Operation and Planning of Power Distribution Systems
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Week - 07
Forward backward load flow approach for power distribution systems
Lecture - 19
Load Flow Analysis of Radial Distribution Networks

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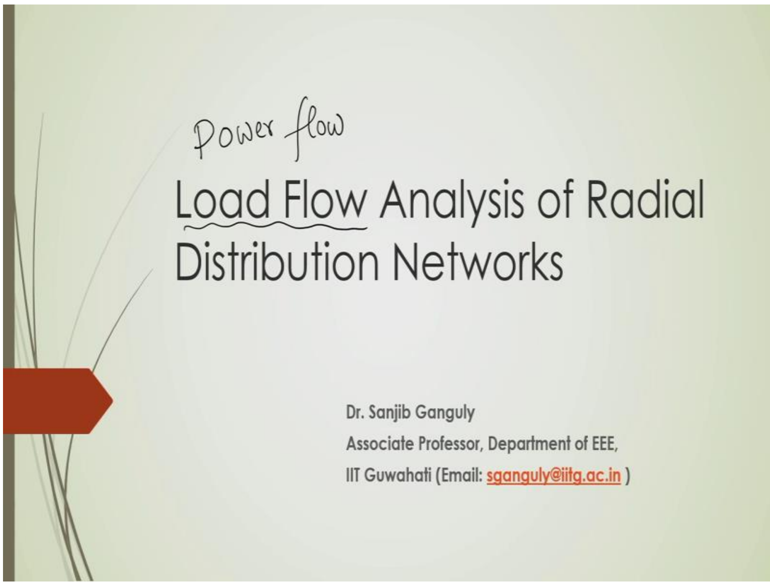

In my today's lecture I will start the next module that is module 4, which is Load Flow Analysis of Radial Distribution Networks. Alternatively, it is also known as power flow analysis of radial distribution networks ok. So, this is an important tool to analyze this performance of a radial distribution network.

And therefore, this is useful in operation and planning of power distribution systems or power distribution networks ok. So, that is why this module although it is a very short module I will need two lectures to complete. But this module is very important for any student or practicing engineer to understand the basic concept of powerful analysis.

And this will be used as support subroutine of various power system research problems, for solving various types of power system research problems ok; whether it is a power system planning problem, whether it is an optimal operation of power distribution network problem. So, those areas this power flow analysis or load flow analysis is an essential tool ok.

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So, in this particular lecture I will talk about this introduction of this optimization problem, then one important aspect that is per unit conversion which will be required for analysis or for having this load flow or power flow analysis, then, this data preparation which is another important aspect.

And then basically this I will talk about a particular type of this power flow approach, which is backward forward sweep load flow or power flow algorithm. So, I will illustrate how it is used what do you mean by this load flow or power flow analysis and what is forward and backward sweep load flow algorithm. And also, I will show you some of the simulation studies for some typical distribution networks, the results that we got from this power flow analysis ok.

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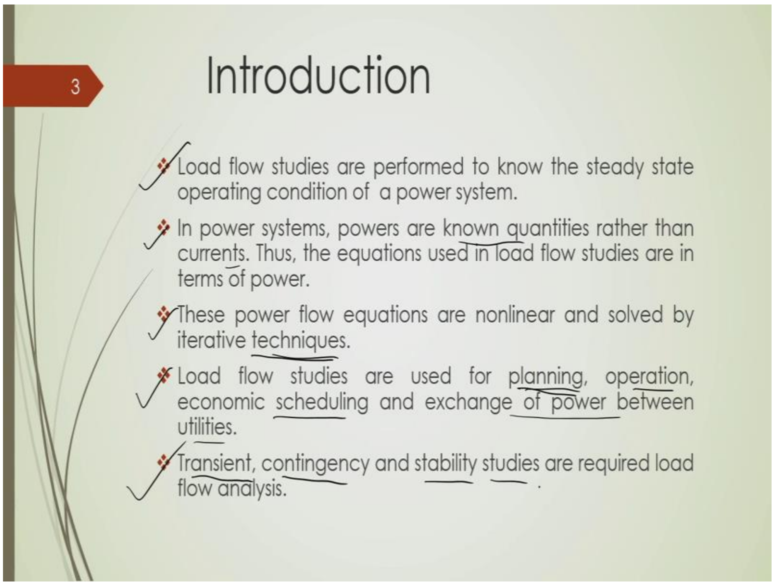

Now as I said this load flow studies are performed to know the steady state operating condition of a power system and that is why it is an important tool for any type of power system problem. So, is the distribution system problem ok. Now in this power system powers are the known quantities rather than the current. So, the equations in load flow studies are in terms of power ok. So, these power flow equations are usually non-linear and solved by iterative techniques.

And we know that there are many power flow algorithms which exist for power system load flow studies, for example Gauss Seidel, Newton Raphson, fast decouple, etcetera ok. So, those things are taught in electrical power system course ok.

And as I said that this load flow studies are essential for this planning operation and economic scheduling and exchange of power between the utilities. So, this is done ah, by electrical utilities to facilitate several aspects for their operation, to have a better operation, to have a better exchange and all these things ok.

So, they also require this type of studies of transient contingency and stability, they are also use for those type of studies we use load flow analysis ok. So, load flow analysis are also used for, you know, contingency analysis, which is very popular area of research in power system ok.

