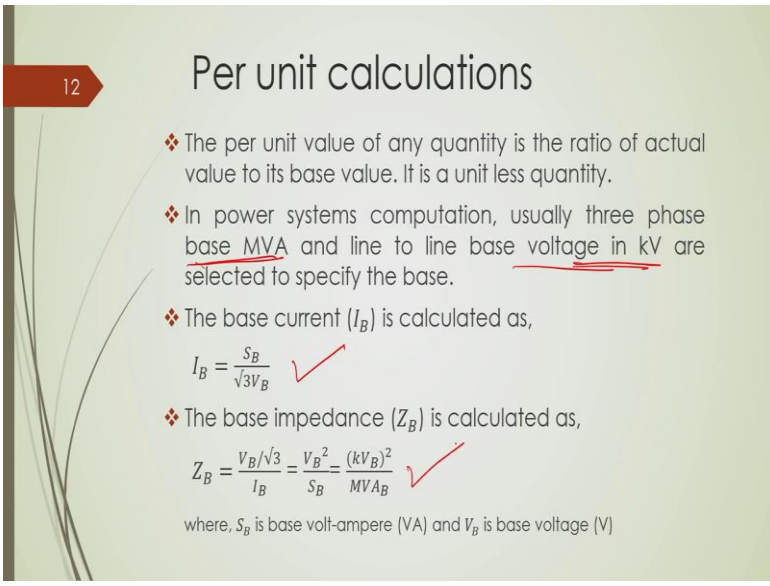

First, we specify this base voltage and base MVA and from that we can calculate this base current and base impedance ok.

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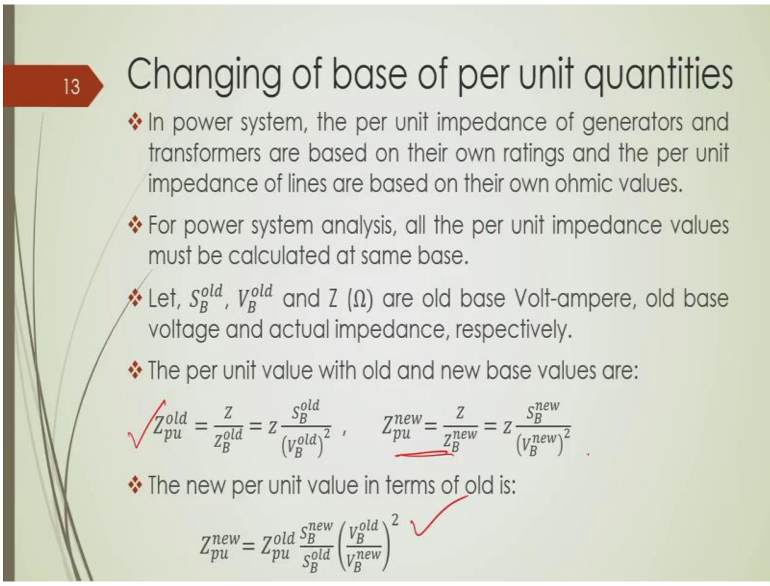

And from this, we can compute this, we can convert these line parameters into per unit and you sometimes base can be changed. So, if the base is changed how to get this computation this is shown over here. But normally in load flow, power flow approach you do not change the base ok for a particular network.

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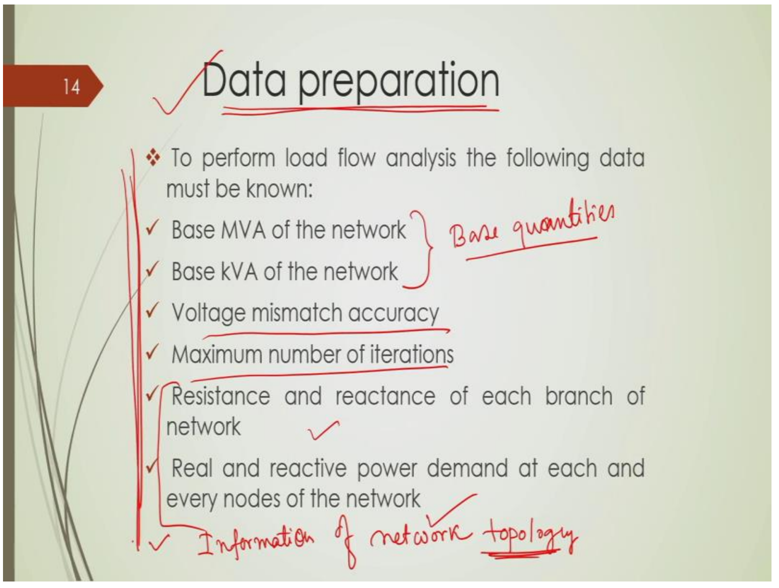

Now, this is the first step, as I said, we have to prepare this data file and these are the quantities we require to create this data file, already I mentioned we need to specify these base quantities. These are the base quantities; that are base values and base kVA or base MVA, we need to also specify this minimum voltage error or accuracy value, also maximum number of iterations, which I already mentioned.

And we need to also have the available information of line parameters, and active and reactive power demand, also which is another important thing which is not mentioned over here, which is missed is information of network topology, information of network topology. Now, how we basically, you know, translate this information? This is already I mentioned while creating this line data file, that is, this is basically translating this network topology.

The sending end side and receiving end side data and this is very important to calculate or to compute this line current ok. So, these are the information we require to create this data files, these are the information we require to create this data file.

