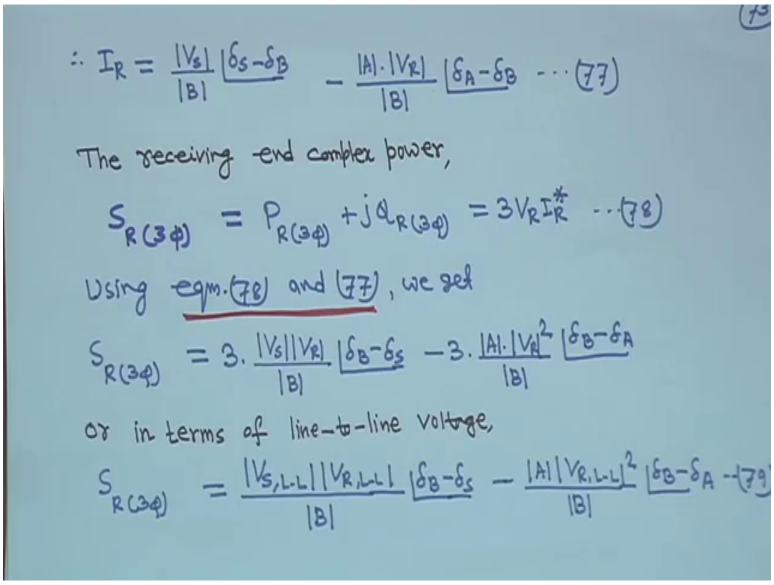
Power System Analysis
Prof. Debapriya Das
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 27
Load Flow Studies (Contd.)

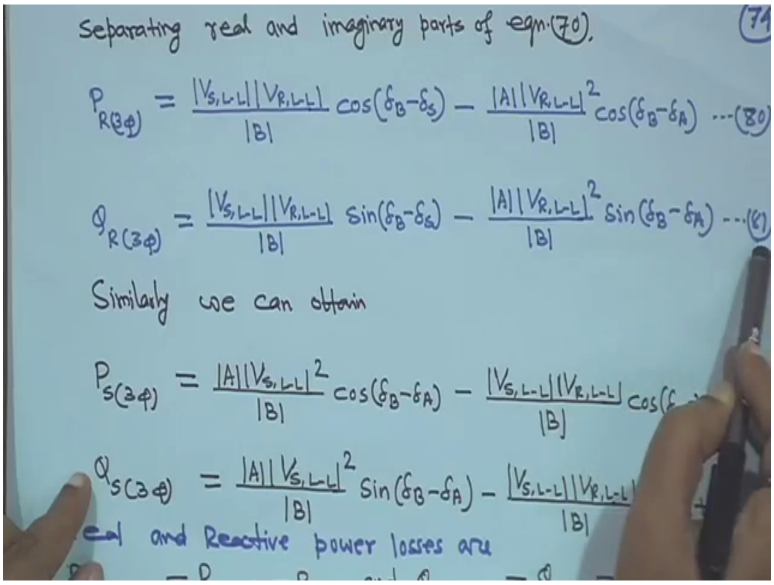
(Refer Slide Time: 00:19)



So, we will come back to this thing. Therefore, you will this thing, just hold on. So, this is that expression for receiving end 3 phase power, right. This is equation 79 right.

Next what you do? This one this angle delta B minus delta S, you can write this term cosine delta B minus delta S plus j sin delta B minus delta S. Here also this one cosine delta B minus delta A plus j sin delta B minus delta A. So, multiply and then you separate real and imaginary part right.

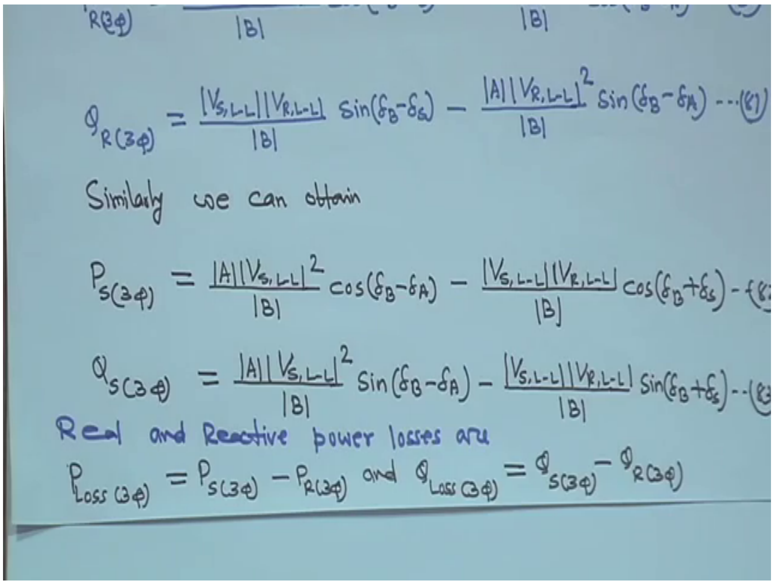
(Refer Slide Time: 00:57)



So, if you do So then, your then it will be receiving end 3 phase power it will be mode V S L-L in to V R L-L that is line to line voltage by mode B magnitude. Cosine delta B minus delta S minus A mode A V R line to line square by mode B cos delta B minus delta A. This is equation 80.

And similarly, this one you are reactive one V S L-L, V R L-L upon B sin delta B minus delta S minus mode A V R L-L, magnitude square up on B sin delta B minus delta A this is equation 81, right. This is receiving end. So, this is an exercise for you find out for the sending end side, but I am giving you the final expression.

(Refer Slide Time: 01:42)

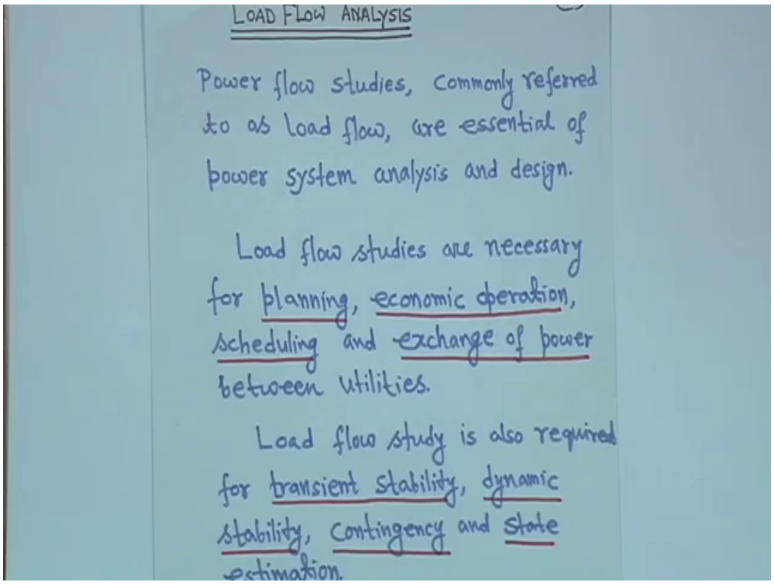


Similarly, we can obtain sending end one right. So, it is P S your sending end 3 phase power it is a V S L-L square up on mode B cosine delta B minus delta A, right. And this is V S L-L, V R minus V S L-L V R L-L upon mode B cos delta B plus delta S, this is equation 82. And similarly Q S is equal to that is 3 phase a V S L-L square up on mode B sin delta B minus delta A minus, V S line to line V R your line to line all magnitude by B magnitude sin delta B plus delta S this is equation 83. So, real and reactive power losses easily you can find; sending end real power, minus receiving end real power that will give you 3 phase real power loss.