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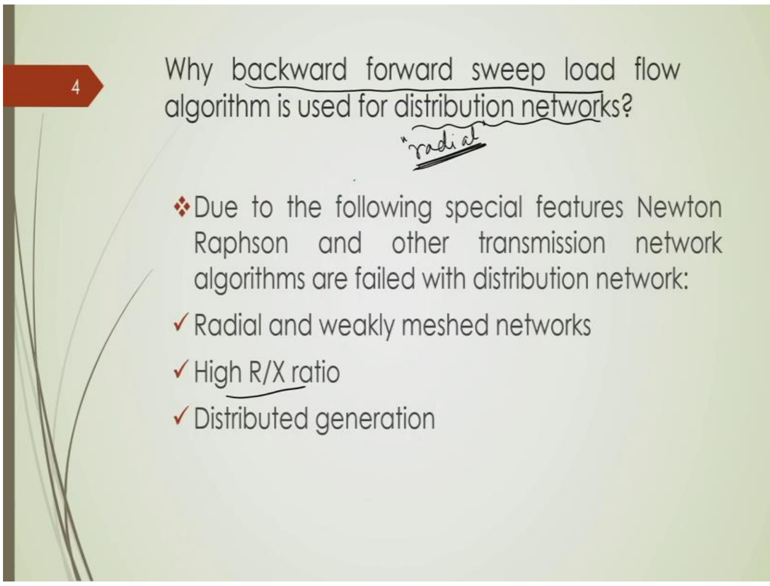

Now here for this particular lecture, I will focus on this forward backward sweep load flow algorithm or backward forward sweep load flow algorithm; which are essentially same meaning ok. And this is useful only for radial distribution network. So, this is only useful for radial distribution networks, because you know, as I said in module 2, I discuss the differences between radial distribution network and conventional power transmission systems ok.

This at the very beginning also I discussed. So, this particular load flow algorithm or power flow analysis is useful for radial distribution networks. And you know that distribution networks are radial only, they operated as radial. Although we have a provision for tie lines which make it weakly mesh, but we use it as radial ok.

Now, for this radial distribution networks some of the conventional load flow approaches they do not work ok. Because they have some specific characteristics particularly this radiality, another is R by X ratio is usually high in power distribution network. So, that is why this conventional load flow approaches like Newton Raphson load flow approach may not converge always ok.

So, that is why the researchers who are working in power distribution system operation and planning, they propose a new approach which is called this forward backward sweep approach or backward forward sweep approach.

So, this is as you know, it is simply application of Kirchhoff's current law and Kirchhoff's voltage law, I will come to that ok. And this algorithm works for radial distribution network only ok. And it is very simple algorithm, it is very easy to implement in any programming language one knows, ok.

So, I will come to that. Now before I show all these details of this slide I will basically show you how to do, what is this load flow approach or what is forward backward sweep load flow or power flow approach, and how it is applicable for power distribution networks.

And in order to mention that I will take a typical radial distribution network topology for example, and I will show you step by step how you will implement this approach or this algorithm to solve any kind of power distribution networks whatever the number of nodes or buses might be ok.

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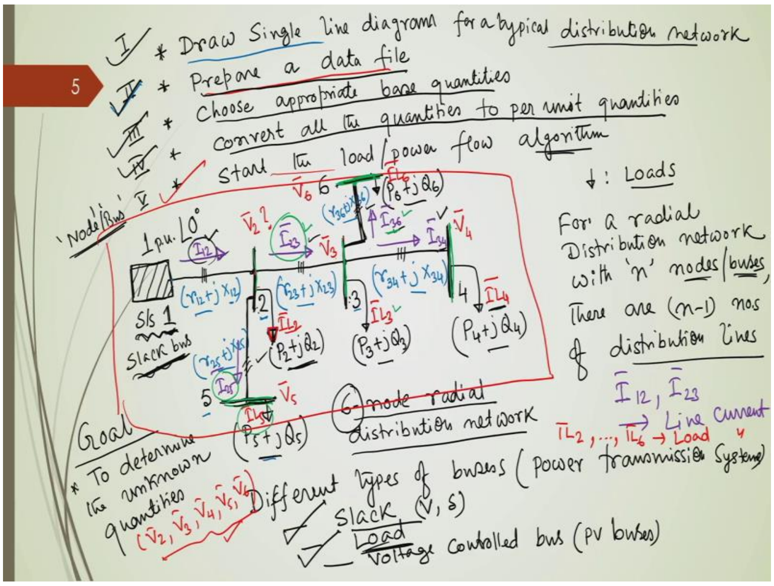

So, first this lecture or in order to start this forward backward sweep load flow algorithm or backward forward sweep load flow algorithm. First thing that you need to draw single line diagram of the distribution network, draw single line diagram for typical distribution networks for a typical distribution network. This is the first step that one needs to follow.

So, this is step 1. So, step 2 is, step 2 is to prepare a data file which consist of the data of the typical power distribution network ok. Now step 3 is to choose appropriate base quantities ok. So, why we need that I will come to that ok.

Now next step is to convert all the quantities to per unit quantities ok and final step is that the load or power flow algorithm. That means before I start discussing about this power flow approach or power flow algorithm or load flow algorithm whatever you may call, there are some steps that I should follow ok.

So, these are the steps, first we need to draw a sketch of the single line diagram of a typical distribution network, for which we are trying to develop this power flow algorithm or load flow algorithm. In fact, if you develop a power flow algorithm that will work for any type of systems, I will come to that but, here in this particular lecture, I will focus on a typical simple typical radial distribution network topology and I will show you step by step; how to solve or how do you go ahead to implement this approach ok. So, first step is to draw the single line diagram for a typical distribution network, which needs this power flow approach ok.