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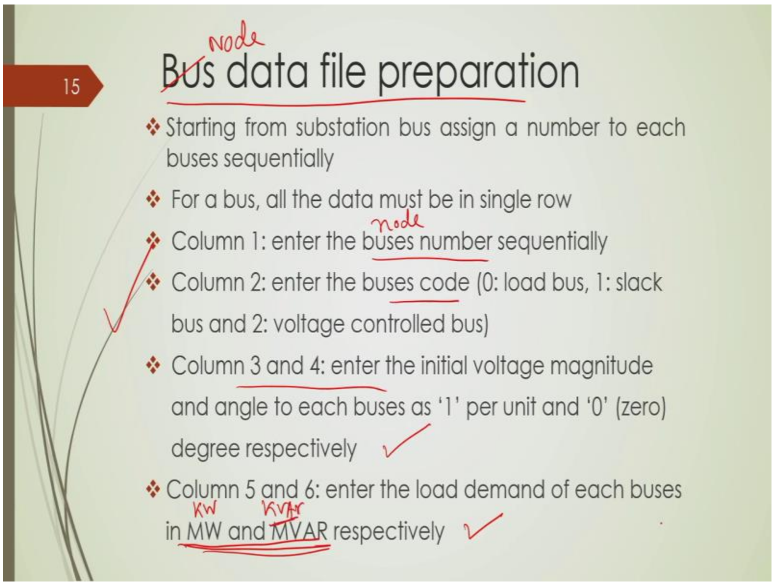

And after getting all this information, we compute this bus data or node data file. So, this already I mentioned, it is almost, I mean, standardized way we will do first column 1 will give you node number or bus number, column 2 will give you this bus code or node code. Columns 3 and 4 of this file will give you these initial guess values of voltages and angles.

And column 5, 6 will give you active and reactive power demand, in basically this distribution network, not in megawatt MVAR, rather they are specified in kilowatt and kVAR ok, because distribution network load is not in megawatt range normally ok.

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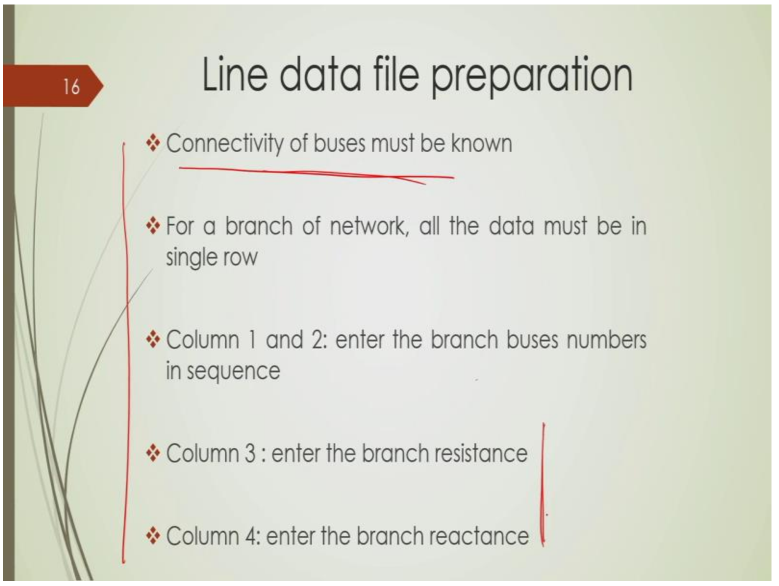

Then we prepare this line data file as well by considering this connectivity of nodes ok and by providing the input of line parameters ok.

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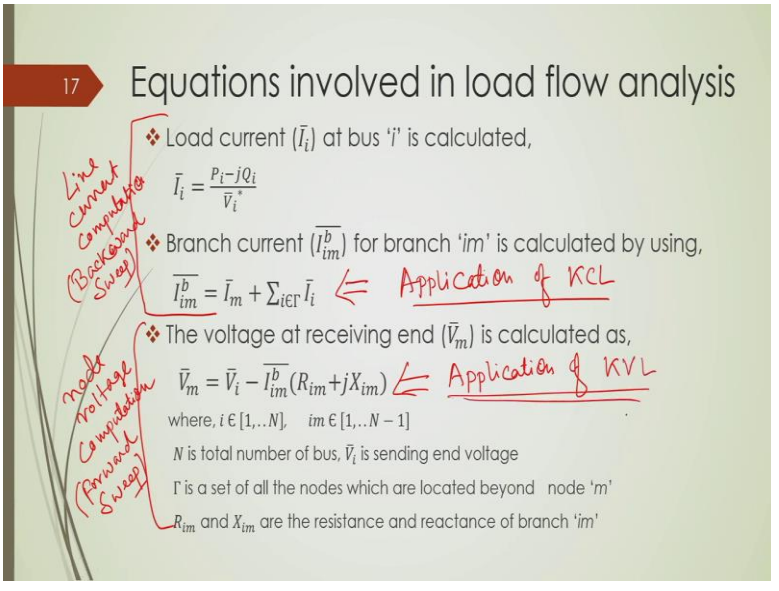

And this is the step of computing this line current and bus voltage. So, these two steps are used for line current computation, line current computation and they are done basically in backward sweep ok.

And this is the step for node voltage computation and this is done in forward sweep ok. So, these are basically the applications of, so this is basically application of KCL, application of Kirchhoff's Current Law KCL, and this is basically application of Kirchhoff's voltage law or KVL Kirchhoff's Voltage Law or KVL.

And with the simple application of these two, we get without any mathematical complexity we get the solution for all the nodes voltage ok.

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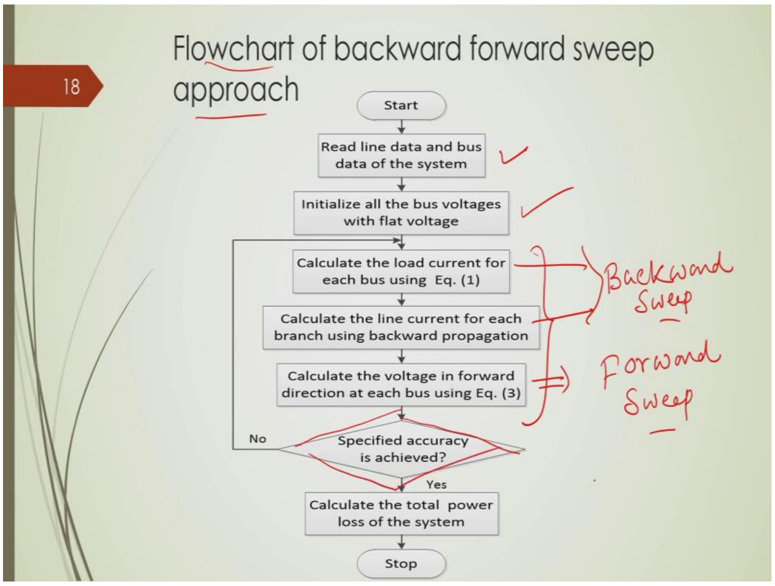

This is the flowchart ok. So, you can see, this flowchart is similar to our pseudo code that we have written today, we read this data file, we initialize these bus voltages with flat start also, we need to specify this maximum iteration and accuracy limit.