So, P loss 3 phase P S 3 phase minus P R 3 phase, and Q loss 3 phase will be Q S 3 phase minus Q R 3 phase, right. This way you can calculate the loss this is another way of calculating there are many ways. So, this is another way of calculating. So, so this performance and characteristic of transmission line this particular topic will be, I think here we will stop, right. And as far as possible we have tried to understand the things of characteristics of transmission line, right. And whatever possible things are available this things are I mean important we have try to discuss right.

So, this characteristic of transmission line this thing is over next one is that most important one is that your power flow or load flow studies right. So, in this case for next one, next one and half hour or so or above that, what will do I have retained your rather horizontal it will be vertically right. So, load flow this thing you have to you know, you have to try to understand little bit right.

(Refer Slide Time: 03:45)

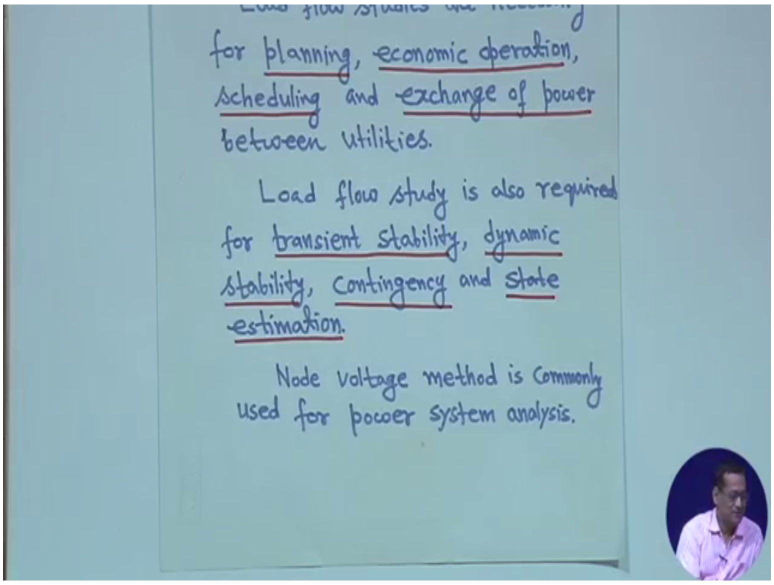


And that particularly this topic actually involves as you know, that involves huge mathematics and when this transmission line load flow will be your load flow or power flow analysis will be covered at the end, I will I will give you one latest thing that is that P bus and P Q V bus that is at the end how to form the Jacobean matrix.

But here in the classroom teaching also we can take we cannot show we can take a small example, because this is a topic where you need computer and you have to write code. Although nowadays So many your what you call your packages or codes are available, but in that case what is happening, that in that code you are giving input and getting the final result that is fine right.

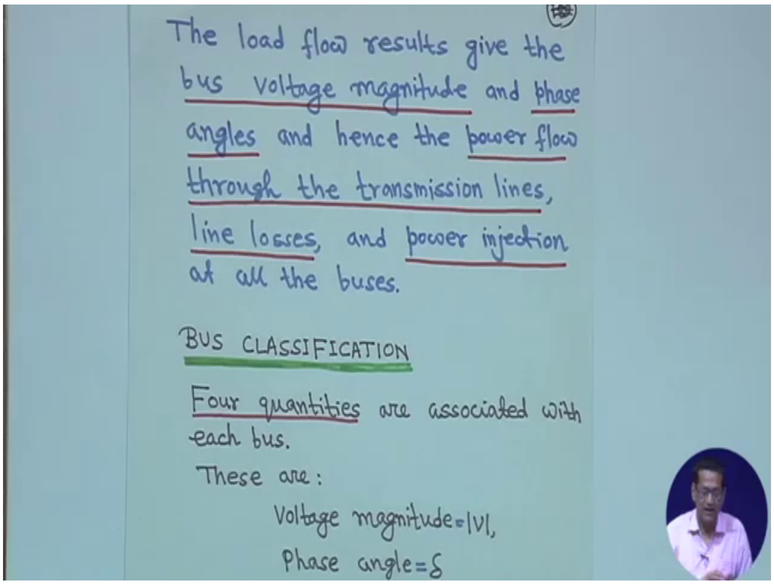
But my question is that if you try to write code of your own then definitely you will learn many things right. So, this load flow analysis will when will go step by step, and what will do that each very step or every line please try to understand for this load flow studies, as much as possible from my side I will try. So, load flow analysis or power flow studies commonly referred to as the load flow, right. Essential for power system analysis and design both right.

(Refer Slide Time: 05:16)



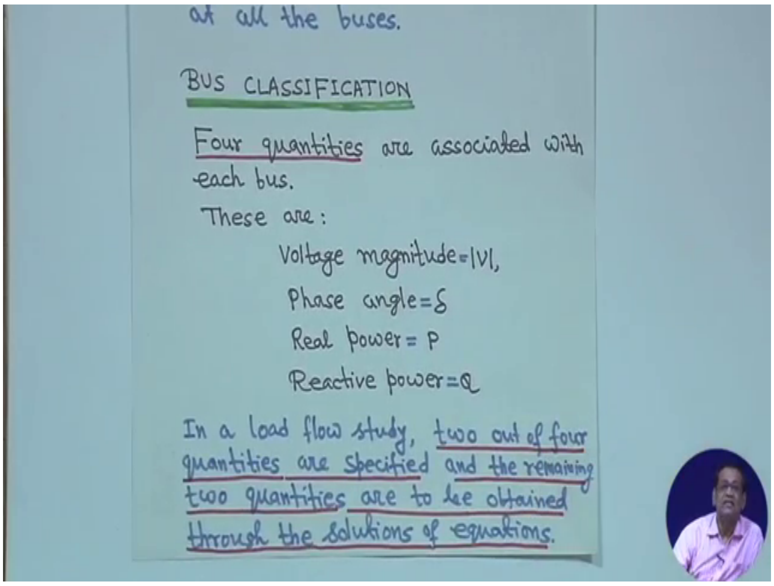
So, basically load flow studies are necessary that planning economic operation scheduling and exchange of power between utilities, your you need that load flow thing, right. Apart from this load flow or power flow is also required for transient stability that small signal stability sometimes will call dynamic stability, contingency and state estimation right. So, everywhere that load flow is requiring, right. And note voltage method is commonly used for power system analysis right.

(Refer Slide Time: 05:52)



Therefore this load flow results give the, what it will give? It will give you the bus voltage magnitude, right. Then it will give your voltage phase angle that is the voltage angle. And then power flow it will be through the transmission line losses you can compute. And the power injection at every bus bar, right. That also you can compute. So, and whenever we do So we have to, we have to see that how we can make it right; so basically in load flow that you have to first classify the bus the bus classification.

(Refer Slide Time: 06:31)



So, basically 4 quantities are associated with each bus right. So, these are actually voltage magnitude, this is voltage magnitude that V then phase angle your delta, and real power is equal to P and reactive power is Q, right. Therefore, in a load flow studies at least 2 out of 4 quantities are specified, right. At least 2 you have to specify and the remaining 2 quantities are to be obtained through the solutions of equations right. But let me tell you, this are the common thing that, we have a slack bus will come to that you have a your what you call P Q bus you have P Q bus, right.