So, let me draw it first. So, suppose this is my substation and I will call that this particular substation at node 1 or bus 1 ok node 1 or bus 1. Then we have a single feeder we have a single feeder which is having some few nodes this is suppose one node this is suppose another node this is suppose another node. So, I can name this as node 2, this at node 3, this at node 4; these are the nodal points ok. Where we have these distribution transformers connected and that distribution transformer is connected to the customers of these distribution networks ok.

So, each of this node is having some load demand and this load demand is shown over this arrow. So, this arrow represents this loads ok connected to the particular nodal point ok now we also have some other loads. So, this is a single feeder network as you can understand we have one substation located at node 1. In fact, in distribution network we either use this terminology node or bus ok.

But usually, we use this terminology node because we use to represent this nodal point, because the same terminology is for similar concept to represent the same thing in power transmission system, we use this terminology bus ok.

So, looking at this single line diagram, so this is a single line diagram you can understand although it has been drawn it a single line, but it is actually of three phase network ok and all these loads are also three phase loads ok. Now, this is as you know main feeder or a trunk feeder and we may have some lateral feeder or laterals like this. So, with bus number 2 we have another nodal point that is node 5 which is having some load demand represented by this arrow.

Similarly with this node 3 we have another lateral feeder like this and it is represented by bus 6 and this is what the arrow which represents the load demand ok alright. And so if you look at this single line diagram as I said all are of three phase ok all are of three phase. And we represent them all lines are of three phase all loads are of three phase and we represent them by these three parallel lines, but the single line diagram shows you the equivalent single-phase form of a three-phase network, as I discussed long time before ok.

So, if you look at this network you will see we have six number of nodes. So, we can call it as a 6-node radial distribution network ok, so it is a six-node radial distribution network ok. And when we have a radial distribution network if you have n number of nodes or buses then there will have n minus 1 number of lines.

So, if you look at this particular single line diagram of a typical distribution network or typical feeder of a distribution network. Here exist five lines or five distribution lines, one line is connecting this node 1 or substation to this node 2 this is one line. Another line is connecting node 2 to node 3, another line is connecting node 3 to node 4. Another line is connected nodes 2 to node 5, another line is connected between nodes 3 to node 6 ok.

So, we have 1, 2, 3, 4, 5 lines. So, for this another thing that you should understand for a radial distribution network, network with n number of nodes or buses whatever you may call we use we prefer this terminology nodes ah. There are n minus 1 number of distribution lines ok.

Now, for a power distribution network, mostly all nodes are of this passive loads. So, they have some active power demand and they have some reactive power demand and we can represent this load demand by something like that ah. For example, that for node

2 the active power demand let us say is P 2 and reactive power demand let us say Q 2 ok. So, P plus j Q 2 is basically the load demand at this node 2 ok.

Similarly, at this node 3, this active and reactive power demand can be represented by as P 3 plus j Q 3. Similarly at node 4 this active and reactive power demand can be represented by P 4 plus j Q 4 ok. At node 5 this is represented by P 5 plus j Q 5 ok. And at node 6 it is represented by P 6 plus j Q 6 ok.

Now in power transmission system there are different types of buses different types of buses ok for power transmission systems ok. And we categorize them as slack bus then load bus then P V bus or voltage control bus voltage-controlled bus or P V bus.

So, these are the typical types of buses ok, but for a passive distribution network as long as there is no source connected to the network; we only have two types of buses one is called slack bus another is called load bus. So, here you can see we have one number of slack bus that is we consider that reference and that is of course, this you know substation bus, so this is slack bus we will consider who is basically importing power to all other nodes ok and rest of all these nodes are or all these buses are of load buses.

So, they are connected to the customers and they these nodes are having some active power demand and reactive power demand which are represented by P 2, Q 2, P 5, Q 5, this ok. Now what is the goal of this power flow analysis or power flow solutions. So, our goal is to find or to determine the unknown quantity, to determine the unknown quantities ok.

Now, what are the unknown quantities we have? The slack bus is usually represented by its voltage and angle, V and delta, voltage magnitudes and angle are specified ok. So, for slack bus we know that magnitude of the voltage and its angle ok.

And this power, active and reactive power which are flowing away from this slack bus are unknown quantities. But for load buses as you have seen this power demand is specified, P and Q, active and reactive power demands are specified.

So, the unknown quantities are voltage and this angle. So, basically this goal of this power flow analysis is to determine the voltage magnitude and the angle of all these load buses ok. Having this slack bus voltage and angle known, let us consider this voltage is represented by 1 per unit at an angle 0 degree or 0 per unit ah. Considering that, we need to find out what would be the voltage of all these different nodal points or different nodes.

So, our goal is to find out this V 2 phasor; that means, magnitude of V 2 as well as its angle. So, this is one unknown quantity, then similarly for nodal point 3, V 3 is our unknown quantities. Similarly at bus or node 4 V 4 is our unknown quantities for you know bus 5 or node 5, V 5 is our unknown quantity and for bus 6, V 6 is our unknown quantities. So, our goal is to determine this V 2, V 3, V 4, V 5, V 6 ok.

So, I have drawn in phasor form. I have written in phasor form to indicate that we need to know that what would be the voltage magnitudes as well as angles of these load buses, so this is our goal. So, that is why we will perform this load flow analysis ok.

So, in load flow analysis we know that some of the quantities are known and some of the quantities are unknown. For load buses the quantities known are this active and reactive power demand and the unknown quantities are the voltage and the angle, voltage magnitudes and the angle.

