Power System Analysis
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Lecture – 47
Three phase fault studies (Contd.)

So how this is coming I am writing one line.

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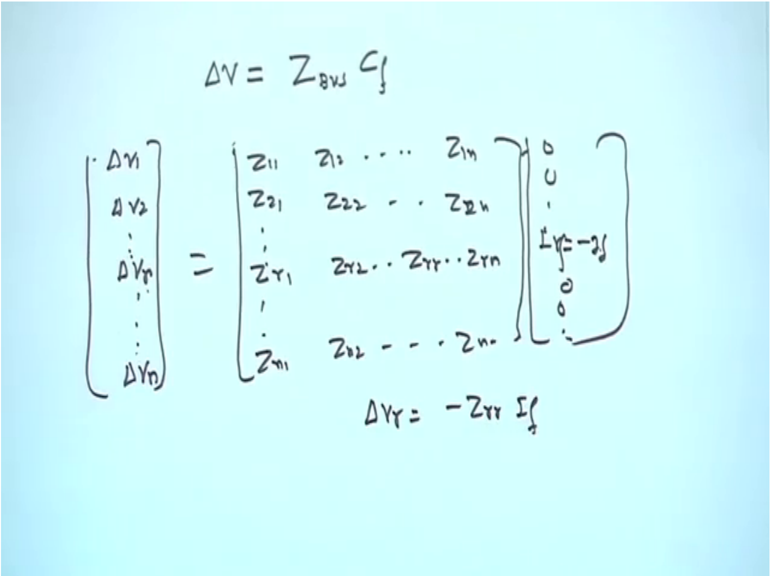

For you that this equation we have taken you know 2 b equation delta V is equal to your Z bus that is C f right. So, delta V actually what delta V 1 delta V 2 then delta V r say r th bus then delta V n right and is equal to this is Z bus. So, Z 1 1 Z 1 2 then Z 1 n then Z 2 1 Z 2 2 Z 2 n right if you come to r th bus. So, it will be Z r 1 Z r 2 somewhere that element Z r r will come then Z r n right then your last your last one that Z n 1 Z n 2 then Z n n right and this fault current C f all are 0es except that r th bus i r is equal to we have taken that you are what you call i r f, i r f is equal to minus I f right and all are all are 0s all are 0s. So, when you take this your delta V r all will be this thing only delta V r will become your this is minus i f. So, minus Z r r in to I f right that is why we are writing delta V r is equal To minus Z r r in to I f this is equation 5 right.

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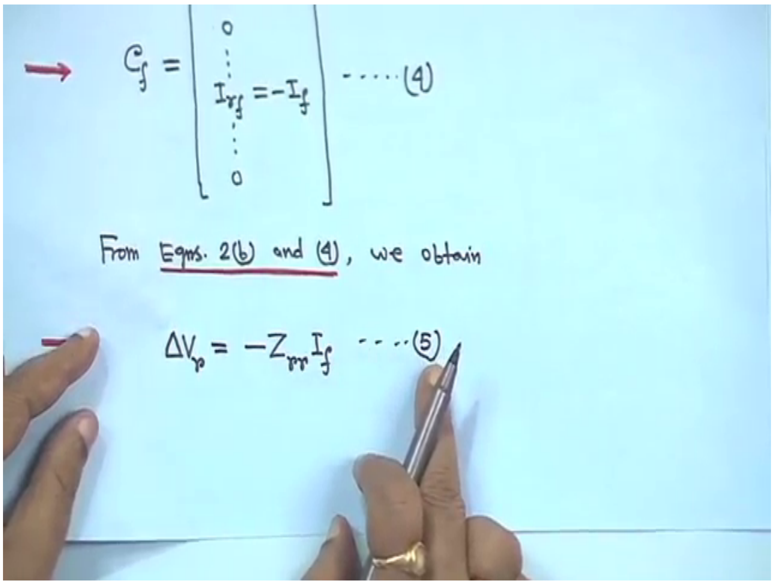

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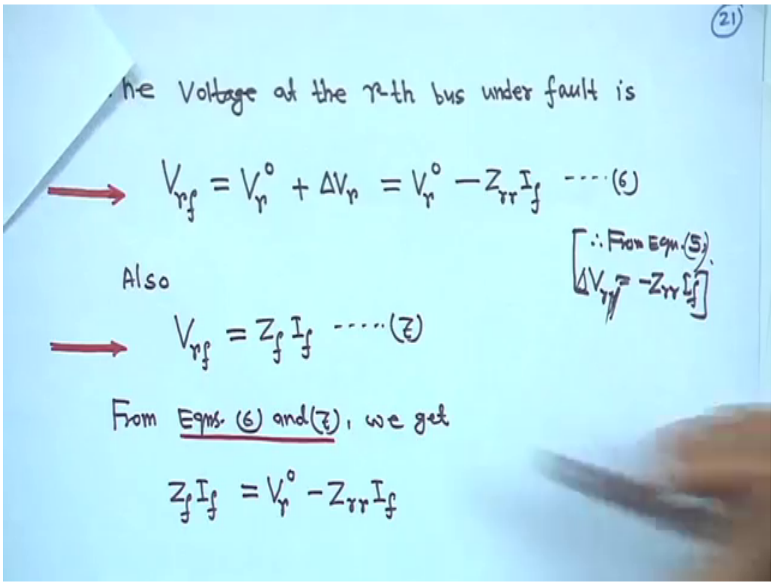

So, now that means, that that; that means, this just hold on; that means, the voltage at the r th bus under fault that is V r 0 V r f rather V r f is equal to pre fault voltage V r 0 plus delta V r whatever changes ground right is equal to V r 0 minus Z r r I f this is equation 6, right also V r f is equal to Z f in to I f from this from this diagram right from this diagram from this diagram right.

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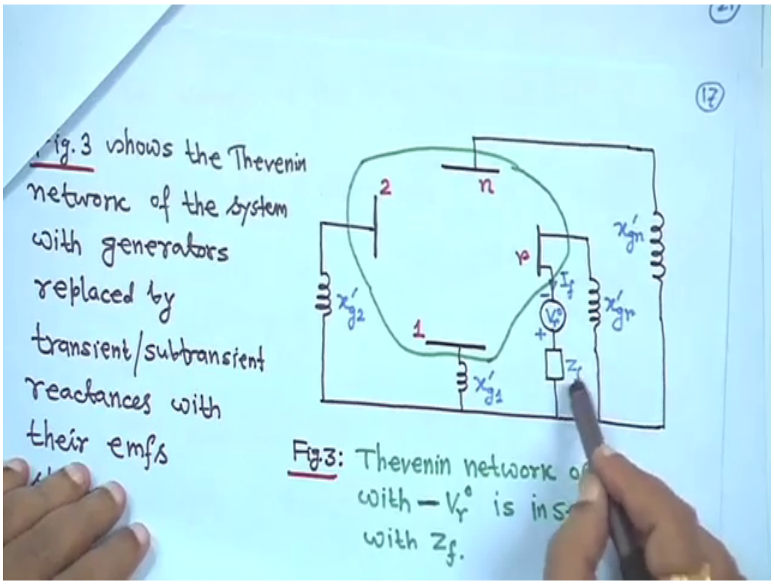

Your; if you write from this diagram that V r f that fault current is I f and this is Z f. So, V r f will be Z f in to your this thing what you call I f right.