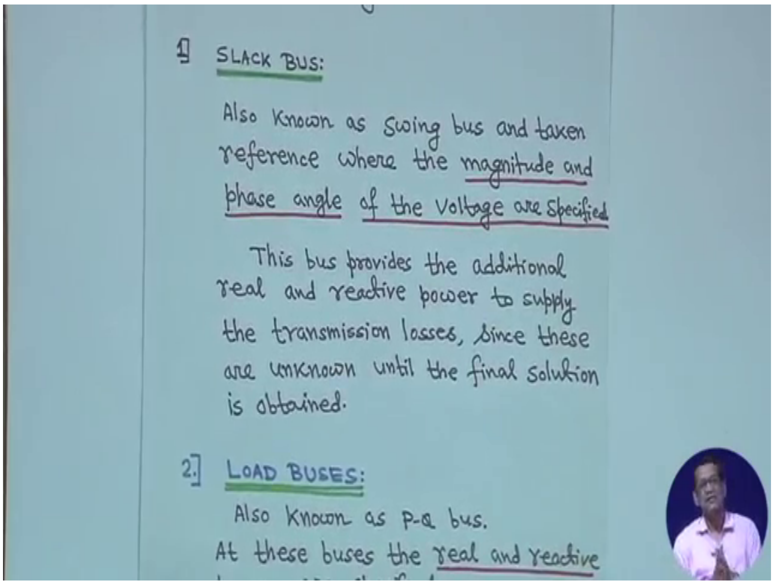
Apart from that nowadays as electrical engineering is changing, right. Because of that smart grid micro grid and renewable energy sources particularly solar you know, and other types of sources, right. That dispatchable diseases and non dispatchable disease all are coming and in your heavy power injection to the power network. So, that is why many cases that apart from this many other type of buses are being introduced right.

P and P Q bus P Q bus is one thing answer other also you can make it, right; as per your requirement. So, for example, if you make if suppose, suppose for although at third year level or even at PG level also this is not this may not be very familiar with you for say, when distribution network, actually working your under eye landed mode. That is it is not connected to the grid right. So, at that time you will find load flow is a different, right. A load flow is completely different and at that time that particularly that dispachable disease like your say biomass disease or diesel generator, one has to consider that droop characteristics right.

So, in that case that Jacobean matrix whatever will see in the load flow studies it will become the function of what you call that frequency also, right. That Jacobean matrix and in that case of course, you can follow the same Newton-Raphson method, but with lot of modifications right. So, thing such changing and electrical engineering also changing particular the power system engineering is changing like anything, right. Because of this smart grid and micro grid although those things are beyond the scope of this course, but I am giving you some hint of this one and for distribution power flow although Newton-Raphson method works well couple of your couple Newton-Raphson method it works very well, but at the same time some other types of load flow techniques also available for distribution network.

Because distribution networks actually mostly it operates your radially, right. I mean a and your what you call transmission message network move it is actually messed distribution messed network right.

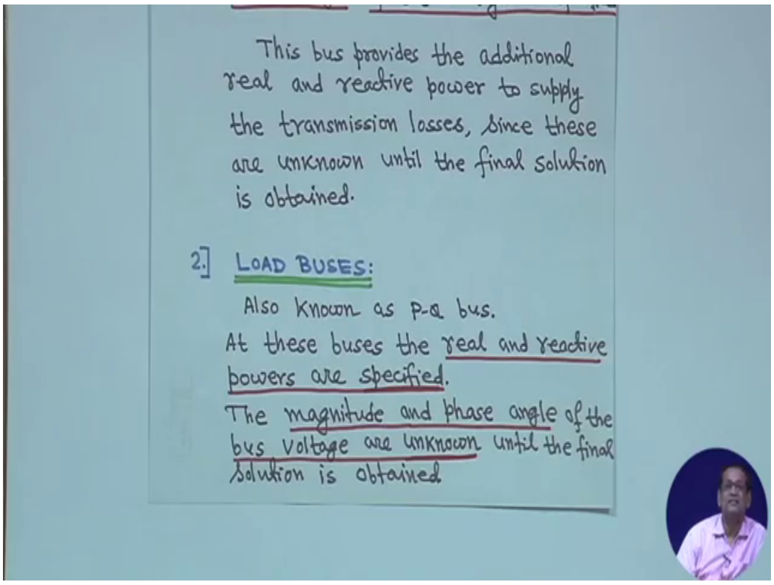
(Refer Slide Time: 09:43)



So, 4 volt 4 quantities for load flow studies will basically handle. The system buses or classified one is first one is that that slack bus. This is sometimes also called the swing bus and taken reference, when the magnitude in this bus actually voltage magnitude and phase angle this 2 are specified, right. And I told you, that your what you call that here you are taking slack bus, but when we are coming to your what you call that, sometimes for micro grid, DC micro grid there we can also see that your slack bus free actually, right. Anyway, those are beyond us scope. So, this bus provides the additional real and reactive power to supply the transmission losses. That is the slack bus we have to choose our reference bus and result will come around that your what you call that slack bus, right.

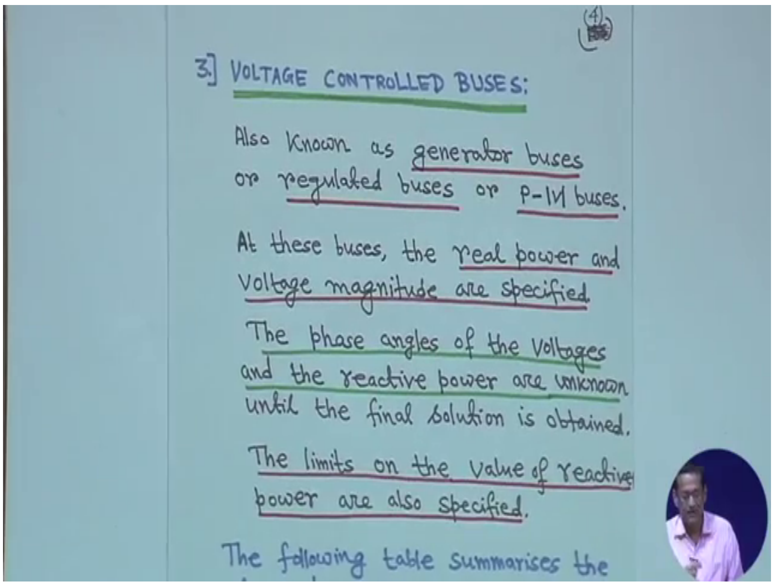
Since these are unknown until the final solution is obtained. Because these slack buses actually provide the additional real and reactive power to supply the transmission losses and these are known until the final solution is obtained because unless and until your solution load flow solution has converted, you cannot do anything, right. You cannot compute a loss also.

(Refer Slide Time: 10:58)



Now, another thing is load bus, sometimes we call this one as a P Q bus; that means, load bus P Q bus means that at that load that P and Q both are specified right; that means, in that bus you will find that power injection P and Q both are known, right. That that and that and magnitude of the voltage of this bus and it is phase angle this 2 are unknown quantity and you will be knowing only when you will solve this load flow this thing in iterative way right. So, unless and until you final solution is not obtain I mean obtained you will never be knowing the magnitude and voltage angle, but P and Q both will be your what you call this thing are this thing specified at the load bus right.