Then here, we perform these two steps. So, these are backward sweep and this is basically forward sweep, ok. So, after performing these two steps, there is a while check whether this accuracy is achieved or whether we have exceeded that or whether we have reached to the maximum iteration. And accordingly, this loop will be, loop will be created and it will be iteratively updated ok. Now, I have some results of different distribution networks data ok.

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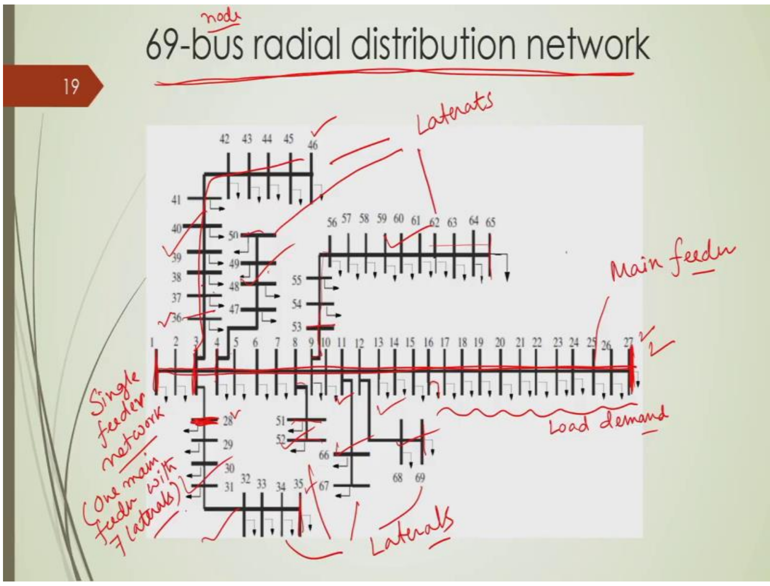

So, first data that I want to present is 69-bus, 69-node, a radial distribution network ok. So, here we have one feeder. So, if you look at this network. So, this is one feeder, so this is a single feeder network, single feeder network and why it is called 69-bus or 69-node distribution network because we have 69 numbers of nodes here, nodes or buses.

So, this is the main feeder, this is main feeder ok and this arrow they are representing, you can see all these nodes as associated with some arrow and they are representing this load demand of individual nodes ok. And apart from this main feeder, we have some lateral. So, this is one lateral, this is one lateral, this is another lateral so these are laterals.

Similarly, here also, here also, here also we have laterals ok. So, we have one, this is also a lateral. So, we have 1, 2, 3, 4, 5, 6, 7 laterals along with a main feeder. So, we have single feeder network with one main feeder, one main feeder with 7 laterals ok.

And you see that this main feeder is from node number 1 to node number 27, then from 28 we have one lateral, this lateral, then this will be up to 35 and then from 36 we have another lateral. In fact, node number 3 is connected to two laterals, one is from node 28 to 35 another is node 36 to 46 ok.

Then node 4 is connected to one lateral, this is from node 47 to 50. Then node 8 is also connected with the lateral which consists of 2 nodes, node 51, node 52. Node 9 is connected to one lateral which is having a node 53 to node 65 and similarly node 11 and 12, two laterals ok. This is 69-node or 69-bus distribution network.

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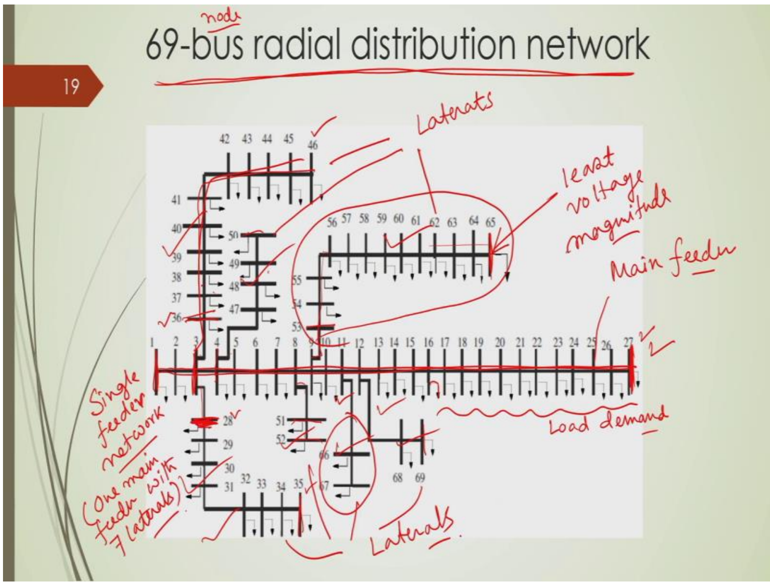

So, first we have to compute this, we have to create this bus data file. So, this is giving the bus data file, you can see this bus number is specified in the first column, bus code is specified in the second column. So, except this slack bus all are 0, indicating that the other buses are load buses.

Then, here, in column 3, column 4, these our guess values of bus voltage and, node voltages and angles respectively, and column 5 and column 6 represent this load active power demand and load reactive power demand in kilowatt and kVAR.