So, that is why we are writing Z f in to I f from this diagram only from here only right; that means, your then equation 6 and 7, but V r f is equal to V r 0 minus Z r r i therefore, this V r f that is Z f I f is equal to V r 0 minus Z r r I f right; that means, your this come to next page; that means, your; from this equation only you can get that I f is equal to V r 0 up on Z r r plus Z f right.

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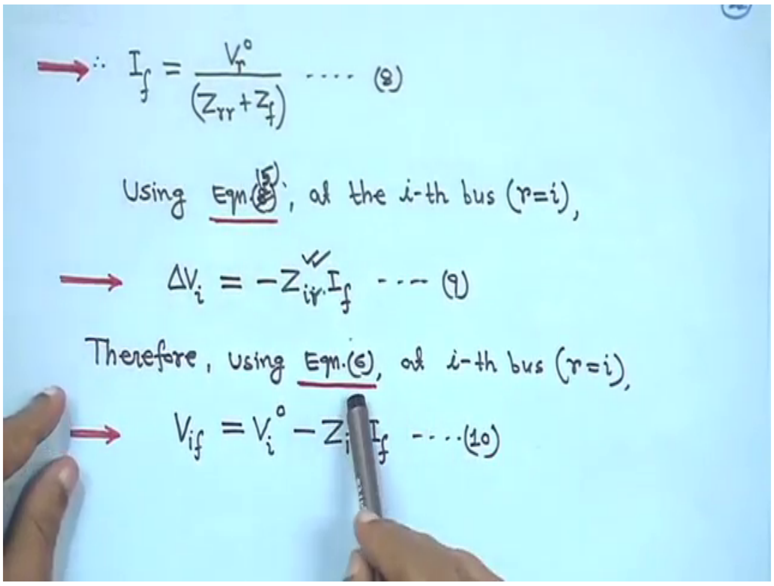

This is equation 8; now using equation 5 at the i th bus when r is equal to i at equation 5 we put look that equation was given delta V r is equal to minus Z r r I f, but at the i th bus put r is equal to i do not it is given Z your delta V i is equal to your minus your Z r r I f, but please do not put both the r you do not replace both i by r or r by i. So, only r is equal to i. So, that equation will become delta V i is equal to minus Z i r right do not make Z i i then it will be mistake minus Z i r in to I f this is equation 9 right; therefore, equation 6 using equation 6 at i th bus when r is equal to in equation 6 you put r is equal to i right; that means, in this equation in this equation you put r is equal to i right. So, in that case your V i f will become V i 0 minus Z i r in to I f this is equation 10 right; that means, form equation 10 and 8 right from equation 10 and 8 that I f is equal to V r 0 up on Z r r plus Z f this one you substitute here this one you substitute here.

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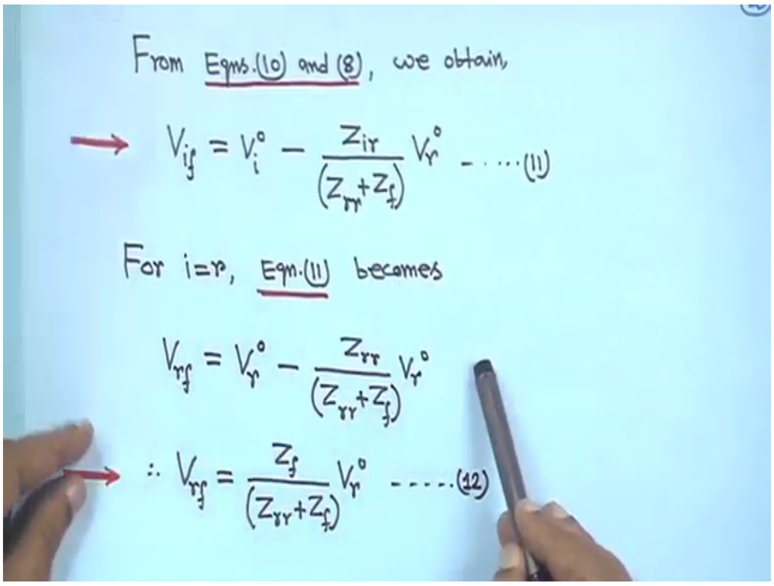

If you do so, then you will get your V i f is equal to V i 0 minus Z i r up on Z r r plus Z f in to V r 0 this is equation 11 and in equation 11 you for i is equal to r when i is equal to r you put it here. Therefore, you will get V r f is equal to V r 0 minus Z r r up on Z r r plus Z f in to V r 0 or simply simplifying this one V r f is equal to Z f up on Z r r plus Z f in to V r 0 this is equation 12 right. So, this are all your; all this fault calculation for a large network right.

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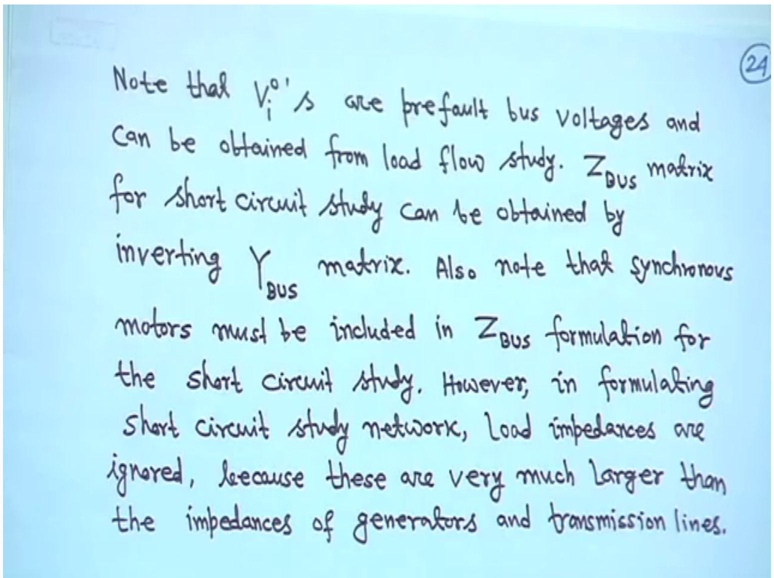

So, this thing; that means, you note that that V i 0s right are pre fault bus voltages and can be obtained from the load flow study and Z bus matrix for short circuit study can be obtained by inverting Y bus matrix right also note that synchronous motors also it must be included in the Z bus formulation for the short circuit studies right if it is there. However, in formulating short circuit study network right your short circuit study the load impedances are ignored because these are very much larger than the impedances of the generator and transmission lines right.