(Refer Slide Time: 11:51)

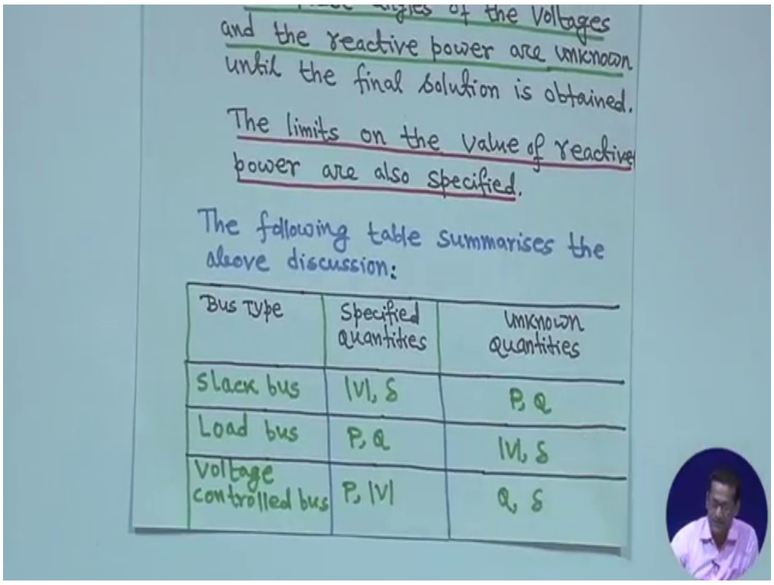


Then another bus is called voltage controlled buses or P V bus, right. Here that real power is known P is known and voltage magnitude is known. That is why we are this is called sometime this is called generator buses or regulated buses or simply P V buses, P I put magnitude V buses because P is known and voltage magnitude is also known for this bus then, what is unknown? Q is unknown and what you call that voltage angle it is unknown, right. This 2 are unknown; that means, at P V buses, right.

That what you call that voltage magnitude of that bus you want to maintain, right. As P is known voltage angle is not known, but Q is unknown right; that means, at that bus you have to inject that reactive power such that you can maintain this voltage magnitude V for that bus. So, this is called sometimes we call P V bus, right. Or generator buses or regulated buses right.

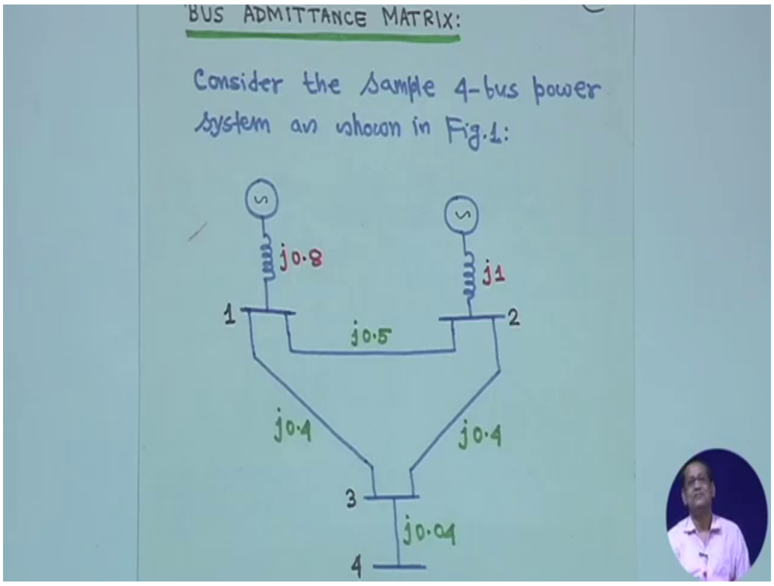
So, in that case that as Q at P V buses Q is unknown; so we have to also set the limit on the Q injection that is some minimum value to maximum value. But let me tell you one thing, as it is a classroom exercise. So, taking Q min Q max all sort of things it is difficult to put in the classroom you one need code computer code one has to write, and one should see observe what is happening? But in this case, in this thing it will take it will take I think few hours to explain all sort of thing, but I will try to I will take throughout this load flow studies, I will take only one example and give all sort of your what you call a this thing methodology right. So, Q limit also you have to consider and it has to be specified for P V buses right.

(Refer Slide Time: 13:48)



Therefore the following table summarizes the above discussion right. So, bus type it is slack bus voltage magnitude and delta both are known that is specified unknown quantities are P and Q. For load bus P and Q are specified right, but voltage magnitude and delta these are unknown quantities. And voltage controlled bus that is P V s, right. P and voltage magnitude real power and voltage magnitude are specified, but Q and delta are not known right. So, with this in our mind slack bus P Q bus and P V bus now will move to see that first the bus admittance matrix right.

(Refer Slide Time: 14:36)

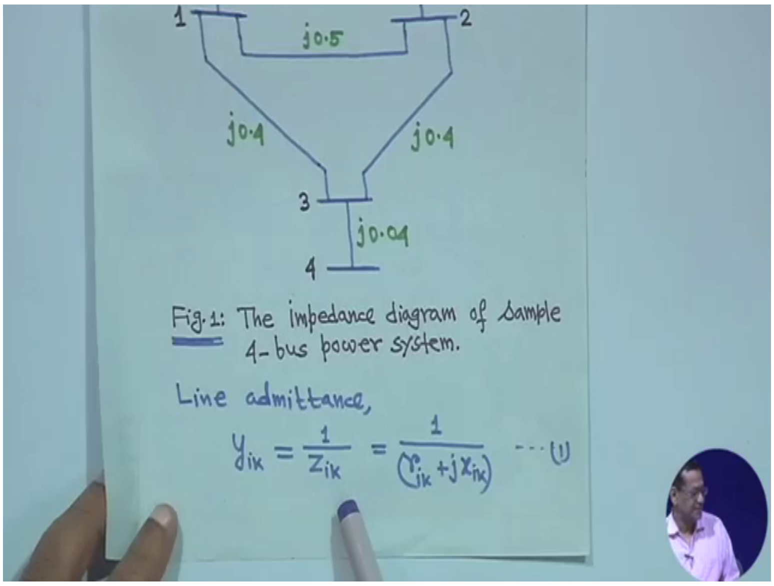


So, in will go for bus admittance matrix I will explain everything, but I put the question to you for load flow studies we use y matrix. But not z matrix that is admission admittance matrix we use, but we do not use your impedance, right; matrix, right. Z we do not do, we make admittance for the full sane. Why we do not use z bus for load flows?

This is a simple question to you and answer also will be simple. So, this should be keep it in your mind, right. Now what will do for bus admittance matrix, we consider this your what you call this sample 4 bus power system. This is a 4 bus power system, right. This is this is one generator this is one generator, right. And for purpose of class classroom exercise what we have done is that R we have not considered, but when will when will consider what you call numerical at that time will take R, but here you do not want to complicate the things.

So, only reactance is what you call consider right. So, this is a this is your suppose generator one, 2 whatever is given and this is your j 0.8 everything you assume it is per unit. So, this j 1, this for line one to j 0.5 j 0.4 j 0.4 and line 3 to 4 j point, I think it is your this thing j point 0 4 right. So, this is the, this is the sample power system 4 bus power system we have taken, and this is the impedance diagram, but we have not considered your what you call that resistance right.