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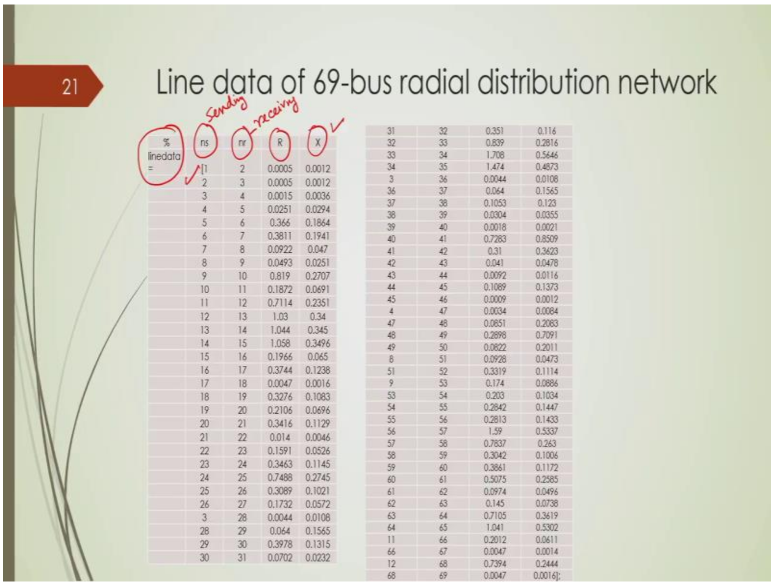

% linedata =	ns	nr	R	X
	[1	2	0.0005	0.0012
	2	3	0.0005	0.0012
	3	4	0.0015	0.0036
	4	5	0.0251	0.0294
	5	6	0.366	0.1864
	6	7	0.3811	0.1941
	7	8	0.0922	0.047
	8	9	0.0493	0.0251
	9	10	0.819	0.2707
	10	11	0.1872	0.0691
	11	12	0.7114	0.2351
	12	13	1.03	0.34
	13	14	1.044	0.345
	14	15	1.058	0.3496
	15	16	0.1966	0.065
	16	17	0.3744	0.1238
	17	18	0.0047	0.0016
	18	19	0.3276	0.1083
	19	20	0.2106	0.0696
	20	21	0.3416	0.1129
	21	22	0.014	0.0046
	22	23	0.1591	0.0526
	23	24	0.3463	0.1145
	24	25	0.7488	0.2745
	25	26	0.3089	0.1021
	26	27	0.1732	0.0572
	3	28	0.0044	0.0108
	28	29	0.064	0.1565
	29	30	0.3978	0.1315
	30	31	0.0702	0.0232
	31	32	0.351	0.116
	32	33	0.839	0.2816
	33	34	1.708	0.5646
	34	35	1.474	0.4873
	3	36	0.0044	0.0108
	36	37	0.064	0.1565
	37	38	0.1053	0.123
	38	39	0.0304	0.0355
	39	40	0.0018	0.0021
	40	41	0.7283	0.8509
	41	42	0.31	0.3623
	42	43	0.041	0.0478
	43	44	0.0092	0.0116
	44	45	0.1089	0.1373
	45	46	0.0009	0.0012
	4	47	0.0034	0.0084
	47	48	0.0851	0.2083
	48	49	0.2898	0.7091
	49	50	0.0822	0.2011
	8	51	0.0928	0.0473
	51	52	0.3319	0.1114
	9	53	0.174	0.0886
	53	54	0.203	0.1034
	54	55	0.2842	0.1447
	55	56	0.2813	0.1433
	56	57	1.59	0.5337
	57	58	0.7837	0.263
	58	59	0.3042	0.1006
	59	60	0.3861	0.1172
	60	61	0.5075	0.2585
	61	62	0.0974	0.0496
	62	63	0.145	0.0738
	63	64	0.7105	0.3619
	64	65	1.041	0.5302
	11	66	0.2012	0.0611
	66	67	0.0047	0.0014
	12	68	0.7394	0.2444
	68	69	0.0047	0.0016];

Similarly, we have a line data file here, which is represented in this slide and here you can see this ns representing this sending end node, sending end node and nr is representing receiving end node, and R and X are corresponding resistance and reactance, they are probably in either per unit or in ohm.

If they are in per unit, that is fine, if they are on ohm; that means, you have to convert them into per unit ok.

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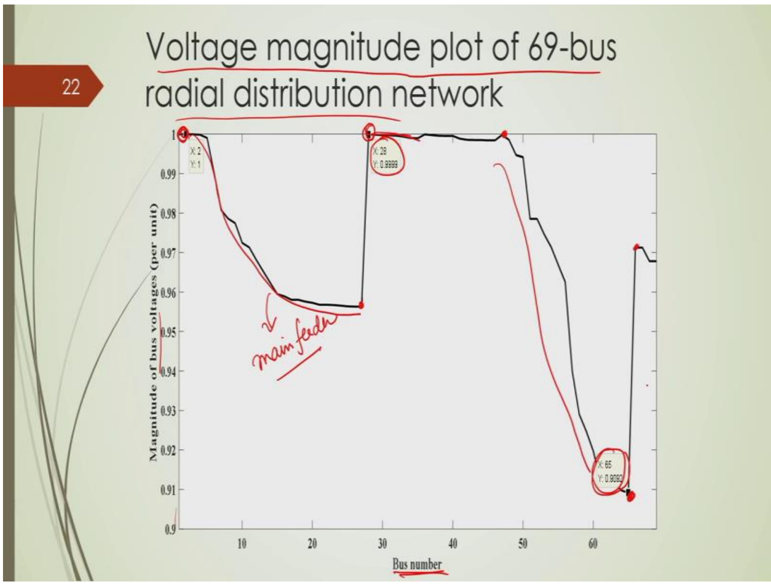

So, this is the bus magnitude, voltage magnitude plot of this 69-node system or 69-bus system, here all node voltages, all node voltages or bus voltages are plotted over this node number.

So, here, this voltage at this point, node 1 is 1 per unit then you can see there is a dip in this voltage magnitude. Till this point here, this is node number 28. Why there is a dip? Because up to node number 28 we have this main feeder, node number 27, we have this main feeder, then node number 28 is basically close to the substation.

So, that is why voltage is higher than this node 27, because node 27 there is that much of voltage drop you know and this is very far away from the substation and there are several nodes that are connected in between and there are several lines.

So, if we subtract this line drop so node 27 will give very less amount of voltage; whereas, this node number 28 which is closer to the substation. So, its voltage is higher than 27 and that is why there is a sudden increase here ok. So, this is actually main feeder profile you know voltage profile, then these are the voltage profiles of one lateral.

