Power System Analysis
Prof. A. K. Sinha
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 20
Power Flow – V

Welcome to lesson 20 on Power System Analysis. In this lesson, we will continue with the Power Flow Analysis.

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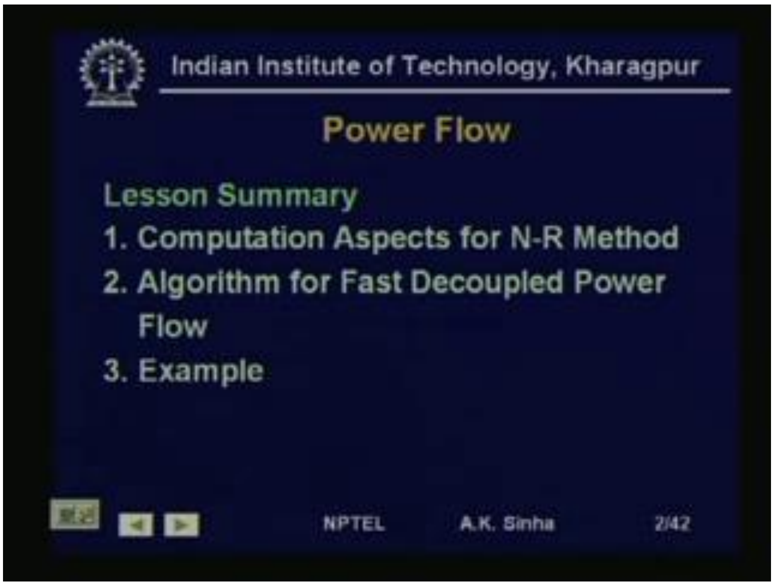

We will start with computational some computational aspects of Newton Raphson load flow method. Then we will develop fast decouple power flow algorithm and we will take up an example for solving fast decoupled power flow problem.

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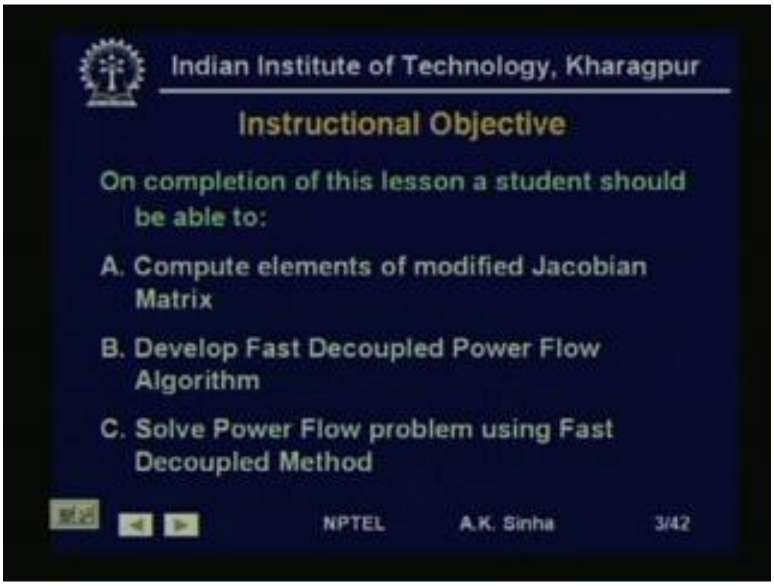

On the completion of this lesson you should be able to compute elements of the modified Jacobian matrix. Develop fast decoupled power flow algorithm and solve power flow problem using fast decoupled method.