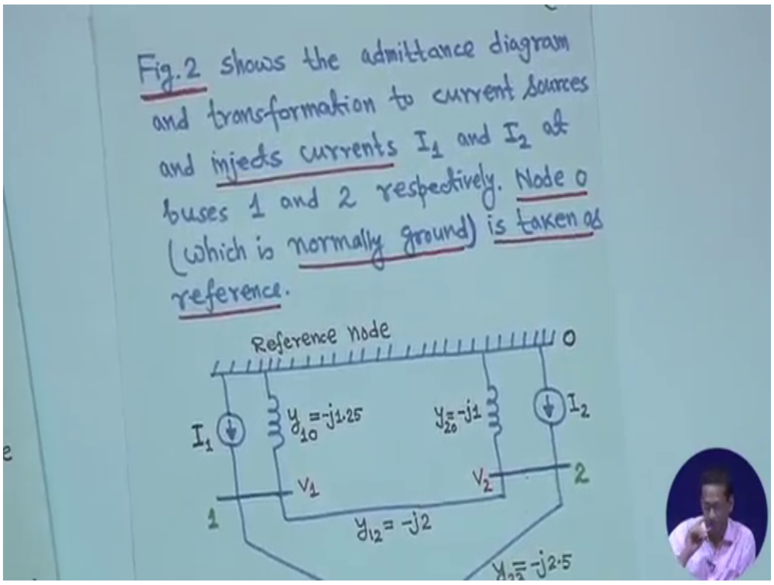
(Refer Slide Time: 16:18)



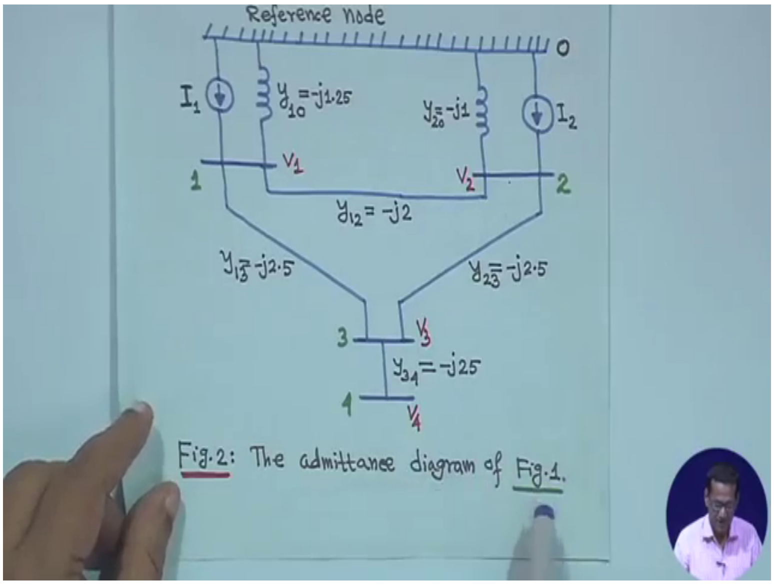
So, generally as you know from your this thing, that line admittance actually for line i 2 k bus i 2 k small y i this is like the small y i k is equal to 1 up on z I. K, right. This small z i k.

Is equal to 1 up on r i z i k is equal to r i k plus j x I k this is equation 1, right. This is the admittance, right. Now what we will do? Why we have taken this everything this 2 sources, right. This 2 1 you transform in to what you call that current source right. So, instead of instead of this 2 generators are given right. So, instead of voltage one you transform in to a current source right. So, if you do so, look at this is the diagram, this is the diagram.

(Refer Slide Time: 17:05)



(Refer Slide Time: 17:08)



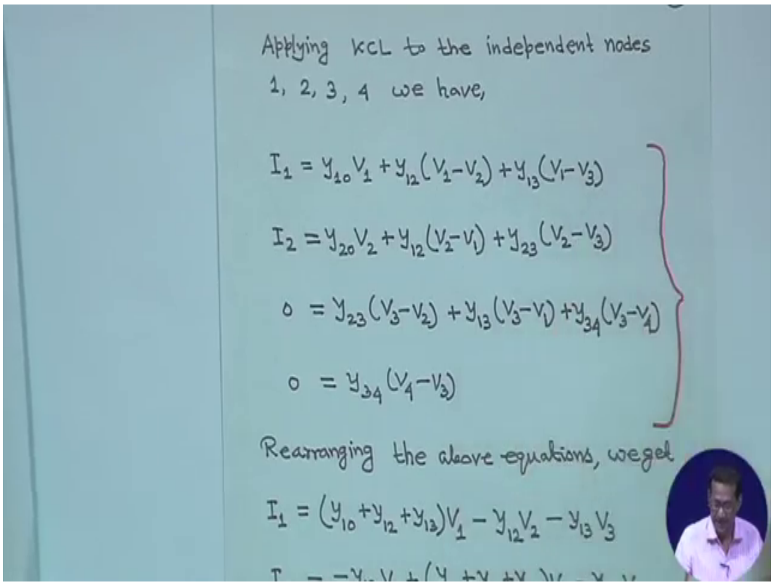
If you look So, though figure 2 look this it shows that your what you call the admittance diagram. In that case what you have to do is that you take a reference node. This node number is given as a 0, and this basically it is a ground and exponential is it is at 0 potential right; that means, and this 2 sources have been converted to current source. So, this is your current I 1 injecting your this current I 1 getting injected here and current I 2 from this side getting injected here and all this all this your reactance thing has been converted to admittance; that means, it was an as it is a current source. So, this will be it is in parallel so; that means, it is j 0.8. So, 1 upon j 0.8 is equal to your y it is making as 1 0 minus j 1.25 this is 0 node this is one node, that is why writing 1 0 minus j 1.25 right

And this is j 1; so 1 upon j 1 that is minus j 1, so, y 2 0 that is 2 to 0 y 2 0 minus j 1, right. And this is I 2 this current is getting injected, right. And this line 1 to 2 voltage here 1, 2, 3, 4 voltage are marks at V 1, V 2, V 3, V 4 this are the complex voltage, right. And this is 1 to 2 the reactance is j 0.5, right. Or impedance you contain R is neglected, that is 1 upon j 0.5 that is minus j 2. So, admittance y 1 2 is equal to minus j 2 is equal to y 2 1, they are same, right. Similarly 1 2 3 is j 0.4. So, admittance is 1 upon j 0.4; so minus j 0.25. So, this is minus j 2.5, right.

And similarly here it is also 0.4 j 0.4 it is also minus j 2.5 and here it is j 0.04. So, 1 upon j 0.04, that is minus j 25. So, this diagram this one actually, transform this 2 sources transform in to current source and all the impedance diagram I have been transform in to admittance diagram, right. So; that means, this is an one reference node is required and this is your what you call this is your normally it is a ground and you can take it as a 0 potential, right. And this is the admittance diagram of figure one that is this is figure 2. I hope this is very easy to understand actually not much is there right.