Then again, this is some voltage in some node number in between 40 to 50 again, there is a dip in the voltage, let us see why it is so. Because there is a from 36 to 46, we have a longer lateral. So, that is why, this voltage drop takes place.

So, there is again a voltage drop and we get some nodes that is node number 65 which is correspond to the minimum amount of voltage ok, minimum amount of voltage again voltage is higher in other lateral at node 66 probably one lateral starts, 66 there is another lateral start and that is why, here this is somewhat bigger lateral. So, here at this point, we get least voltage magnitude, least voltage magnitude.

Then another lateral starts which gives a bit higher voltage and that is how this voltage profile can be described ok.

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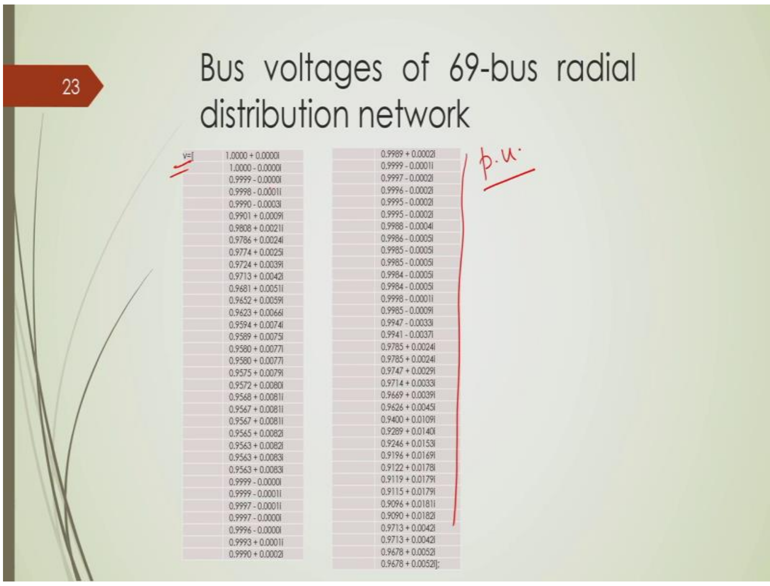

Now, these are the values of these bus voltages in per unit or load voltages in per unit. So, this is the complex voltage which gives you voltages as well as this, angle. So, if you take the absolute value of this, this will give you voltage magnitude, if you take the angle of, this will give you the voltage angle.

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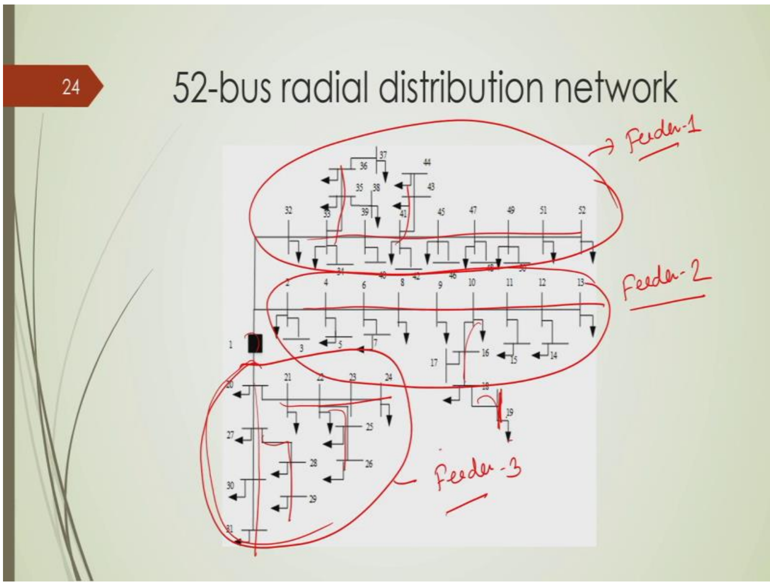

Now, this is another distribution network which is having 3 feeders. So, this is one feeder, this is one feeder, this is another feeder. So, suppose this is feeder 1, this is suppose feeder 2, this is suppose feeder 3. So, we have 3 numbers of feeders here and this, we have several laterals which has this is one lateral, this is another lateral, this is main feeder or there is this another longer lateral and so.

So, here we have, this is main feeder having several laterals like this. So, this gives how a practical distribution networks will look like ok. A distribution network might have multiple feeders, each feeder may be associated with one or more than one main feeder and along with several laterals; one main feeder only along with several laterals.

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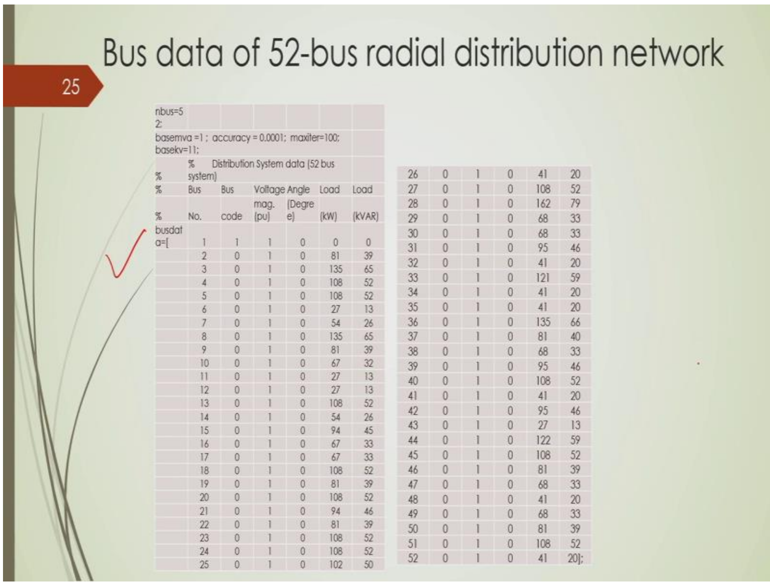

nbus=52;
basemva =1 ; accuracy = 0.0001; maxiter=100; basekv=11;