So, we will determine this with this load flow ok. So, now we have completed the step 1 only; and we need to go to the step 2, that is, we need to prepare a data file ok ah. We know that some of the data one is as I have shown you that active power and reactive power demands of the load buses, other things that we will know, that is, basically the line parameters.

So, let us represent this line parameter as r 1 2 plus jx 1 2. So, where r 1 2 represents this line resistance for the line which is connecting this node 1 to node 2. Similarly, x 1 2 is representing the line reactance which is connecting this node 1 and node 2 ok. Now since this distribution line is already existing, we know that what would be the line parameter.

So, we from this conductor specification we can find out that what would be the line resistance. And we also know that what is the length of the line usually conductors are specified that much of ohm per unit length. So, if you multiply this length of the particular line with this r that is resistance per unit length.

So, you will basically get the resistance of that particular line. So, similarly we also know that this line parameters of all the lines. For example, line connecting this node 2 to node 3 it is a parameter let us write it as r 2 3 plus j x 2 3. Similarly, for this line which is connecting node 3 and node 4 the line parameters are r 3 4 plus jx 3 4 ok.

For this line which is connecting node 2 to node 5, line parameters we can write it as r 2 5 plus j x 2 5. Similarly for this line we can write it as r 3 6 plus j x 3 6 ok. So, these line parameters are known to us. So, we need to determine these voltages with the information of line parameters as well as the information of this active and reactive power demand of the load buses.

But apart from that we also know the network topology, how this network is connected by drawing this single line diagram, this is also an important knowledge without that we cannot go ahead ok. Now let us see how can we systematically present these known and unknown quantities to create a data file, to create a data file ok.

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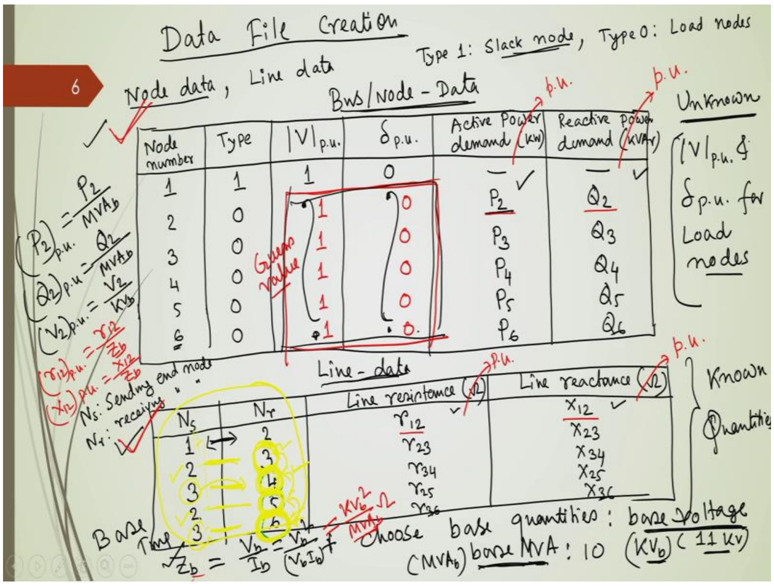

So, in next page I will show you how to create data file; data file creation let us say. So, we will create two data files, one is the node data, another is line data ok. Now let us first start with node data. In node data we know that we have total, we have 6 number of nodes.

So, let us create a node data or bus data file which is for the 6 number of nodes ok. The first column, that is, to keep as this node number ok. So, we have 6 different numbers of nodes you can see that 6-node system it is. So, we can write node number as 1, 2, 3, 4, 5 and 6 ok.

Now next we will keep as that what type of the node we have type ok. So, this is basically this shows that you know categorization or classification of the nodes ok. As I said in passive power distribution network or radial distribution network, we have two different types of nodes; one is called slack bus or slack node, another is called load node.

So, let us represent this node type either by 1 or by 0; 1 means it is of slack node and rest are you know load node, so type one represents slack node and type 0 represents load node ok. Then we will be having the information of bus or node voltage and magnitude. So, V magnitude ok and angle ok, so angle can be in per unit or in degree.

So, this V we represent in per unit and it can be also represented by per unit what is per unit, I will come to that ok; and how to convert this in per unit all these things ok. And as we know this for a slack bus or slack node this voltage and angles are specified it these are known quantities. So, I can write them as 1 at an angle 0; for other nodes we do not know what is the value of this V and delta and we are supposed to determine this ok, and that is what our goal for this load flow approach.

Now, we know another two quantities which we will write is write it in column 5th and column 6^{th}, which is active power demand, reactive power demand. Usually this is in kilowatt for distribution networks because distribution networks loads are in kilowatt level not in megawatt or watt ok. Similarly for reactive power demand, it is normally represented as KVAR ok. Now for slack bus it is not a load bus, so active and reactive power demands are not there.

But for all other buses we know active and reactive power demand. So, you can write for example, for node 2 this active power demand is P 2 reactive power demand is Q 2. For node 3 active power demand is P 3 reactive power demand is Q 3, for node 4 active power demand is P 4 reactive power demand is Q 4. For node 5, P 5 Q 5; for node 6, P 6 Q 6 ok.

So, this we will make this bus or node data. So, these are the data available to us and only thing is that we need to know that what is that you know voltage and angle of these load buses; these are unknown quantities ok. So, I put a question mark sign, so that question mark, so that this we will derive.

Now apart from that, as I have shown you, as I have told you we know some of the data here is line parameter. So, this line data we will represent it another table. So, for line data we will prepare another table ok. Now as we have discussed for a 6-node system we have 5 numbers of line ok. So, the first two columns we will keep, to know that these lines are connected to which node to what node ok.