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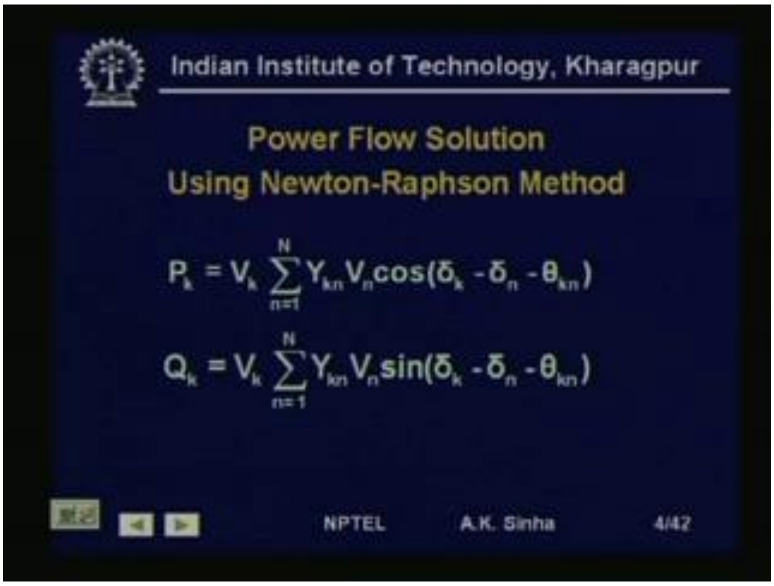

We will start with the power flow equations that we had developed earlier, where we had said that a power real power injection at any bus k is given by P k. And P k is equal to V k summation n is equal to 1 to capital N Y k n V n cos delta k minus delta n minus theta k n, where V k and V n are the voltage magnitudes at bus k n n delta k is the voltage phase angle at bus k delta n is the voltage phase angle at bus n. And theta k n is the angle of the admittance between bus k n n. That is the angle associated with the element Y k n. That is k n element of the Y bus matrix and Y k n is the magnitude of that element. Similarly, the reactive power injection at bus k is given by the relationship Q k is equal to V k summation n is equal to 1 to capital N Y k n, V n sin delta k minus delta n minus theta k n.

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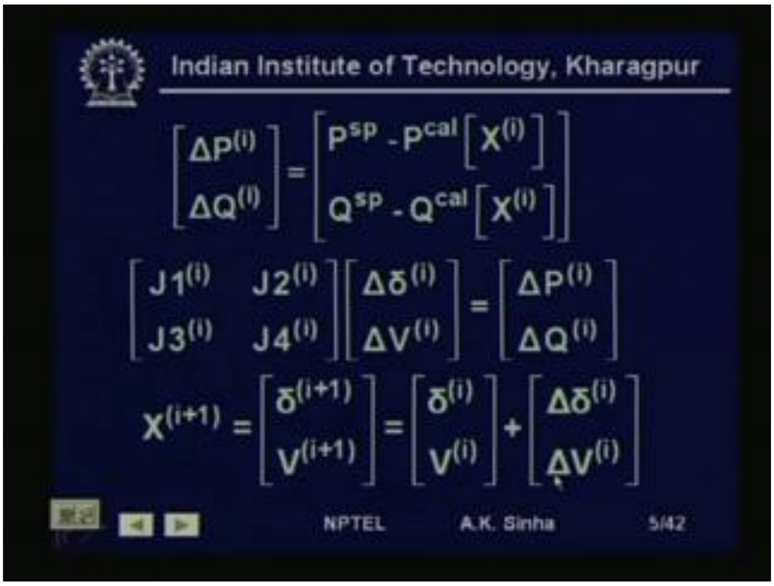

We from these relationships for Newton Raphson load flow. We had developed the model, where J into delta X is equal to delta P delta Q; where delta P delta Q matrix are the vector is given by P specified minus P calculated which is a function of the state variables at i th iteration. So, this state variable as we have already discussed are the voltage phase angles and the magnitude value at all the buses.

Similarly, delta Q i that is the change in Q at i th iteration is equal to Q specified value minus Q calculated value, which is a function of the state variables. So, state variable delta delta and delta V is solved using this relationship where J 1 J 2 J 3 J 4 are the sub matrices of the Jacobian matrix. J 1 is del P by del delta terms, J 2 is del P by del V terms, J 3 is del P by del Q by del delta terms and J 4 is del Q by del V terms.