%	% Distribution System data (52 bus system)					
%	Bus	Bus	Voltage	Angle	Load	Load
%	No.	code	mag. (pu)	(Degree)	(kW)	(kVAR)
busdata=[	1	1	1	0	0	0
	2	0	1	0	81	39
	3	0	1	0	135	65
	4	0	1	0	108	52
	5	0	1	0	108	52
	6	0	1	0	27	13
	7	0	1	0	54	26
	8	0	1	0	135	65
	9	0	1	0	81	39
	10	0	1	0	67	32
	11	0	1	0	27	13
	12	0	1	0	27	13
	13	0	1	0	108	52
	14	0	1	0	54	26
	15	0	1	0	94	45
	16	0	1	0	67	33
	17	0	1	0	67	33
	18	0	1	0	108	52
	19	0	1	0	81	39
	20	0	1	0	108	52
	21	0	1	0	94	46
	22	0	1	0	81	39
	23	0	1	0	108	52
	24	0	1	0	108	52
	25	0	1	0	102	50

26	0	1	0	41	20
27	0	1	0	108	52
28	0	1	0	162	79
29	0	1	0	68	33
30	0	1	0	68	33
31	0	1	0	95	46
32	0	1	0	41	20
33	0	1	0	121	59
34	0	1	0	41	20
35	0	1	0	41	20
36	0	1	0	135	66
37	0	1	0	81	40
38	0	1	0	68	33
39	0	1	0	95	46
40	0	1	0	108	52
41	0	1	0	41	20
42	0	1	0	95	46
43	0	1	0	27	13
44	0	1	0	122	59
45	0	1	0	108	52
46	0	1	0	81	39
47	0	1	0	68	33
48	0	1	0	41	20
49	0	1	0	68	33
50	0	1	0	81	39
51	0	1	0	108	52
52	0	1	0	41	20];

So, similarly for 52 bus system, we have created this bus data file here in similar way and line data file here.

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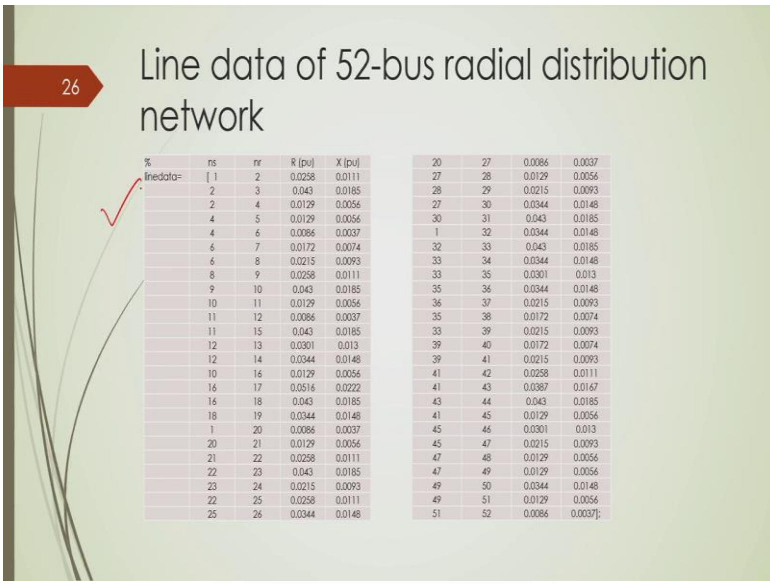

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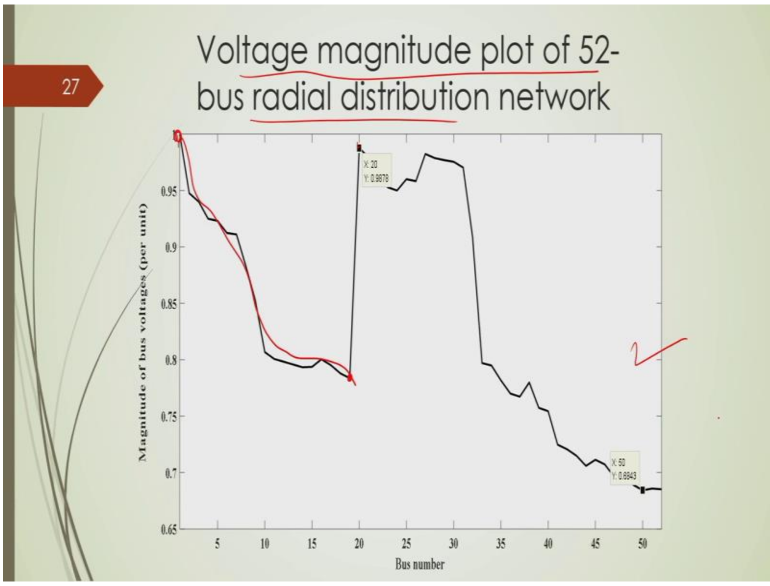

And this is the voltage profile ok, this is voltage magnitude plot. So, here again, you can see the dip in the voltage, starting from the substation to some nodes value, here at node number 19 because, node number 19 is the least I mean, farthest bus you can see. Node number 19 is the farthest bus, of one, of the farthest of this node from this substation.

Then after 19 another feeder starts. So, again these voltages increase to the substation voltage and so on ok and so on. So, this is how this you know, 52-bus node system work ok.