For example, so this is called, let us say, N s sending end node, and this is, let us call it N r, where N s is sending end node, sending end node and N r is receiving end node. Because as you know, in the radial distribution networks, power is flowing uni-directionally.

So, power always flow from 1 to 2. So, for line this 1 to 2, it is, sending out node is 1, receiving end node is 2. So, I can write is N s as 1, N r 2 and there are two other columns which represents line resistance which is normally represented in ohm and line reactance which is also represented by ohm.

So, for this line which is connecting node 1 to node 2, line resistance is represented by let us say r 1 2 and line reactance is represented by x 1 2. Similarly, the next line is between these nodes 2 to node 3, so we write it node 2 to node 3 and corresponding resistance and reactance we right r 2 3 and x 2 3.

Similarly, the next line is between nodes 3 and 4, so I write it 3 and 4, r 3 4, x 3 4. Similarly, this is another line which is connecting nodes 2 and node 5. So, I can write 2 5 this is r 2 5, x 2 5 ok. And similarly, there is another line which is connecting nodes 3 and node 6 this is another lateral line, so 3 to 6, r 3 6, x 3 6 ok.

So, these are the information which is known to us and in line data all quantities are known. So, these all quantities are known, so these are known quantities and these are the unknown quantities here. So, unknown quantities are V per unit and delta per unit for load nodes.

So, these are unknown quantities, these are unknown quantities and our goal for doing this whole analysis is to find out the magnitudes of this unknown quantities only. So, we are intending to find out this V and delta for this load nodes ok. Now, with the preparation of this bus data file and line data file or bus data table or node data table or line data table, we have completed this step 2 ok. So, this is an important part of understanding this forward backward sweep load flow approach.

We have not started the algorithm so far ok, so we are in the process of creating data file only. Now the next step would be to choose appropriate base quantities; next step should be to choose appropriate base quantities and next two steps are to choose appropriate base quantities and convert all the specified quantities to per unit quantities ok. So, this per unit conversion is an essential thing in any sort of power system calculation ok.

So, it not only makes the calculation easier, but also it has several advantages. I will talk in my next lecture ok. So, now, in order to convert this per unit quantities what we will do; we have to choose base quantities ok. Now what are the base quantities? We require; we need two base quantities; one is base voltage ok, another is base volt ampere. So, this volt ampere we represent either kilovolt ampere or MVA, mega volt ampere ok.

Now, how do you choose their values? This base voltage is usually chosen considering the system voltage ok for 11 KV system. So, we consider this base voltage as 11 KV and whatever voltage values we have? We will convert all by normalizing with this base voltage, that is, in terms of this 11 KV ok. So, 1 per unit voltage represents it is an eleven, 11 KV voltage.

Similarly, base MVA we choose 10 MVA or 1 MVA or 100 MVA according to the power demand ok. So, after selecting these base quantities we need to convert all quantities into per unit quantities ok. So, how do you convert this? It is very easy as you know in order to convert this active power to this per unit. So, let us write it P 2 per unit will be equal to actual value of P 2 divided by this base MVA or MVA base ok. So, this base MVA we write it as MVA base ok.

Similarly, this base KV we write it as KV base ok. Similarly, all these, you know, reactive power will be converted to per unit by normalizing with this MVA base alright. Similarly, all the voltages actual, this V 2 per unit will be actual voltage divided by this base KV ok. So, by dividing by normalizing with these base quantities we will convert this kilowatt and KV are to the per unit ok.

Similarly, we also know this line reactance or line resistance, these quantities also you need to convert to per unit ok. Now in order to convert to this resistance to per unit, per unit, let us find out this base impedance that is Z b ok base impedance.

So, how do you find this Z b? Z b you know it is V b divided by I b. So, base value divided by base current. So, if you multiply this numerator and denominator with this b. So, what you will get? V b square divided by V b I b ok. So, it is basically Z base or base impedance, it is a ratio of base voltages square to the volt ampere base ok.

Now, we know that, here we have this base voltage in KV and volt ampere base in MVA. Now we can also write it as, this is equal to KV b square divided by MVA b. Because if you multiply this KV by kilo volt means 2 kilo volt quantities, effectively it will result in 10 to the power 6 in the numerator. And this, if your denominator is in MVA this is nothing but, the actual quantity multiplied by 10 to the power 6.

So, those 10 to the power 6 will cancel out from numerator and denominator which makes your Z b in ohm ok, so this is in ohm. So, once we get this base you know impedance. So, what we can do? We convert all this line resistance into per unit by normalizing with this base impedance and also line reactance as well. So, this r 1 2 per unit will be actual value of r 1 2 in ohm divided by this Z base ok.

Similarly, x 1 2 per unit will be actual value of x 1 2 in ohm line reactance divided by Z base ok. Now you convert this ohm to per unit before starting your load flow algorithm, similarly all kilowatt active power demand into per unit and all KVAR reactive power demand into per unit before you start this load flow programme ok.

So, this is the simple step one need to understand. When you prepare these two files you need not to remember this network structure every time, you need not to remember this network structure. Rather these two data files will provide you all information related to your network topology, related to your network load demand, related to whatever you want about this network ok.

Now. In fact, this topology is you can trace out from this information of this sending end and receiving end node ok. Similarly, this was node voltages you know these are unknown quantities, but node active and reactive power demand you can get from this node data information. Similarly, line parameters you get from this line data information.