So, now this calculated value is computed and then delta P delta Q is calculated. That is put here J 1 J 2 J 3 J 4 are computed at the ith iteration state variable values. So, once we know this matrix, we know this using the solution for this linear system of equations a x is equal to b kind of a system. We can solve for this X and this X is given by this.

So, once we get this X at delta X at ith iteration, then we can find out X at I plus 1th iteration. As that is delta at I plus 1th iteration and V at I plus 1th iteration is equal to whatever was the value of delta. And V at ith iteration plus the change which we have computed just now, that is delta delta at ith iteration and delta V at ith iteration.

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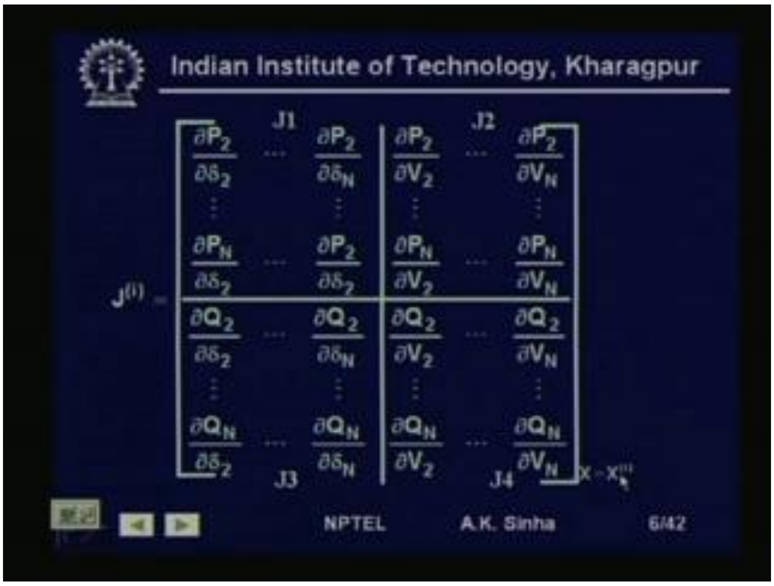

The Jacobian matrix as I said earlier is this J 1 is del P by del delta sub matrix J 2 is del p by del V sub matrix. J 3 is del Q by del delta sub matrix and J 4 is del q by del V sub matrix. At the values are computed at ith iteration by substituting the value of the state variables at ith iteration.

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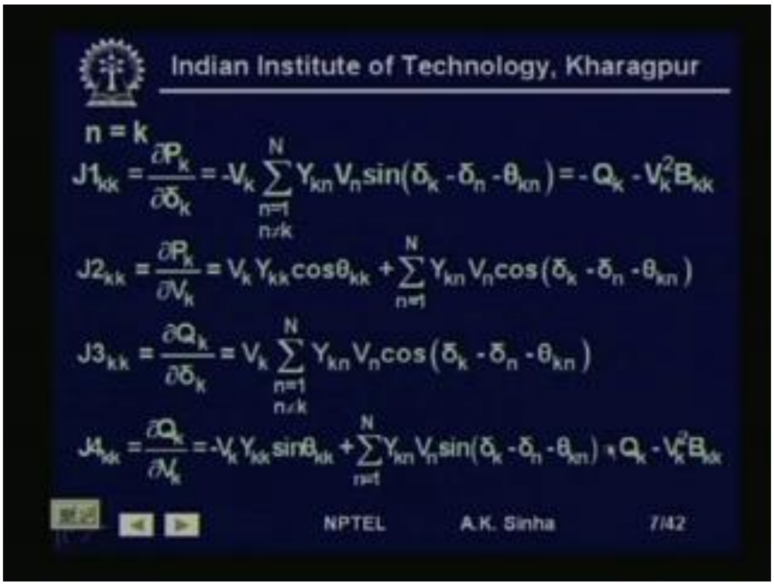

Now, we can calculate the elements of the Jacobian matrix, this we had done in the earlier lesson. So, for the diagonal elements for J 1 that is del P k by del delta k we have the relationship as. Del P k by del delta k is equal to minus V k summation n is equal to 1 to capital N, where n is not equal to k.