So, that load impedances are ignored right. So, these are what you call that this is a general thing that you have a power network fault has occurred at a particular bus bar and that all the all the generators e m f’s are short circuited by their your whatever you required why the reactances transient or sub transient right and for fault the bus for fault has occurred right.

So, you have to get a the venin equivalent. So, here you excite that one by pre fault that is pre fault voltage is there minus V r 0 in series with that your fault impedance right and accordingly all other calculations are same. That means, all this all that equivalent network that your current injection at the faulted bus will be there that is minus I f are or are rest of the buses there is no current or current injection is 0 based on that we got this one right.

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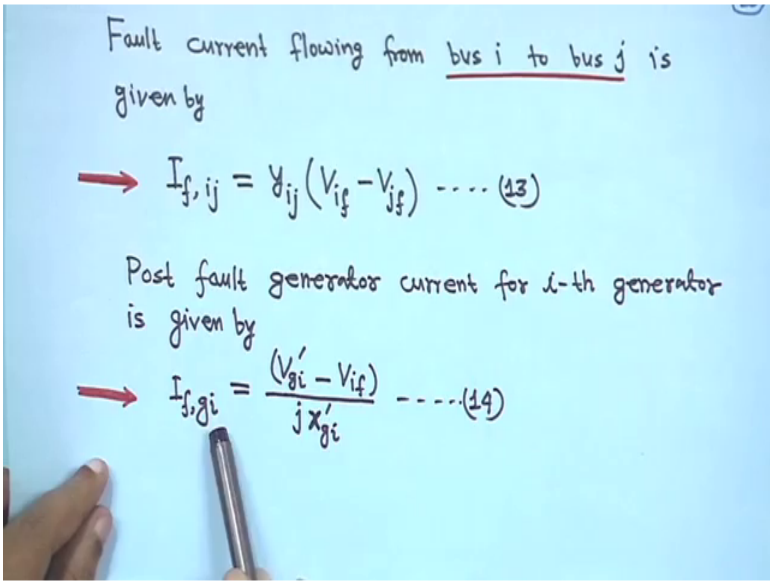

That means, that means this fault current flowing from bus i to bus i j that is i f i j is equal to Y i j V i f minus V j f if you know V i f if you know V j f then you can easily calculate and post fault generator current for i th generator in general I f g i V g i dash minus V i f up on j x g i dash this is equation 14 right. So, this way we can I mean this way you can go for your what you call that the venin equivalent and accordingly you can compute all the all the fault voltages and the current right now before going to the Z bus algorithm before going to the Z bus algorithm we will take one example for example.

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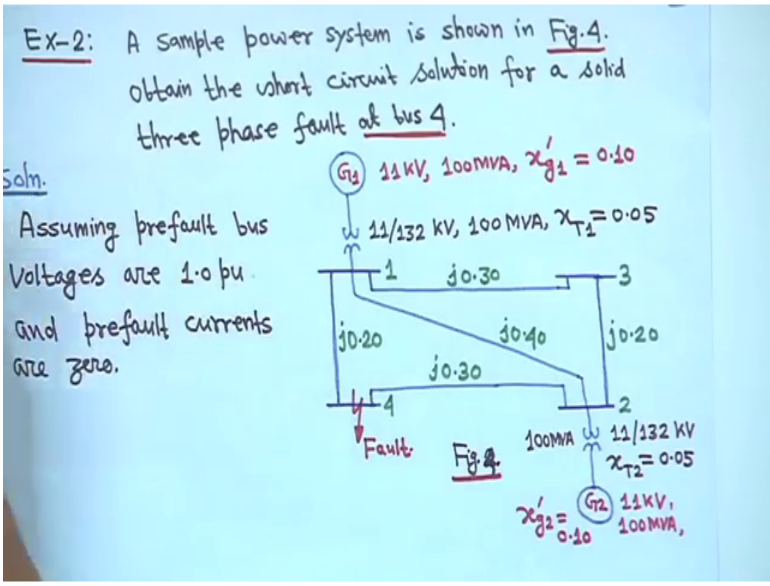

This one your what this is a network transformer is there is reactance is given generator is there x g 1 dash is given here also same rating 11 KV 100 MVA right the transform or reactance is given 0.05 generator is given x g 0.10 and this are all the line impedances are given resistance is neglected and bus fault has occurred at bus 4 right.

So, assume pre fault bus voltage all are one and pre fault currents are 0 right. So, this assumption we have to make and you have to find out your what you call that your short circuit your short circuit solution all this thing you have to get first thing is you have to obtain the Y bus. So, in this case this the you have to obtain the Y bus in this case what will happen we will compute the Y bus that suppose Y 1 1 it will be Y 1 3 it will be Y 1 2 it will be Y 1 4 plus that your another thing if you makes make some bus number Y 1 0 some bus number 0. So, this generator x g 1 dash and transformer t one this also you have to consider right; that means, you have to consider that 0.05 and 0.11 here there in say your what you call series.

So, 0.15; that means, your what you take this is impedance is given. So, you have to find out Y 1 3 Y 1 2 Y 1 4 plus say Y 1 0 right; that means, this 0.1 and 0.05 with that you construct the Y bus matrix right after constructing the Y bus matrix this matrix I have with me, but I am not giving you this matrix you construct and you will get Z bus is equal to Y bus inverse this is actually all Z's are given this will given now question is our object our interest is to get the Z bus matrix right.

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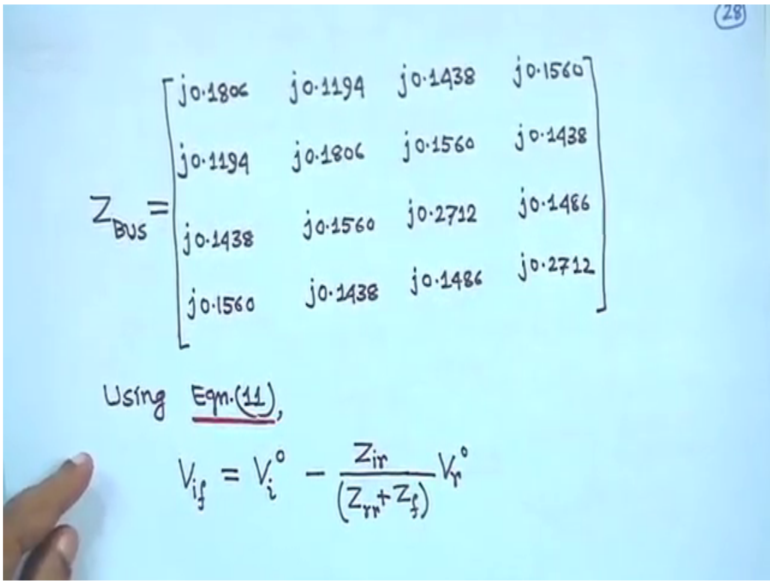