Next is you have to apply KCL to the independent nodes 1 2 3 4 right. So, look this is this current is getting injected here I 1 if you write if you apply KCL, right. At this bus bar I 1. So, what will be your equation, right? I 1 should be is equal to if this voltage is V say 0 potential. So, if I make V 0 is equal to 0, and this current is getting injected and you take all this current out then, I 1 is equal to your first before my writing I 1 is equal to this take out; so y 1 0 V 1 plus y 1 2 in to V 1 minus V 2 plus y 1 3 in to V 1 minus V 3. But everywhere your y I j or y i k is equal to Y k i I mean it both are same. Y 1 3 is equal to y 3 one, small y of course, small y this one, small y 1 2 is equal to small y 2 1 and small y 2 3 is equal to small y 3 2 small y 3 4 is equal to small y 4 3.

(Refer Slide Time: 20:53)



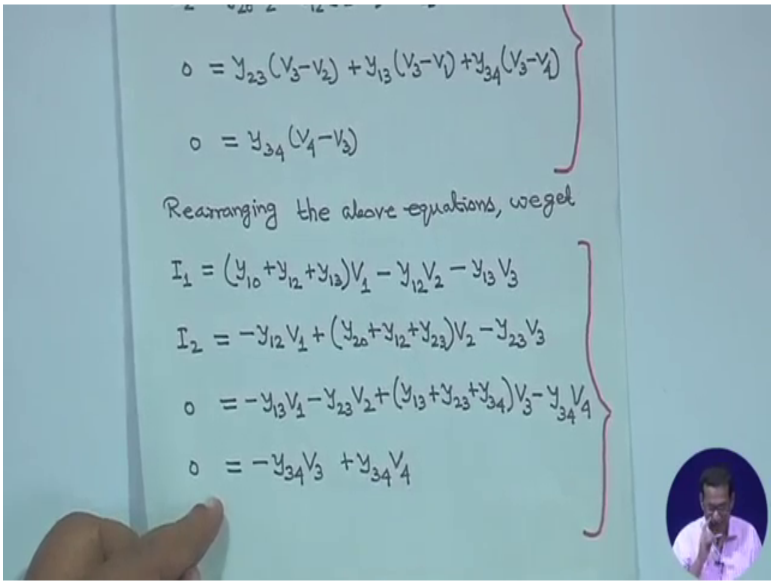
That means, this current at this one I 1 is equal to y 1 0 V 1, this thing then you take this one and plus y 1 2 V 1 minus V 2 y 1 2 V 1 minus V 2 plus y 1 3 V 1 minus V 3 y 1 3 V 1 minus V 3, right. No equation number. Similarly, for this one I 2 is equal to your y 2 0 V 2 minus I told you this 0 potential, so basically y 2 0 V 2 minus 0 basically y 2 0 V 2. So, it is y 2 0 V 2 plus your y this current that y 1 to y 2 1 same. So, I will write y 1 2 only y 1 2 in to V 2 minus V 1 because current leaving from this 2 to one. So, V 2 minus V 1

So, y 1 2 V 2 minus V 1 because y 1 2 2 1 same. So, I am not writing 2 1 understandable right; so V 2 minus V 1 plus 2 to 3 so y 2 3 V 2 minus V 3. So, here it is y 2 3 V 2 minus V 3 this is the second equation for the second bus bar, right. Now third bus bar here there is no current injection, this bus bar and this bus bar. Because in this diagram in this diagram it is it is nothing was given. So, no current injection; that means, 0 right; that means, this; that means, 0 is equal to for the bus 3 you take all the outgoing current, right.

For example, your y 2 3 in to V 3 minus V 2 V 3 minus V 2 y 2 3 V 3 minus V 2 then, y 1 3 V 3 minus V 1, because y 1 3 is equal to y 3 1 so V 3 minus V 1. So, it is taken y 1 3 V 3 minus V 1. Then you take this outgoing one that is y 3 4 V 3 minus V 4 plus y 3 4 V 3 minus V 4 and no current injection here. So, it is 0 is equal to this one this is the third equation. Now fourth one when you come here, this bus bar 4, right. Current injection is 0, right. And this is and if you take that 4 2 3. So, it is y 3 4 V 4 minus V 3. So, 0 is equal to y 3 4 V 4 minus V 3. So, for the all bus 4 1 2 3 4 you have got this 4 equation sets of equation for the time being not putting any equation number. So, this one from this diagram, from this diagram you have got we have got this one this we have understood very easy right.

And from this you write down all this equation in terms of admittance, right. Line admittance, charging capacitance will come later first you understand this.

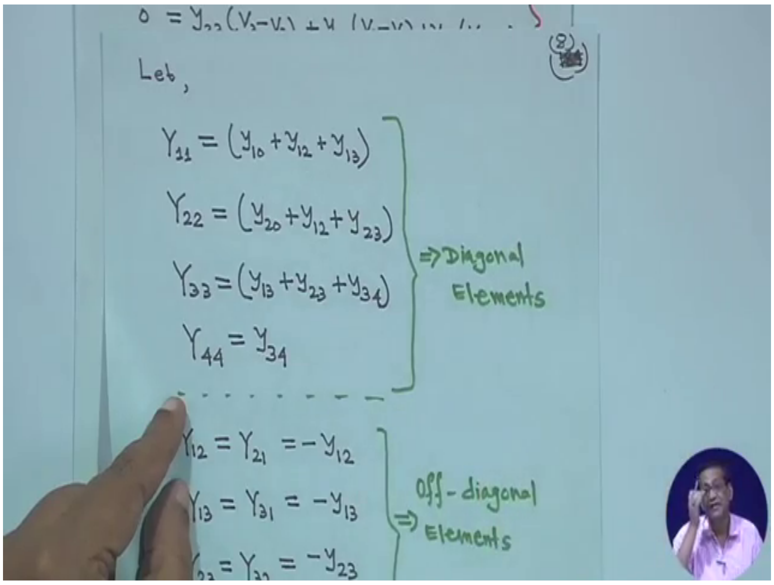
(Refer Slide Time: 23:33)



Now, rearrange this all this 4 equation above equation; that means you collect all the terms to V 1 V 2 and V 3. So, I 1 you can write y 1 0 plus y 1 2 plus y 1 3 in to V 1 I mean this equation we are rewriting then minus y 1 2 V 2 minus y 1 3 V 3. Similarly this one also you can write I 2 is equal to minus y 1 2 V 1 plus y 2 0 plus y 1 2 plus y 2 3 V 2 minus y 2 3 V 3, right. Then this one you can write the third one, that 0 is equal to minus y 1 3 V 1 minus y 2 3 V 2 plus y 1 3 plus y 2 3 plus y 3 4 V 3 minus y 3 4 V 4, right.

And last one 0 is equal to this one minus y 3 4 V 3 plus y 3 4 V four; that means, we are arranging V 1 V 2 V 3 V 4 this way right. So, this is I 1 I 2 this is 2 current injection 0. So, variant, but no equation number is given, right. Once it is done then you define for example, for example, that you define capital Y 1 1 capital Y 1 1 is equal to y 1 0 plus y 1 2 plus y 1 3.