So, the objective of preparing this table is to translate all this information or to convert all this information in a typical data file. From which one needs the access to write down the programme codes ok for solving this. Now, so far, I did not discuss how do we solve this power flow approach, let us discuss right now ok. So, next step as I said, we will start this load flow or power flow algorithm.

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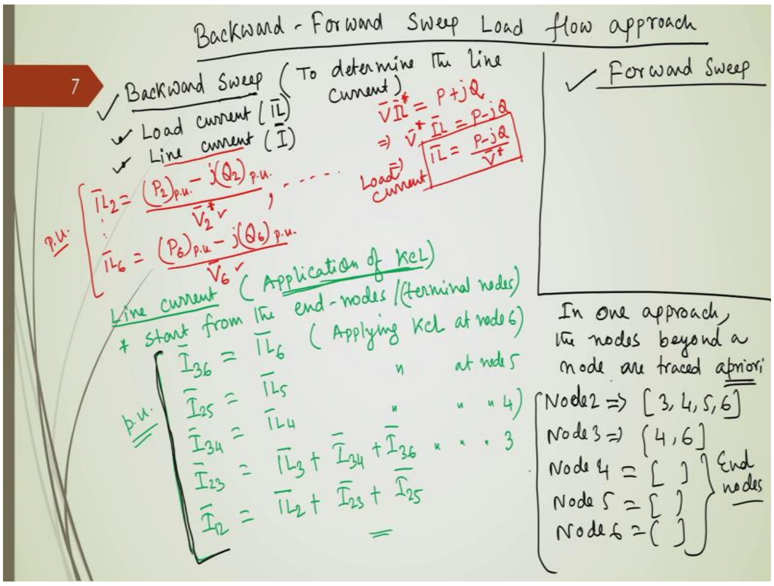

So, we will write backward forward sweep or forward backward sweep both are used in literature, backward forward sweep load flow approach ok backward forward sweep load flow approach.

So, in backward forward sweep load flow approach we have two major steps; one is called backward sweep, another is forward sweep. So, this is backward sweep for example, and this is forward sweep. These are sequential steps and we need to first perform this backward sweep and then forward sweep, forward sweep is very easy to understand ok. Backward sweep is a bit complex, but it is not as complex as the other type of load flow algorithm ok.

Now, in backward sweep we basically, our objective is to determine the line current ok. So, here we have a concept of load current, another is line current; this load current is the current drawn, this one particular load is drawing what current is that the load current of that particular node ok. So, it is represented by IL bar, this bar represents that it is a phasor quantity, of course, all voltage currents are of phasor quantity.

Similarly, this line current is represented by only I, I bar ok. So, that is not standard nomenclature again I am using here, so that you can differentiate this load current and line. So, basically if I go back and show you in that figure, then you can understand this difference of this load current and line current; this line currents are what current is flowing through this.

So, these are the line current, so these are represented by I 1 2 bar I 2 3 bar then I 3 4 bar and so on ok; so here I 2 5 bar and here I 3 6 bar. So, these are this I 1 2 bar I 2 3 bar these are basically line current, these are basically line current ok and this load currents are, as you know, the current drawn by this load.

Let us represent in red colour, so load current is basically IL 2. So, what current is drawn by this load which is connected this node 2, similarly IL 3, IL 4, IL 5 and IL 6 this is IL 6 ok. So, this IL 2 to IL 6 IL 6 they are load current ok.

Now, this line currents are function of load current only. So, load current is the current drawn by a particular load and line current is current flowing through a particular distribution line. Obviously, this, if you apply KCL at any of the nodes this you know line current would be function of this load current.

So, a load current we can easily determine and then we will determine this line current with the simple application of Kirchhoff’s current law, how to do that let us see. First how do you find out this load current? As you know this, we know that V phasor I phasor conjugate is equal to IL phasor I am writing, because it is related to this you know load current.

This is equal to P plus jQ ok. So, we can write it as V phasor conjugate IL, ILis representing this line current is equal to P minus j Q. So, I can find out IL is equal to P minus jQ divided by V star.

So, this is how we can find out this load current, this is how we can find out load current. So, we can find out this load current for all these locations because we know this P and Q for all these locations. Let us write it like IL 2 is equal to P 2 per unit because we already converted this power into per unit minus jQ 2 per unit divided by V 2 star ok.

Similarly, we will determine all other load currents IL 6 will be equal to P 6 per unit minus jQ 6 per unit divided by V 6. V 2, V 6 they are already in per unit, so I am not writing, so all quantities are per unit and which will result in this line current they are also in per unit ok. So, they are in per unit.

So, they will lie within 0 to 1, their fractional quantity ok. So, we will determine this, you know, load current and line current with the available information for P Q and V. Now you can see that here our V are unknown this V 2, V 3, V 4, V 5, V 6 these are unknown. So, what we will do, how to find this load current then? Because we need the informtion of voltages here ok.

So, since as I said, this algorithm is a powerful approach; is of iterative approach, we will initially, we will choose an initial guess values of this unknown quantities. So, we will choose the initial guess values and this guess value we make a flat start meaning that we assume that the initial guess initial guess for all these bus voltages or node voltages are 1 per unit and these angles are 0 ok.

So, these are not actual value this is basically our guess value or initial value ok. So, we assume that all these voltages initial means at the iteration 1, because when some quantities are unknown, if we cannot determine it directly then we will determine it indirectly and that indirect determination is an iterative determination ok.