So, that is into Y k n V n sin delta k minus delta n minus theta k n. This comes out to be equal to minus Q k minus V k square into B k k. Similarly, J 2 sub matrix the diagonal elements del P k by del V k is computed as V k Y k k cos theta k k plus summation n is equal to 1 to capital N Y k n V n cos delta k minus delta n minus theta kn.

J 3 k k that is del diagonal elements of J 3 sub matrix del Q k by del delta k is given by V k summation n is equal to 1 to capital N n not equal to k. Y k n into V n cos delta k minus delta n minus theta k n. And J 4 k k that is diagonal elements of J 4 del Q k by del V k is equal to minus V k Y k k sin theta k k k plus summation from n is equal to 1 to capital N Y k n V n sin delta k minus delta n minus theta k n. This is equal to Q k minus V k square B k k.

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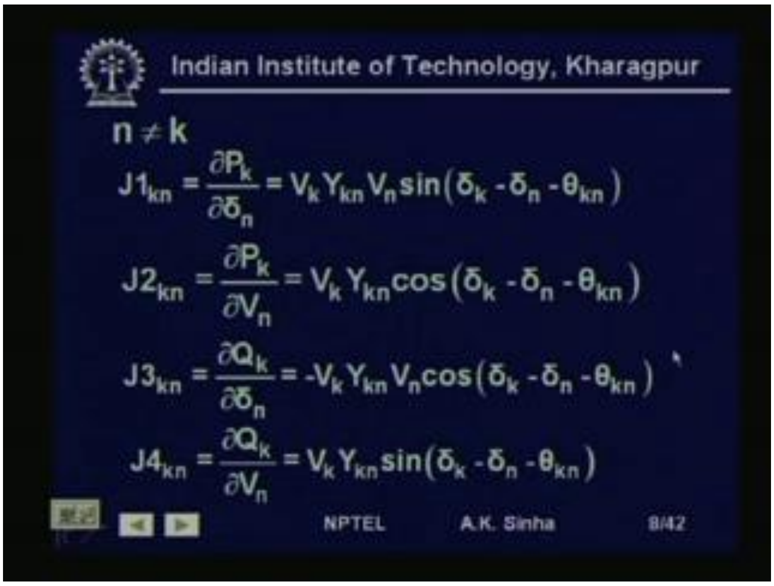

The off diagonal terms or obtained in like this J 1 k n that is off diagonal terms of J 1 del P k by del delta n this is given by V k Y k n sin delta k minus delta n minus theta k n. The off diagonal terms of sub matrix J 2 is given by del P k by del V n is equal to V k Y k n cos delta k minus delta n minus theta k n.

Similarly, the off diagonal terms of J 3 sub matrix del Q k by del delta n is given by minus V k into Y k n minus V n cos delta k minus delta n minus theta k n. And the off diagonal terms of J 4 sub matrix del Q k by del V n is given by V k Y k n sin delta k minus delta n minus theta kn. Now, if we see these, the elements of the off diagonal elements of the Jacobian matrix as well as the diagonal elements of the Jacobian matrix; we find some similarity in the terms.

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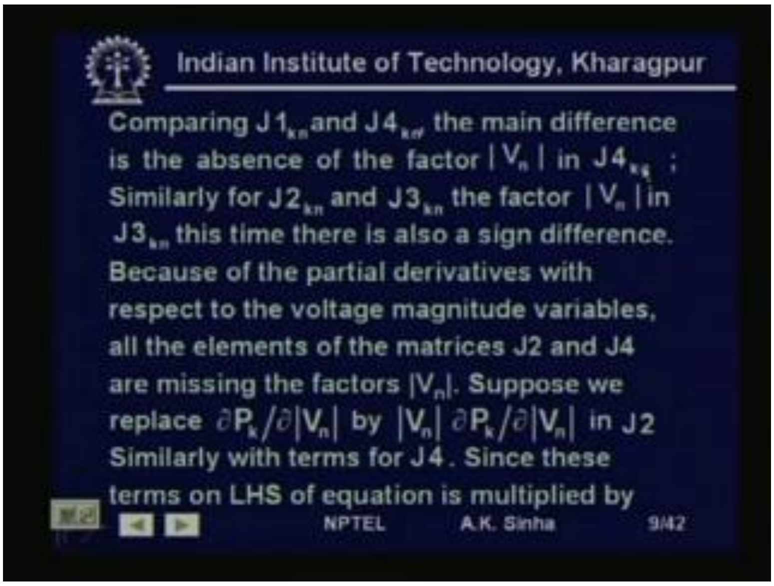