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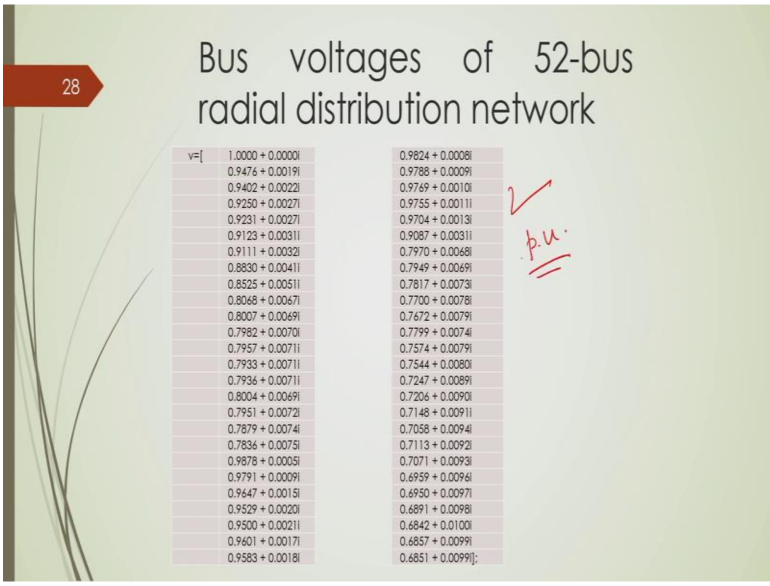

Then this is again, this voltage in value of this 52-bus system in per unit, from here you can get the magnitude of the voltage as well as angle.

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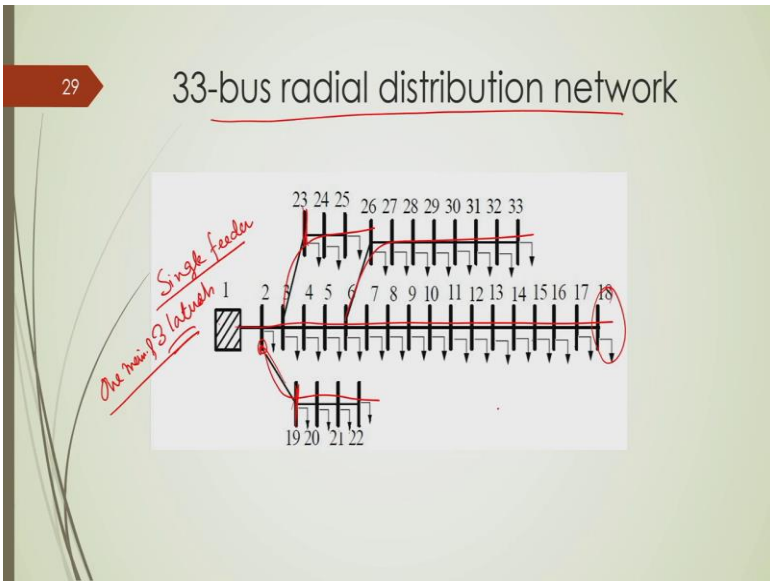

And this is another radial system, which is called 33-node system or 33-bus system having one main feeder. It is also a single feeder network, it is also a single feeder network, single feeder network along with some laterals. This is one lateral, this is another lateral along with 3 laterals, 3 laterals one main feeder, one main feeder and 3 laterals ok, 3 laterals.

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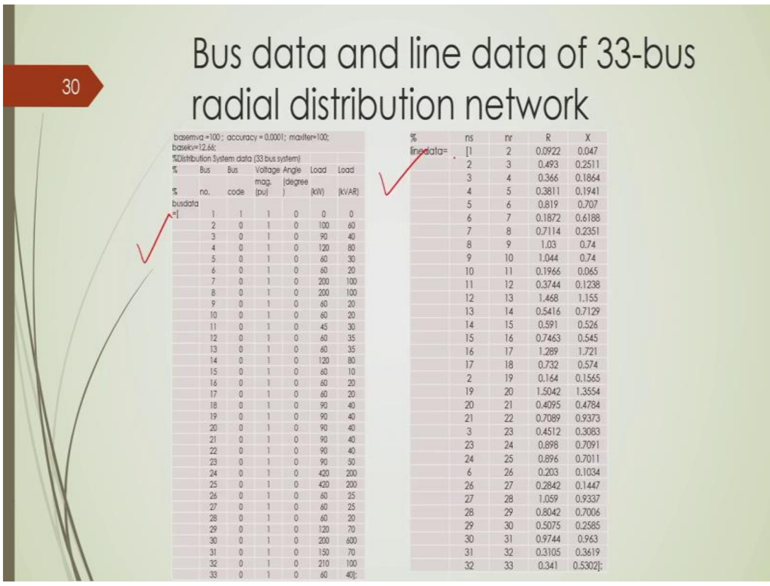

And the other things are similar. So, this is how we can create this bus data file for that particular system.

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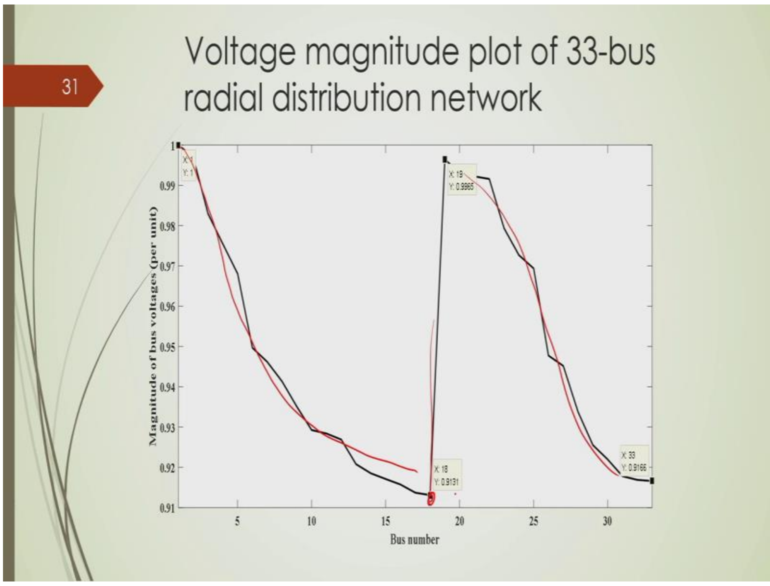

And line data file is given from these two data files, one can find out this voltage magnitude plot. You can see similar voltage magnitude plot here. So, up to 18 there is one main feeder, then at 19 lateral starts, yeah 19 lateral starts which is closer to the substation then this is the farthest point of this main feeder.

So, its voltage magnitude is higher. Similarly, this voltage magnitude of 23 is higher because it is near to the substation. So, this is how, this net bus voltage magnitudes plot looks like.