So, we will start with some iteration count, let us say iteration 1 and then slowly we will update this, you know, guess values. So, for iteration 1 we assume that all these unknown voltages are of 1 per unit and all unknown angles are of 0 per unit ok; that means, voltages and angles are of 1 at an angle 0 per unit each ok.

So, that means for initial iteration we consider V 2 star is equal to 1 because it is 0 per unit angle, so V 6 is equal to 1 and so on. Now next we will determine this line current ok; how do you determine this line current? Now determination of line current needs the application of Kirchhoff’s current law KCL application of Kirchhoff’s current law ok.

Now how do we apply this Kirchhoff's current law here? So, here for this, you know, determination of line current, we will start from the end nodes, end nodes or terminal nodes, terminal nodes ok.

So, we will start with end nodes or terminal nodes ok. Now that means, we will start with this terminal node either from 4 or from 5 or from 6. So, why we will do so; I will come to that ok. So, since in our line data matrix our last entry is 6. So, we can start with 6, or then 5, then 4 and so on.

So, for this, you know, 6th node this current which is flowing through this you know node 3 to node 6, that is I 3 6 will be equal to this IL, if you apply KCL at this nodal point that is at node 6. So, what we will get? We will get I 3 6 that is the line current which is flowing from nodes 3 to 6 is equal to IL 6.

This we get applying KCL at node 6 ok. So, as I said, line current calculation is simply application of KCL; similarly next I will come to this node 5 which is again the terminal node because there is no node connected with that. So, what we will do? We will apply this KCL at this point and application of KCL says that this I 2 5 will be equal to IL 5. So, you can write it as I 2 5 is equal to IL 5 ok, again we apply KCL at node 5.

Similarly, we apply again this KCL at this node 4; node 4 is again this terminal node there is no node connected beyond. So, what we can do? We write for this node line current, that is, 3 to 4 is equal to IL four if we apply KCL over here that I 3 4 is equal to IL 4, I 3 4 is equal to I L 4, this is also application of KCL at node 4.

Now, again we apply this KCL at node 3. So, this will give you this line current, which is entering through this node, that is, I 2 3 this. So, this will be equal to, if you apply KCL at node 3 this will be equal to this line that summation of this outgoing current that is I 3 6 and IL 3 and I 3 4.

So, what we can write I 2 3 is equal to IL 3 plus this I 3 6 and I 3 4, I 3 4 plus I 3 6. This is again by applying this KCL at node 3. Then I 1 2 also, we can determine this will be IL 2 plus if we apply KCL at this node 2 this will be equal I 1 2 will be equal to IL 2 plus this current that I 2 3 plus I 2 5 that is I 2 3 plus I 2 5 alright ok.

Now this is how we compute this, all this line current, these are all in per unit, these are all in per unit ok. So, this is how we calculate this, all this line current ok, And this line current calculation is somewhat complex term for this for backward sweep analysis as I said ok. And there are many approaches for this determination of line current by using some algorithm or iterative way ok.

So, in one approach this the nodes beyond a node are traced ok and accordingly they determine this line current ok. For example in fact, this is possible from this, you know line data information or from this topology we know that beyond this node 2 we have node 3, node 4, node 5 and node 6.

That means, all these nodes power demand is flowing through this node 2. So, beyond this node 2, we have, we have node 3, 4, 5 and 6 and beyond this node 3 we have node 4 and node 6 ok. So, beyond this node 3 we have node 4 and node 6 and node 4 node 5 and node 6 they are terminal nodes.

So, beyond that there is no node these are void ok, so these are terminals end nodes. So, there are no nodes beyond that ok. So, once you can trace this, then your task to determine this current, line current would be easier ok because this does not need any iterative approach, only you need to know that determine this we need to trace, that what are the nodes are beyond a particular node and with this available information you can find out this line current.

How? For example, this when you trace that beyond node 2 this node 3, node 4, node 5 and node 6 are there then this power or current which is flowing through this node 2 will be some of the load current of node 2 itself along with node 3, node 4, node 5 and node 6 ok.

How? Let us see suppose this IL 2 is equal to IL 2 plus I 2 3 plus I 2 5. So, this we can write it as IL 2 and I 2 3 is equal to IL 3 plus I 3 4, I 3 4 is equal to IL 4 plus I 3 6, I 3 6 is basically equal to IL 6 and I 2 5, I 2 5 is basically equal to IL 5 ok.

So, you see that this current which is flowing through this node 2 is sum of the all load currents which are beyond this node 2 along with its own node current that is IL 2. So, it is summation of IL 2 plus IL 3, IL 4, IL 5 and IL 6 ok.

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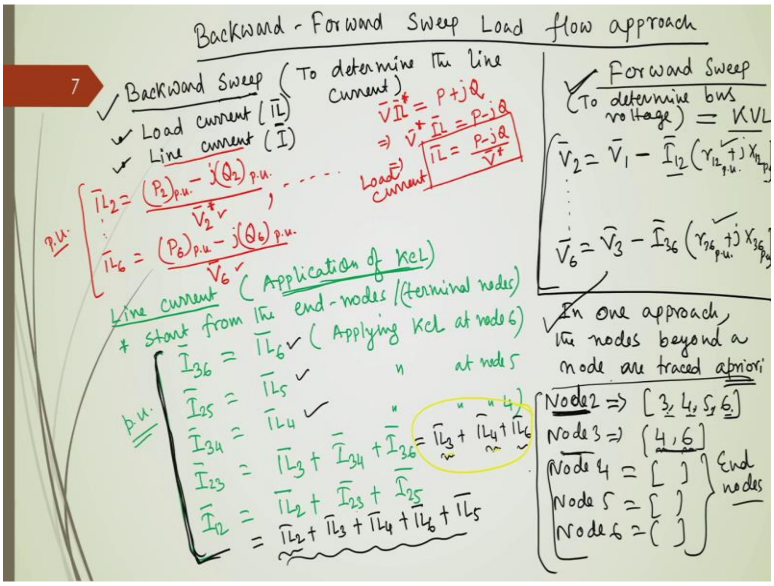