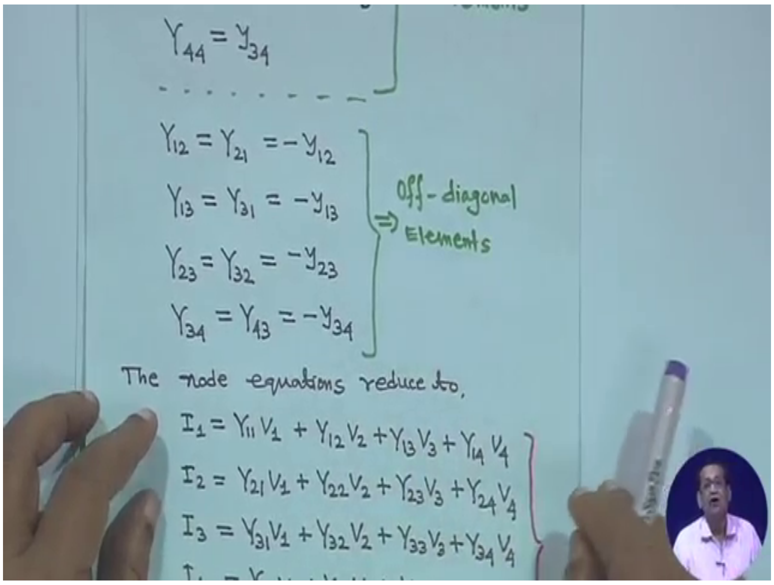
(Refer Slide Time: 24:57)



So, write capital Y 1 1 is equal to y 1 0 plus y 1 2 plus y 1 3. This was capital Y 1, right. Similarly first diagonal elements you define then y 2 2 this one. Capital Y 2 2 you write y 2 0 plus y 1 2 plus y 2 3. So, capital Y 2 2 is equal to y 2 0 plus y 1 2 plus y 2 3, this are only diagonal elements we are writing, right. Then third one this y 3 3, this is y 1 3 plus y 2 3 plus y 3 4 the third one. That is your y 3 3 is equal to y 1 3 plus y 2 3 plus y 3 4, right. And this y 4 4 is equal to the last one, y 4 4 is equal to y 3 4. So, capital Y 4 4 is equal to y 3 4 these are all diagonal elements right.

Next you make off diagonal elements. Off diagonal elements this one whatever we have from this for this equation that y 1 2, right. This is y 1 2 capital Y 1 2, you define and y 1 2 is equal to 2 1 you write capital Y 1 2 is equal to capital Y 2 1 is equal to minus y 1 2.

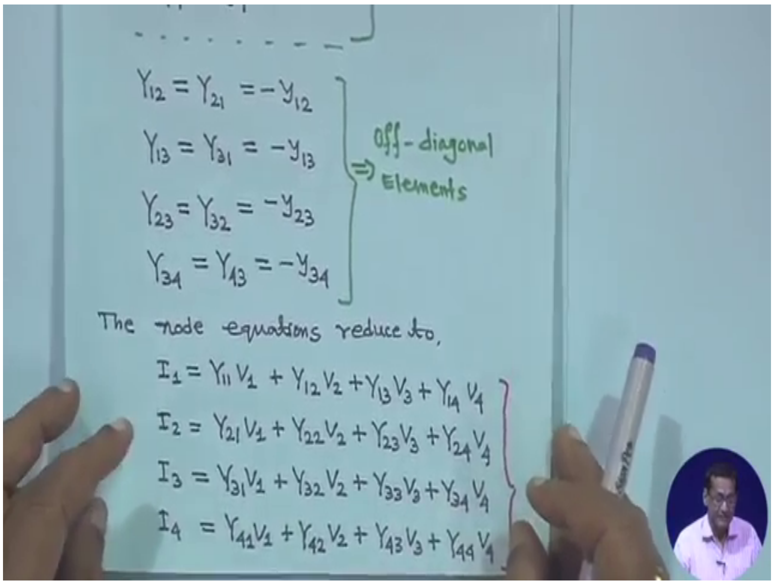
(Refer Slide Time: 26:00)



Similarly, this is V 3. So, it is one 3 right. So, capital Y 1 3 is equal to capital Y 3 1 is equal to minus small y 1 3. So, capital Y 1 3 is equal to capital Y 3 1 is equal to minus small y I 1 3, right. Similarly you come to the next is the 2 right. So, y 2 3. So, your what you call this is a symmetric matrix.

So, y your what you call y 1 2 y 2 1 will minus y 1 2 here also 2 2 1 capital Y 2 1 will be minus y 1 2 symmetry. So, that is why it is what you call this y 2 1 is minus y 1 also 2, right. It is symmetry matrix then 2 2 2 3 capital Y 2 3 will be is equal to capital Y 3 2 is equal to minus small y 2 3. So, capital Y 2 3 is equal to y 3 2 is equal to minus y small y 2 3, right, and then y 3 4, right. You your come to this one this are symmetric matrix. So, directly you will come here y 3 4 capital Y 3 4 is equal to capital Y 4 3 is equal to minus small y 3 4. So, capital Y 3 4 is equal to capital Y 4 3 is equal to minus small y 3 4. So, this are all our off diagonal elements right.

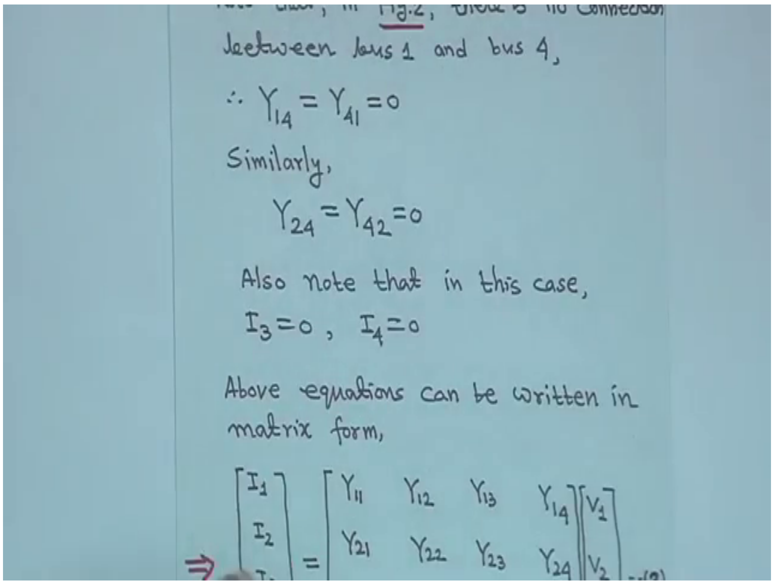
(Refer Slide Time: 27:23)



Now So, now when you write this equation you write like this, I 1 is equal to capital Y 1 V 1 1 plus capital Y 1 2 V 2 plus capital Y 1 3 V 3 plus capital Y 1 4 V 4. This way you write some of them why you will become zero, but make it like this, right. I 2 is equal to similarly again and again not again and again, I am not uttering that capital understandable; so y 2 1 V 1 plus y 2 2 V 2 plus y 2 3 V 3 plus y 2 4 V 4, right. Similarly I 3 I 3 actually 0 I 4 actually 0 some of the voice elements are also zero, but we make it like this first.