So, in this case in this case what will happen that Z bus actually it is a 4 bus problem it is a 4 bus problem. So, Z bus will be a 4 in to 4 matrix note that classroom we cannot do 4 in to 4 matrix inversion from Y bus it is not possible in the classroom we need computer. So, whenever we are giving numericals or problems this data will be provided right. So, whatever Z bus will come that directly data will be provided right otherwise one cannot solve the problem in the classroom, but when we take that you construct the Y bus and if you take the inverse right and for example, you convert Y bus then in mat lab it is a 4 in to 4 in matrix. So, Y was inversion we will get it will not be the nearer right and this is actually your Z bus it is a full matrix it is a Z bus right. So, Z 1 1 Z 1 2 this is Z bus so; that means, from here you all the Z elements will get for Z 1 1 Z 1 2 everything and it is a symmetric matrix right. So, using equation 11 that V i f is equal to V i 0 minus Z i r up on Z r r plus Z f in to V r 0 right. So, now, your all pre fault condition your just hold on all pre fault condition right your V.

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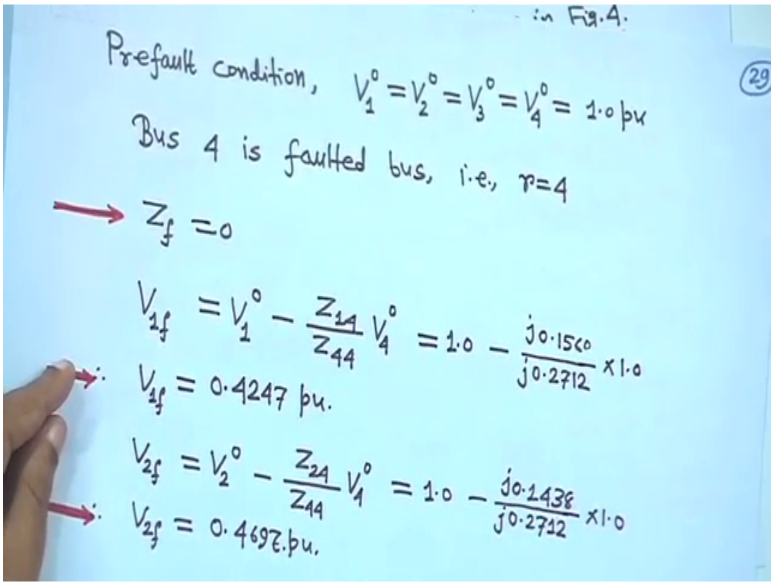

One is equal V 1 0 V 2 0 V 3 0 V 4 0 they all are one per unit and bus 4 is faulted that is r is equal to 4 that r th bus is a faulted bus; that means, fault impedance Z f is 0 because it is a solid fault we have taken. So, V 1 f is equal to V 1 0 minus Z 1 4 by Z 4 4 in to V 4 0; that means, this equation this equation in this equation you put i is equal to 1 2 3 4 right then you will get V 1 f is equal to whatever you substitute all this value whatever you will come 0.4247 per unit.

Similarly, V 2 f you will get V 2 0 minus Z 2 4 by Z 4 4 in to V 0 whatever it comes you will get 0.4697 per unit right similarly your V 3 f.

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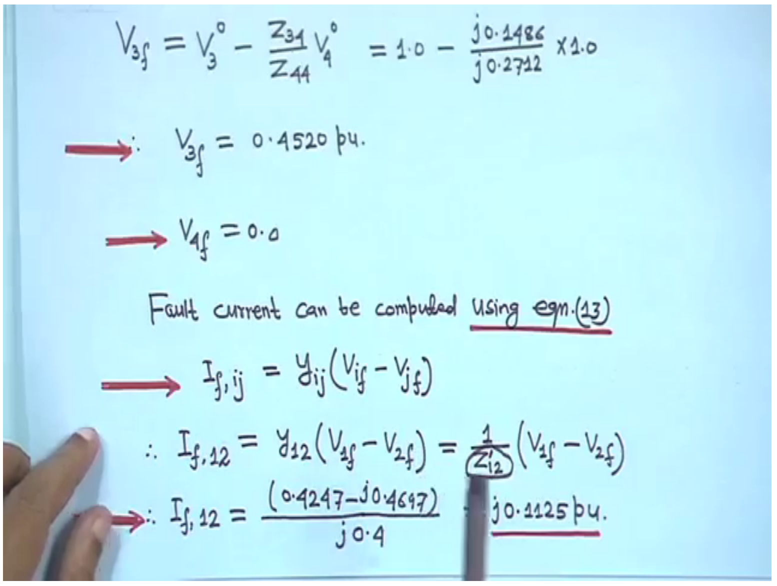

You also you will get this V 3 0 minus this one you will get 0.4520 and fault has occurred at bus 4. So, V 4 f will be 0 right. So, V 1 f V 2 f V 3 f V 4 f you have got now fault current can be computed using equation 1 3 I f i j Y i j your V i j minus your V V j f right. So, Y 1 2 actually is equal to 1 up on Z because now we are actually do not take capital Y this thing Y matrix it is a small y because you only line fault your line current line fault current your computing. So, i is equal to 1 j is equal to 2 I f 1 2 Y 1 2 V 1 f minus V 2 f that is 1 up on your Z 1 2 right in to V 1 f minus V 2 f you will get I f 1 2 is j 0.1125 per unit. So, this is a small y and z is given. So, Y 1 2 is 1 up on Z 1 2 accordingly you calculate.

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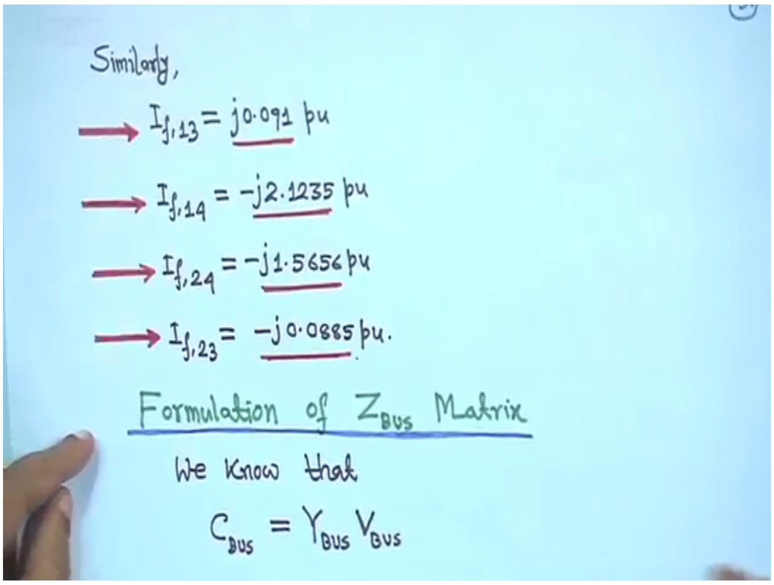

Similarly for all other things for I f 1 3 you will compute right then I f 1 4 again you will compute I f 2 4 you will compute I f 2 3 you will compute right. So, this is actually that is simple example that using that your what you call that the venin equivalent right at the easily you can compute your what you call that all the fault currents right, but only thing is that you have to have that Z bus matrix in fault studies Z bus matrix is necessary right.