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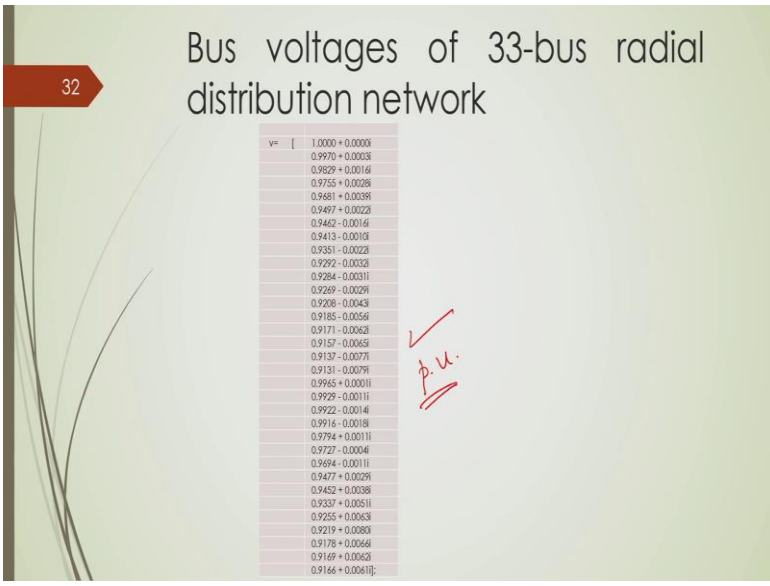

This is again the value that we get after execution of all the iteration and this is of course, in per unit ok.

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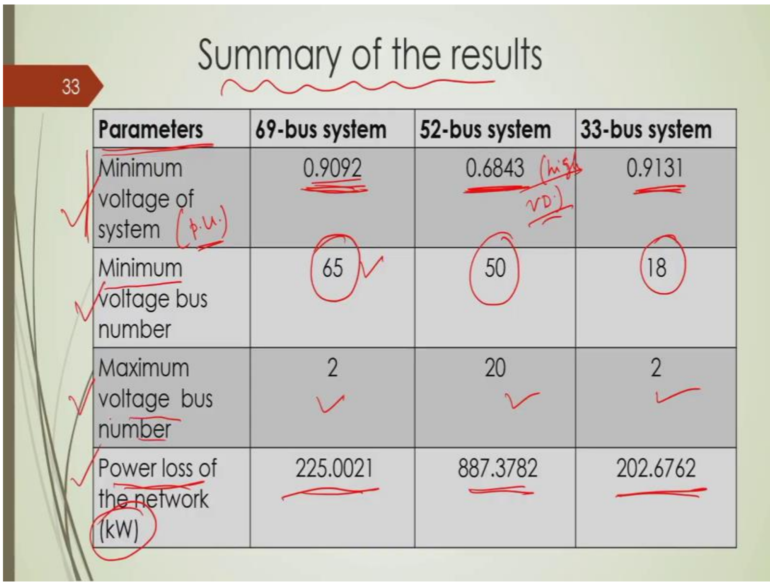

Now, we have a summary of results which gives some important parameters which we use to assess the performance or operational performance for a network; one is called minimum bus voltage, now what is minimum bus voltage that we get, all this is in per unit, this is in per unit. So, minimum bus voltage we get in per unit, 69-bus system it is 0.9092 per unit, for 52-bus system or 52-node system it is much lower 0.6843, that correspond to 32 percent voltage drop.

Here we have 10 percent of voltage drop, which is somewhat acceptable, but here it is very very high voltage drop, high voltage drops. Similarly, here also it is 9 percent voltage drop and also this low, least voltage magnitude occurs at which nodes or which buses. So, here for 69 bus system, it occurs at 65th bus or 65th node. Similarly, for 52 bus system it occurs at 50th bus or 50th node.

Similarly, for 33-bus it is 18th node and maximum you know voltage is of course, except substation they are near to the substation and the power loss it is computed in kilowatt, for 69-bus system it is 225, for 52 bus system it is bit higher because its voltage profile is very poor and for 33 buses 202 kilowatt, around 202 kilowatts.

So, this gives a comparison and these are some important parameters we use in assessing the operational performance for a network ok.

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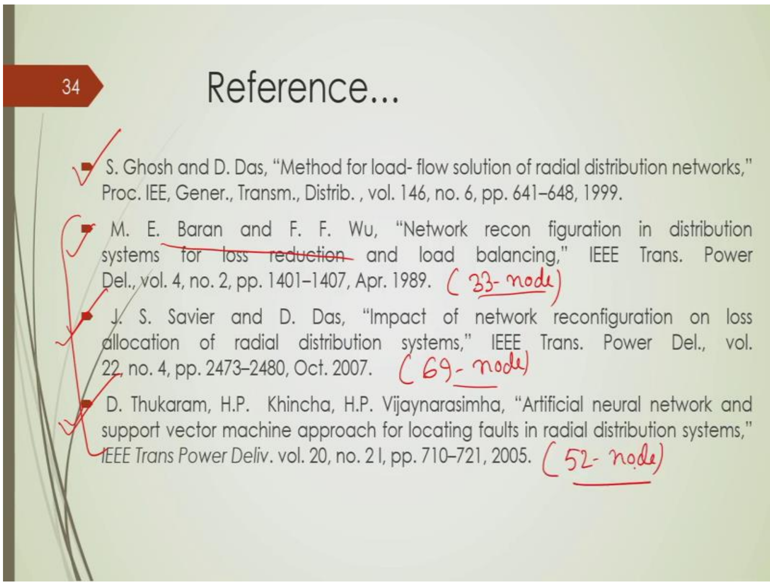

So, these are the references from where I took many concepts, this is the one we get this idea of forward backward sweep load flow algorithm and these three will give you the data files. So, this will give you the data file of 33-node system, this file will give you the data file for 69-node system, one can download this paper and go through and get the data and this reference will give you the data for 52-node system.

So, you can go through this paper in addition to what I discuss today, in order to have a finer information. And finally, thank you very much for attending this lecture and this will finish the module 4, which is one of the shortest modules in this course.

Thank you.