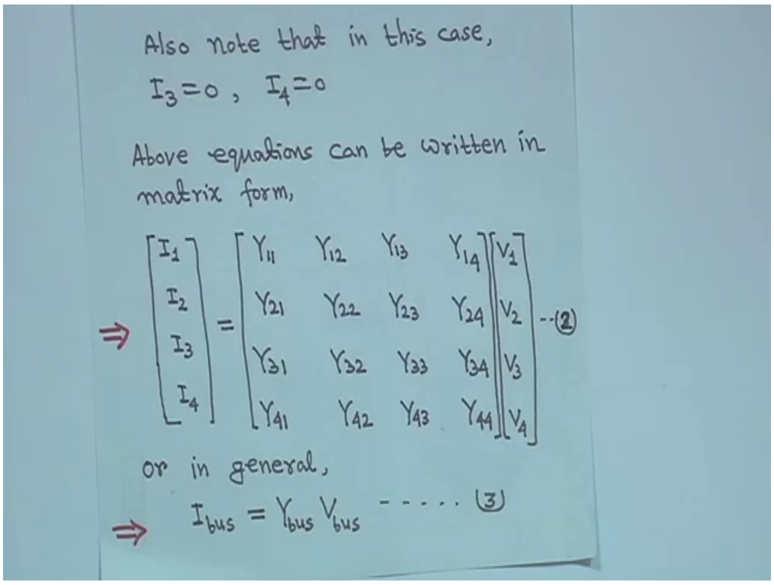
So, I 3 is equal to y 3 1 V 1 plus y 3 2 V 2 plus y 3 3 V 3 plus y 3 4 V 4, right. Similarly I 4 is equal to y 4 1 V 1 plus y 4 2 V 2 plus y 4 3 V 3 plus y 4 4 V 4 this way first you make right, but now you see the connectivity of the line right.

(Refer Slide Time: 28:33)



So, but I 3 and I 4 they are zero, but we have to put them in matrix form so; that means, that your just one minute; that means, in that your in figure 2 there is no now there is no connection between bus 1 and bus 4. So, there is no connection between 1 and 4. So, actually y 4 is equal to y 4 1 is 0 similarly there is no connection between 2 and 4, right. That is why 2 y 2 4 actually y 4 2 will be 0 and at this node I 3 and I 4 actually 0. So, also note that in this case I 3 0 I 3 I 4 0. So, in this equation in this equation I 3 I 4 will be 0 and other 2 elements of why I told you that also will be 0, right; so but for the sake of your mathematics and completeness.

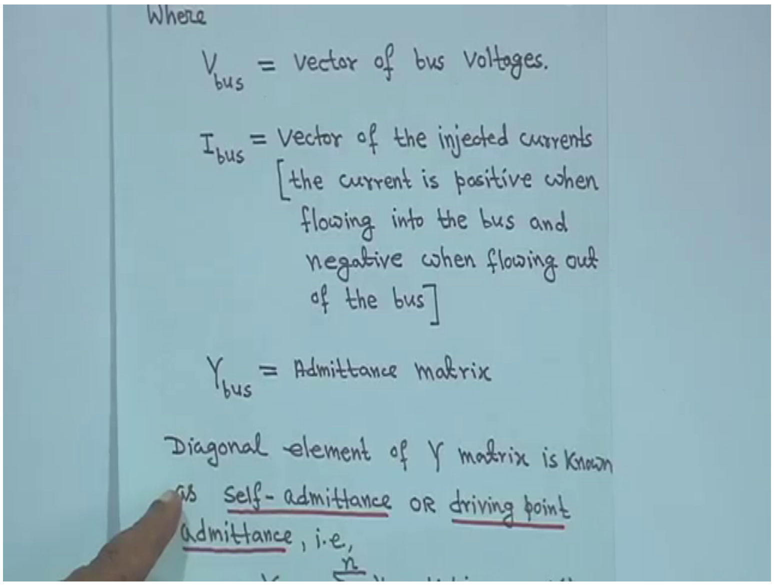
(Refer Slide Time: 29:22)



We have to make this equation I 1 I 2 I 3 I 4 is equal to this is y matrix V 1 V 2 V 3 V 4, right. And this is actually just hold on just one minute this y i k equation actually 1 upon z i k this actually equation 1, right. And this equation your I 1 I 2 I is equal to basically y V this equation actually equation 2 or in general you can write it that I bus, this is the bus current injection I bus is equal to y bus this is that bus admittance matrix y bus in to V bus this is the bus voltage right.

So, this is actually equation 3. So, we represent this equation basic in general I is equal to y V right.

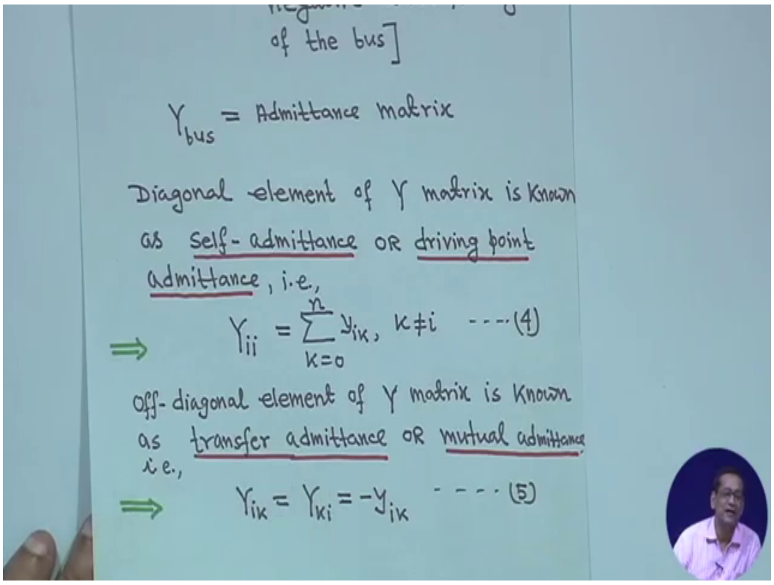
(Refer Slide Time: 30:14)



So, V bus now we are giving the nomenclature. V bus is equal to vector of bus voltage V 1 V 2 V 3 and up to V 4, right. And I bus is equal to your vector of the injected currents, right. That is I 1 I 2 I 3 I four, but later will see when you will form the Jacobean that when you choose one bus is slack bus that voltage is known, right. In that case you will see Jacobean matrix and other things will be how it how it we one can form, but this is the preliminary thing. So, y bus that I bus is the vector of injected currents right. So, the current is positive when flowing in to the bus and is negative when flowing out of the bus the convention will follow. And y bus is equal to that bus admittance matrix right.

So, diagonal elements of y matrix actually is not known as self admittance or driving point admittance right.

(Refer Slide Time: 31:06)



That diagonal elements that is that y 1 1 y 1 2 y 3 3 and y 4 4, this elements diagonal known as self-admittance or driving point admittance, right, that is in general in general capital Y I is equal to k is equal to 0 2 n you write y i k, but k not is equal to I right; that means, in that case also if you take your what you call that your including the reference bus that is 0 to four; that means, we expand y 1 1 y 2 you will get the same thing right. And off diagonal elements of y matrix is known as transfer admittance or mutual admittance that s i y capital y i k is equal to capital Y k i is equal to minus small y i k, right this minus sign for small one because this is each your branch admittance 1 upon z i k.

So, that is capital y i k is equal to capital Y k i is equal to minus small y i k and this is actually equation 5. And this y 1 this y I actually k is equal to 0 2 n is taken and it is y i k, but k not is equal to I such that, and later much detail I will explain when you will take this, right. And in to and when you will if you if you that row wise y matrix later when we will consider charging admittance when you will when you will add the elements of a particular row of y matrix at that time you really something else right. So, from that you can check out whether your y matrix is construction is correct or not. So, this is that general thing.

Thank you, again we are coming.