So, up to this actually intention of this chapter is to show you couple of example of this fault studies and main thing is that your Z bus building algorithm that how one can make that Z bus building algorithm rather than taking your Y bus inverse because Y bus inverse if it is for a large network right computationally may not be that this thing you have to go for a different algorithm direct inverse you direct if you take direct inverse for large system it may give errors. So, some special technique is there, but for getting inversion, but will not discuss that, but our object is now to formulation of Z bus matrix right. So, this 3 phase symmetrical fault as I told you that it is very rare, but still we have to consider we have to study this one right.

So, detail symmetrical component and that positive negative and 0 sequence component at the time all for detail will see while will take different types of examples now formulation of Z bus matrix. So, basically i bus is equal to Y bus V bus I am writing it as c bus is equal to Y bus V bus c actually current c stands for current is equal to Y bus V bus right this is the formulation of your Z bus matrix now this V bus then is equal to Y bus in bus c bus that is equal to V is equal to Z bus i bus actually i bus instead of i bus I am taking c bus right. So, this is equation 15 where Z bus is equal to Y bus inverse now Z bus formulation by current injection technique although this technique is not good enough, but just see how things are right.

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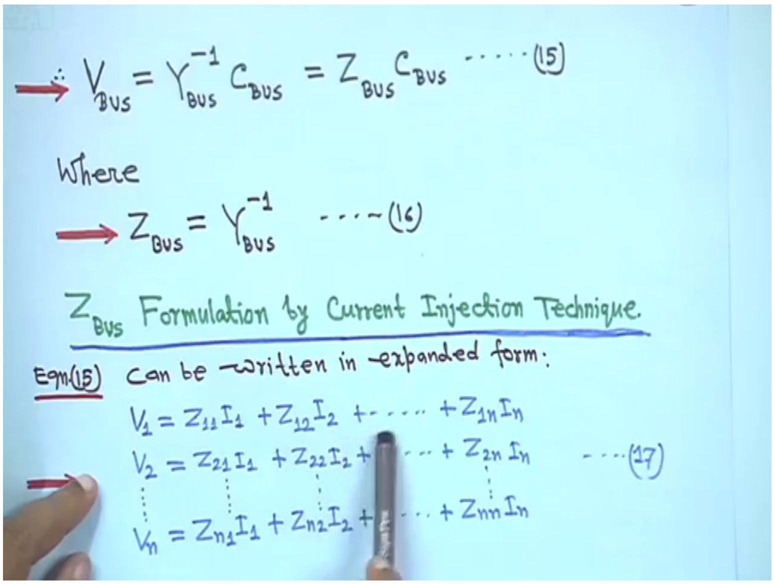

So, this equation 15; that means, this equation if you write them in I mean all the equations rather than matrix from all the equation then V 1 you can write Z 1 1 i 1 plus Z 1 2 I 2 plus Z 1 n i n right similarly V 2 is equal to Z 2 1 i 1 plus Z 2 2 I 2 up to Z 2 n i n this is equation 17 right I means set of equation of course, V n is there. So, Z n 1 i 1 plus Z n 1 2 I 2 plus Z n n this set of equation we are making that this is equation 17 right. So, in equation; that means, this equation seventeen that if we want to compute Z 1 1 Z 1 2 right then we can write.

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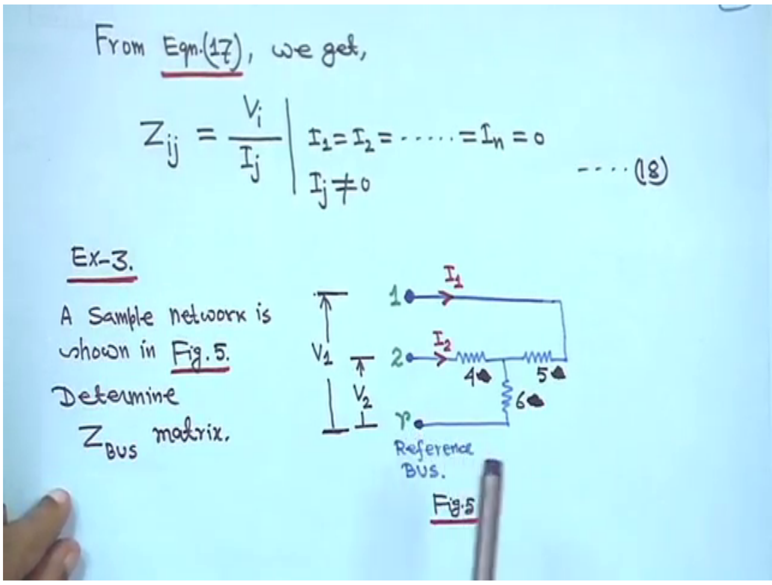

That Z i j you can write Z i j is equal to V i up on i j when I 1 is equal to I 2 for all i n 0, but i j not is equal to 0 then we get Z i j this way we can obtain now. So, in this case will take one small example right suppose you have a simple your bus 1 bus 2 and 1 reference bus is there. So, this is V 1 voltage this arrow means it is plus polarity and here it is minus right here same thing for V 2. So, a current is here showing I 1 here it is I 2 and this 4 this is something some resistive is going 4 5 and 6 right you can take per unit only right and this is reference bus. So, you have to obtain the Z bus matrix for this system that V 1 is that is and V 2 that is a voltage of that bus 1 bus 2 right to respect to this reference bus and this are that branch element 4 5 6 we have taken.