We will see how we can take advantage of these similarities. Now, comparing term for J 1 k n and J 4 k n. The main difference is the absence of factor, V n that is the magnitude value of voltage at n nth bus in J 4 k n. That is if we see here J 4 k n and J 1 k n are very similar expect that this V n term is not present in this.

Similarly, if we see J 2 and J 3 again we find that J 2 is missing V n. Whereas, this J 2 and J 3 are very similar expect that J 2 is missing this V n. Also there is a sin minus sin associated with J 3. Now, if we can take advantage of these similarities our computation for the Jacobian matrix can be made much simpler.

Now, this difference is coming why. The difference is coming mainly because the partial derivatives with respect to the voltage magnitude variables. All the elements of matrices J 2 and J 4 are missing the factor V n. That is since these J 2 and J 4 are partial derivatives with respect to the voltage magnitudes. Therefore, the voltage magnitude term are missing in J 2 and J 4.

Now, suppose we replace this del P k by del V n by multiplying it by V n. That is the magnitude value V n. So, we replace this by V n into del P k del by V n in J 2. Similarly, for terms for J 4 can also by multiplied by V n. And since these terms are on the left hand side of the equation is multiplied by V n’s.

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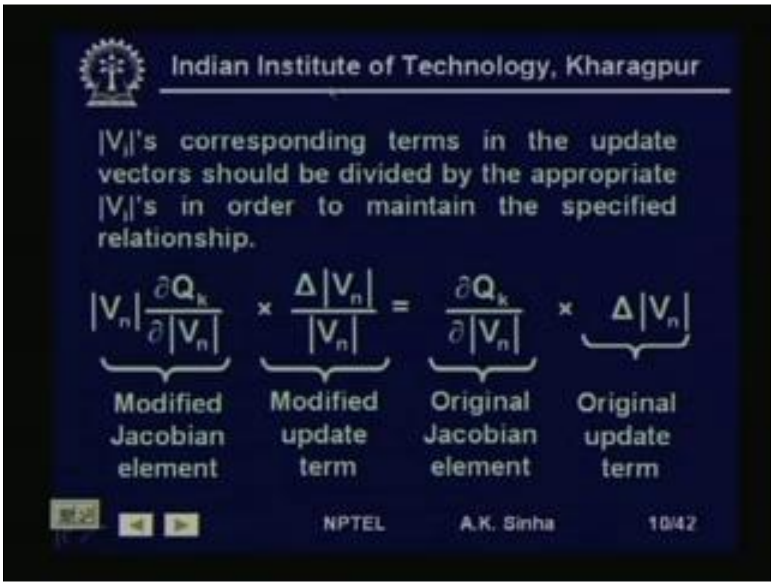

I am sorry this should be V n’s the corresponding terms in the update vectors should be divided by the appropriate V n’s in order to maintain the specified relationship. That is what we have done is del Q k by del V n we have multiplied by V n right. So, what we are doing we will this delta V n term, we will divide by V n.

So, then what we will get, will be del Q k by del V n into delta V n, which is the same term as the original matrix. So, what we are doing we are multiplying the terms of the J 4 matrix by V n. Similarly, multiplying the terms of J 1, J 2 sub matrix with V n. We will divide this delta V n term by V n, then we get the same relationship. So, the relationship or the equation is maintained by multiplying the J 2 and J 4 terms with V n and dividing delta V n by V n.