Similarly, this, for I 2 3 also you can find out as this is equal to, this is equal to IL 3 plus I 3 4 is equal to IL 4 plus I 3 6 is equal to IL 6. So, once you find out that beyond this node 3, only we have these two nodes 4 and 6. So, this current, which is flowing through this node 3 will be equal to sum of this load current of node 4, node 6 and its own node current that is IL 3 IL 3 IL 4 IL 6. And since these are the terminal nodes, they are; for these n nodes their line current is individual, there load currents only.

So, this is one approach by which one can trace, the nodes beyond a particular node and accordingly after that you need not to have this information of network topology. And you can eventually find out what would be the line current or what would be the current flowing through that particular node ok.

Now, similarly, this is one approach ok, another approach is from this you know this N s and N r information one can find out this a line current ok. How one can find out this line current? Let us first start with this end node that is node 6. You find that node 6 is the receiving end of one particular line and then you find out who is the sending end side of that particular node, that is node 3 ok. Now after that we will determine this line current which is flowing from 3 to 6 ok for that particular line.

Now, after that you check whether the 6 node is appearing at least any time in the sending end side, but you see there is no node 6 at the sending end. So, if so then we can understand that node 6 is a terminal node or end node and the line current between 3 to 6 is equal to the load current of the node 6.

Now after that, we forward to the next row, that is at node 5. Again, you check whether node 5 is appearing anytime at the sending end side, no it is not appearing, so again node 5 is also a terminal node and its current that is flowing through this node 2 to 5 is basically the load current of node 5 only ok.

Then go to the next stage that is you find this line 3 to 4 where again this node 4 is a terminal node why, because it is not appearing anytime in the sending end side ok. So, any node which is not appearing at the sending end side, of course, is the terminal node. So, the line current that I 3 4 is basically equal to the load current of this node 4 ok.

Then you go to the next step, that is, you look at this node 3. So, this is the line I 2 3 which is having this receiving end side at node 3. Now you see whether node 3 is appearing any time in the sending end side, yes, it is appearing at least twice ok; at least once that is between 2 to 5.

So, when it appears that along with this line current, along with this load current of node 3 you also count this load current of node 5, which is the receiving end side of this node 2 ok. Sorry, not 5 it should be four because 3 is appearing here in the sending end and corresponding this receiving end side is 4.

So, for this calculation of I 2 3 your load current of I 3 as well as load current of IL 4 should be counted. And, also you see whether 4 is appearing any time in the sending end, so it’s answer is no. So, 4 is not any, 4 is not having any send receiving end side, so it is a terminal node. So, basically this I 2 3 is equal to IL 3 plus IL 4, so you can check whether it is true or not.

So, it is equal to IL 3 plus IL 4 ok. So, this 3 is again appearing 2 is as I said 1 is node 4 another is node 6, so you have to add this, both this load line current that is IL 4 IL 6 and IL 3 in order to compute this current flowing through this line 2 to 3 and so on. So, this is how also one can trace this line current ok; now once you have traced this line current then your task of this backward sweep is over.

Then you come to this forward sweep; forward sweep is to compute or to determine bus voltage ok and this is by application of KVL and that will flow through the forward direction.

Why in previous case it was backward direction? Because you see in order to find how much current will flow through this line 1 to 2, I need to know that how much current is flowing through this node 3, node 4, node 5 and node 6.

So, I need to find out those currents who are independent and that is why we start it from the terminal nodes. Because this current this IL 2 I 1 2 it is a function of all these load current. So, you cannot determine the value of this without determination of individual load current or individual line current ok.

But this I 3 4 it is independent of the loads of node 2, node 3, node 4, node 5, node 6. So, you can easily determine with simply the information of this load of the node 4 ok. So, that is why this backward sweep is done in the backward direction. While this forward direction this we will do the forward sweep because we know the substation voltage it is specified to be 1 at an angle per 0.

So, I can simply calculate this voltage V 2 by subtracting this drop from this V 1 and this drop is basically happens due to this at this line 1 to 2. So, it is equal 2 I 1 2 to multiplied by r 1 2 per unit plus jX 1 2 per unit ok. Similarly, you calculate for all, we do it for all we can calculate this end that is end node that is 6th bus voltage simply subtracting that V 3 with this voltage drop that is I 3 6.

So, simply, we get V 6 is equal to V 3 minus I 3 6 multiplied by r 3 6 per unit plus j 3 6, jX 3 6 per unit. So, similarly we can calculate this is very easy step; there is no any sort of, this is very easy, not at all complex. Simple step forward you need not to have any problem for determination of this. Because once you get this line current and this line parameters are already known we can eventually find out these voltages.

And one we get these voltages these voltages we need to update here we need to update in the guess value ok and we need to keep on this updatation till, we get some converged value of this unknown voltages ok. So, here we will have some convergence criteria which is normally the voltage error, the error, minimum value of maximum error.

So, max error, that we if we achieve that, if we achieve this convergence criteria we can say that load flow is converged ok. So, I will stop at this point today we will discuss the results and other aspect in the next lecture ok.

Thank you.