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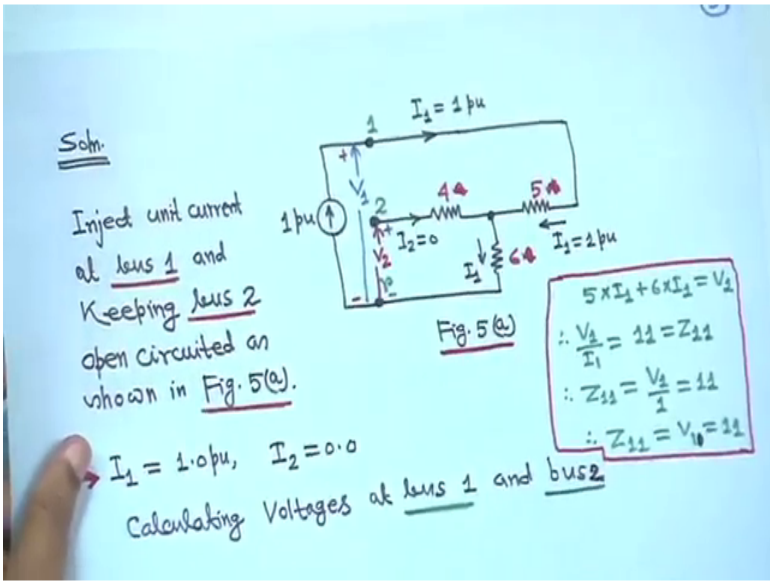

For example that first what you do at bus 1 keeping you bus 2 open bus 2 is open circuited right and if bus 1 you inject 1 per unit current right you just inject 1 per unit current at bus 1, but bus 2 is open circuited right; that means, this I 1 this i 1 1 per unit current it will this as nothing is injected here. So, current here from this bus 2 basically this I 2 is equal to 0 right and I 1 is equal to 1. So, this I 1 current is flowing here then as this current is 0 same I 1 is flowing here right and this way it is returned part right this way returning now in this case what will do. So, I 1 is equal to 1 I 2 is equal to 0 what you do first that you apply first your KV l in this equation first in this equation first sorry in this loop first and apply KV l if you do. So, it will be I 1 in to 5 right plus your I 1 in to 6 right is equal to V 1 because this voltage here it is V 1 right. So, I 1 in to 5 plus I 1 in to 6 is equal to V 1; that means, V 1 by I 1 is equal to 11. So, V 1 I 1 is equal to nothing, but Z 1 1. So, Z 1 1 is equal to 11 right similarly in this loop you apply K KV l in this loops. So, I 2 is 0 0 in to 4 0 plus I 1 in to 6 is equal to V 2 right.

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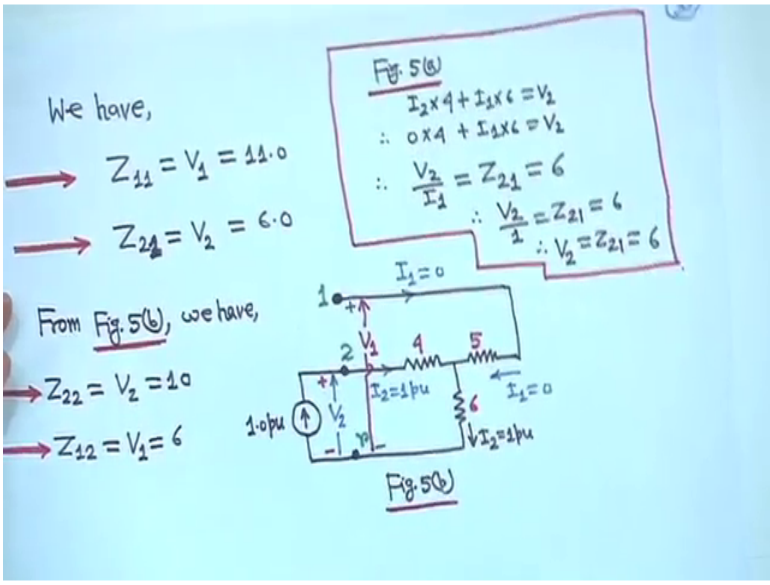

So, this I have written in the your next page that means Z 1 1 is equal to we got it 11 right V 1 up on I 1 i, 1 is 1 per unit. So, directly writing this one and in the second case it is 0 I 2 is 0 0 in to 4 plus i in to 6 sorry I 1 in to 6 is equal to V 2 V 2 by I 1 that is equal to Z 2 1. So, Z 2 one is equal to actually is equal to 6 because I 1 is 1; that means, Z 2 1 is equal to V 2 that is equal to 6 right. Similarly keep this one open right and at bus 2 you inject one per unit current right and same way you apply KV l once in this loop and apply KV l in this loop you will get Z 2 2 is equal to V 2 up on I 2 because I 2 is 1 per unit you will get one 10 and similarly Z 1 2 you will get V 1 by I 2 that is equal to 6 once in this loop you put KV l another one here you put KV l everything is given right; that means, Z 1 1 Z 1 2 Z 2 1 Z 2 2 you have got it right.

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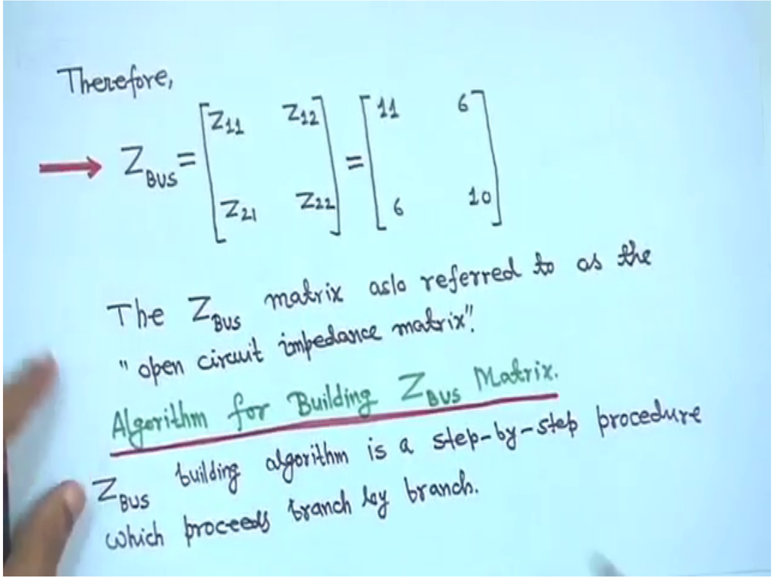

So, Z bus this is a current injection method. So, Z bus is equal to Z 1 1 Z 1 2 Z 2 1 Z 2 2 is equal to 11 6 6 10 this is the Z bus Z bus matrix also referred to as the open circuit impedance matrix. So, this is one methodology I showed you that one can obtained that your this thing, but for large network this is actually getting Z bus is difficult one right for this way. So, now, algorithm for building Z bus matrix. So, Z bus matrix actually just step by step procedure which proceeds branch by branch right. So, we have to move branch by branch and this one right you have to we have to try to understand this that how to go for algorithm for Z bus building algorithm, but let me tell you as far as coding is concerned this quite easy those who knows coding and interested about all this thing in coding actually is easy.

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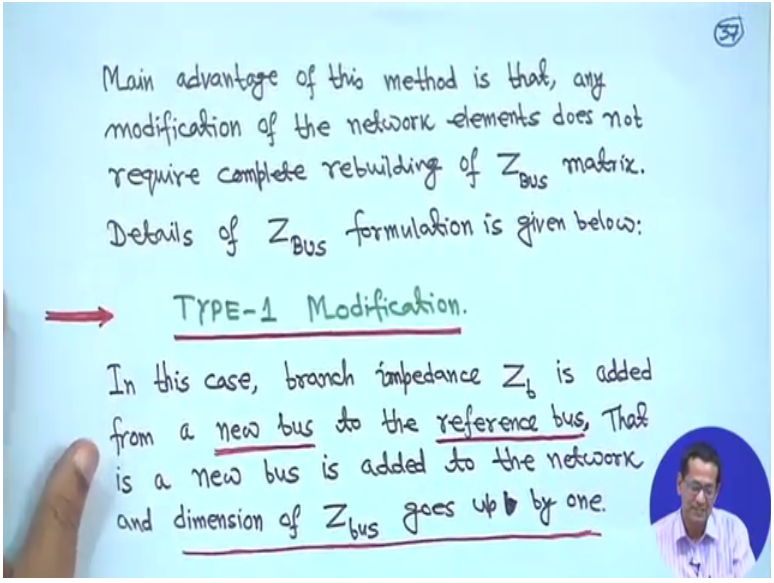

So, main advantage of this method is that any modification of the network element does not require complete rebuilding of Z bus matrix right; that means, if some modification is there in the network right. So, this using this algorithm whole network no need to modify only certain portion you have to wherever you need that there you have to modify, but if you go for inversion Y bus matrix then even you have small modification also you need the whole inverse thing right which is not desirable. So, that is why we will go for Z bus building algorithm. So, first is some sometime we say that type one modification right.

So, type one modification means that what is some type one type 2 type 3 type 4 this way we name it. So, in this case I will explain it I will show the figure that branch impedance Z b is added from a new bus to the reference bus we will as consider some buses are new bus some buses are old bus right and one reference bus. So, in this case branch impedance Z b is added from a new bus to the reference bus that is a new bus is added to the network and one dimension of Z bus goes dimension of Z bus goes up by one; that means, suppose you have a you have n bus problem and you are adding a new bus means that Z matrix will dimension will increase by one suppose it is a 10 bus problem suppose Z is 10 in to 10 matrix say and you are adding one more bus 11 bus. So, Z bus will be 11 in to 11 matrix it will go up by 1.

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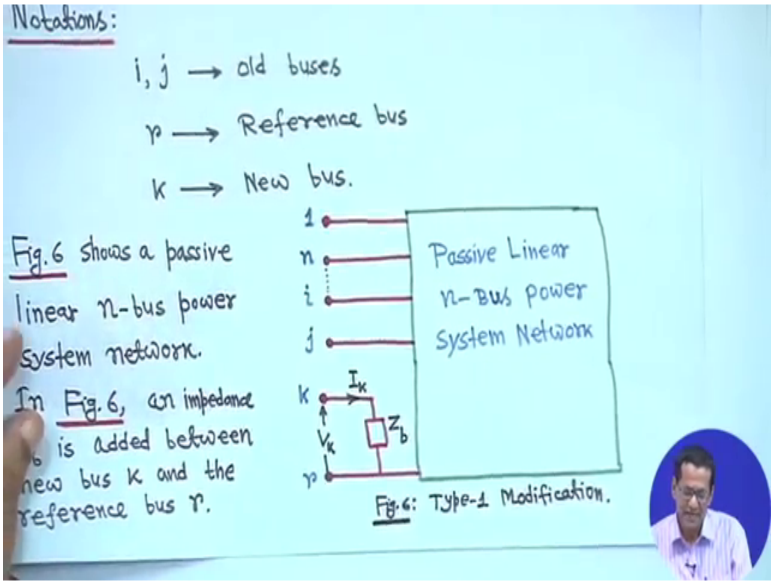

So, what you will do it you take a passive linear n bus power system network right you have bus 1 bus n bus i bus j and K bus is a new bus and r is the reference bus. So, how will proceed actually this notation you have to understand that bus i and j this is old buses right bus r reference bus; bus K it is a new bus right tell me the new bus is added to the network right so; that means, this is a K bus is a new bus and it is added to a it is connected to a reference bus right. That means, this is type one modification that branch type one modification that branch impedance Z b is added from a new bus to the reference bus; that means, this is a K bus is a new bus i have written there this notation very important that K is new bus it is added to ref through an impedance Z b therefore, voltage with respect to reference bus here K th bus voltage is V K and current is i K right this current injection at this bus K bus is i k.

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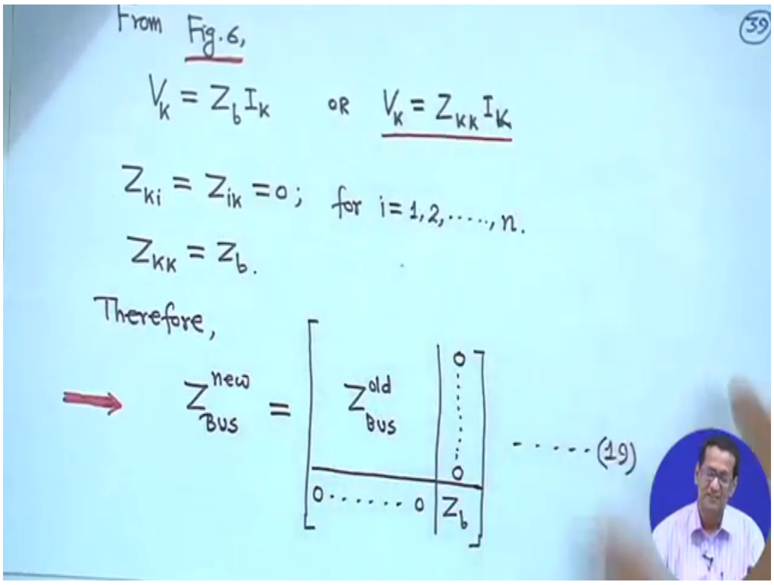

So, if it is so; that means, you can say that V K is equal to i K in to Z b this is directly you can write V K is equal to i K in to Z b right or so from figure 6 from this figure only that V K is equal to Z b in to i K that is your V K is equal to instead of Z b it is a it is a branch impedance added we can write V K is equal to Z K k in to i K because V K i K is here. So, better notations will be Z K k, but as K is not connected anywhere right you better you make Z K i is equal to Z K i 0 for i is equal to one to n. So, all other Z's are 0 you need not consider actually the mathematical equation.

That means Z K k actually is equal to Z b and order as bus your Z matrix order has increase one. So, Z bus new will be whatever Z bus was there it was there all and, but dimension is increase by one. So, all these all these this row up to this it is 0 up to this is 0 only diagonal will be Z b that is your Z K k right; that means, this is because this is V K is equal to Z K k. So, K th bus is added. So, that is why dimension as is increased by one and this Z bus old was available to you for the system; however, doing it later will know right. So, this is equation nine this is called type one modification. So, simple one the first one right only 1 element will be added to the diagonal of the old Z bus. So, and these are all 0s, this row this column up to this and this rows up to this all elements will be 0 right next is that your type 2 type to modification.

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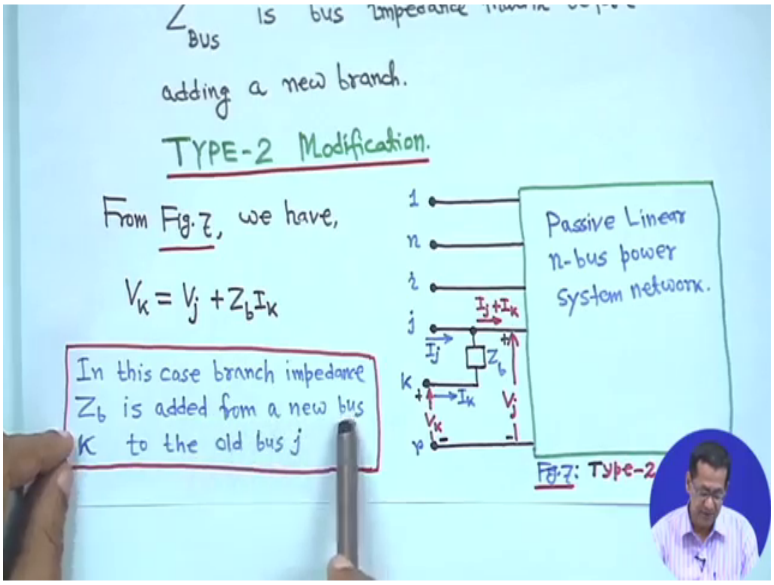

So, previous one Z bus old is the bus impedance matrix before adding a new branch that I told now type 2 modification in this case what will happen that branch impedance Z b Z b is added from a new bus K to the old bus j. So, I have told you that bus i and j they are old buses right and K is a new bus and r is a reference bus. So, in this case branch impedance this is a type 2 modification that branch impedance Z b is added from a new bus this is a new bus to that your old bus say j; that means, this bus is added through impedance Z b

This current is i K this is I j. So, current injection here is i j plus i K and this voltage here j th bus voltage is V j and K th bus voltage is V K right. So, that means, from this from this figure in this case you apply K in the apply KV l. So, it will be i K in to Z b plus V j minus V K is equal to 0; that means, V K is equal to V j plus Z b i K this way i have drawn for you such that it will be easy to understand right.

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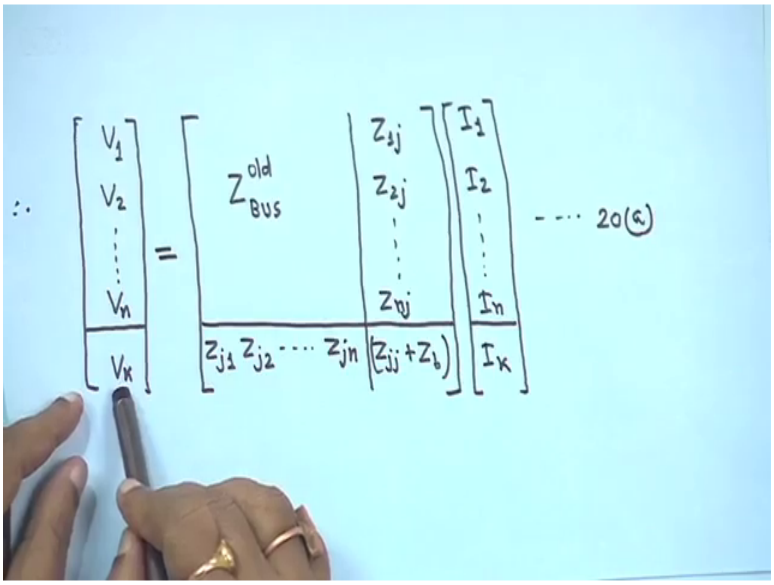

So, now, this V K is equal to V j plus Z b i k; that means, we can write right we can write this is your this equation that as a whole we can write V 1 V 2 V n right and this is Z bus old right and this is your this Z j one Z j 2 Z n and here how it is coming we will see and this is your current i k. So, if you see that V K is equal to it is V j plus Z b i K right. So, V KV K is equal to; that means, i am coming here that V K is equal to it is V j plus Z b i k; that means, V K is equal to Z j one Z j one I 1 plus Z j 2 I 2 up to plus Z j j i j that is V j right plus Z j n i n now let us Z b i K right. So, this thing actually Z j j plus your this thing if i go to the first equation Z j 1 I 1 plus Z j 2 I 2 plus Z j j i j plus i K because here current injection is i j plus i k. So, Z j j i j plus i K plus dot dot dot Z j n i n and plus Z b i K because in this equation where it has gone in this equation V K is equal to V j plus Z b i.

So, first we have written V j up to this the red color plus Z b i K after that if you simplify it will come plus Z j j plus Z b i k; that means, this equation Z bus new Z bus old will be there and this last one V K th 1 it will be Z j one Z j 2 Z j n it is symmetric matrix it is Z j one means Z 1 j Z j 2 means Z 2 j Z n j and this diagonal last diagonal one Z j j plus Z b this is Z j j plus Z b right that is why that is why i was writing this one just hold on this your what you call this Z bus new is equal to this one right.

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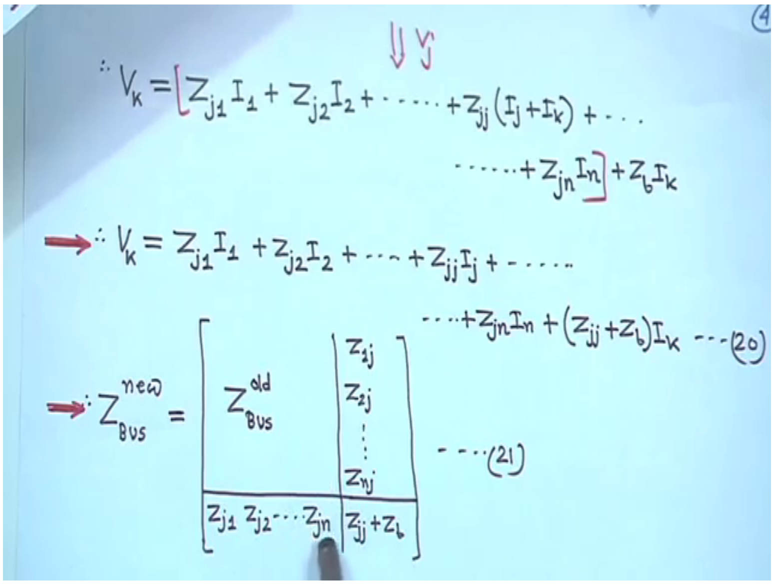

So, so this is actually your Z bus new Z bus old. So, only from this equation only V K th equation will be added right and then you simplify. So, in this case also dimension of the Z bus matrix will go will increase by one because it is K bus is earlier it was added to reference bus now added to your old bus. So, only this element one has to compute right particularly this one other things are known, but it has increase by this one right. So, this is actually Z bus new.

Thank you again we will be coming back.