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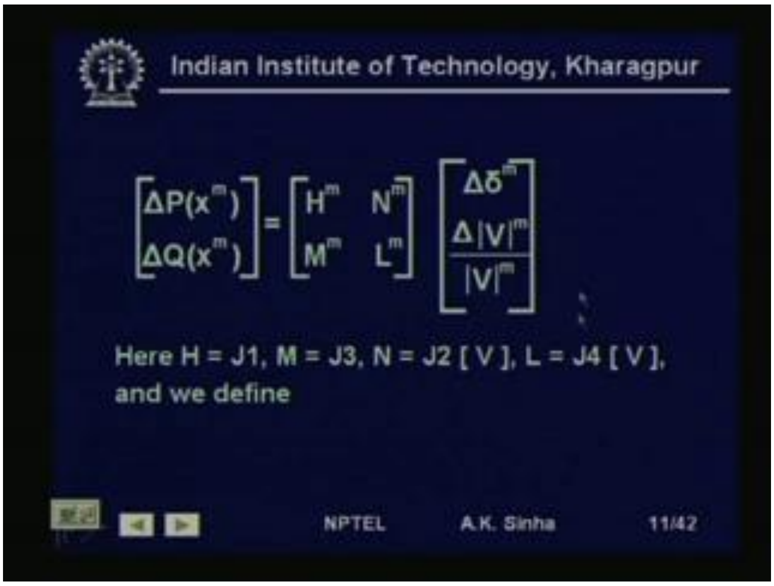

Therefore the relationship now comes out be del P and del Q at with the at mth iteration that is with the values substituted for X, which is delta delta and delta V; which is V and delta angles. So, X is V n delta. So, substituting the value for that in the equation for P and Q. So, we will get P specified minus P calculated and that will give me delta P and delta Q at that state with that state variable.

And the Jacobian now we have renamed, because we have multiplied the elements of J 2 and J 4 by V n. So, we have renamed these sub matrices as HNM and L, where H is same as J 1, M is same as J 3, N is J 2 multiplied by V and L is also J 4 multiplied by V. And also in the term delta delta remain same bus this term delta V, which was there is now divided by magnitude V, because we have multiplied the terms of J 2 and J 4 by this V.

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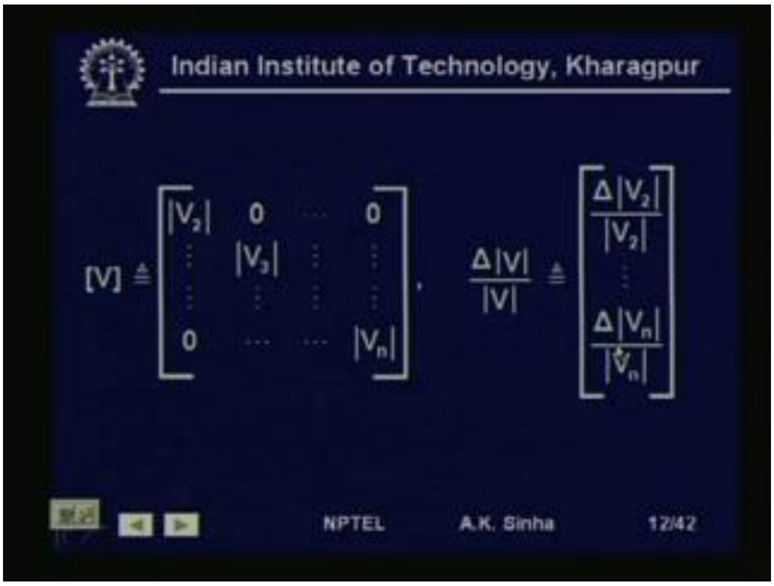

So, if we do this then we have where V we are saying is the, if you look at this J 2 into V actually this V is basically a diagonal matrix of voltage magnitudes. Therefore this V is defined as V 2 V 3 V 4, here we are assuming that bus 1 is our slack bus that is what we had been using from very beginning. So, bus 1 is considered a slack bus. So, V is V 2 V 3 up to V n and delta V by V is delta V 2 by V 2 and so on, delta V n by V n.

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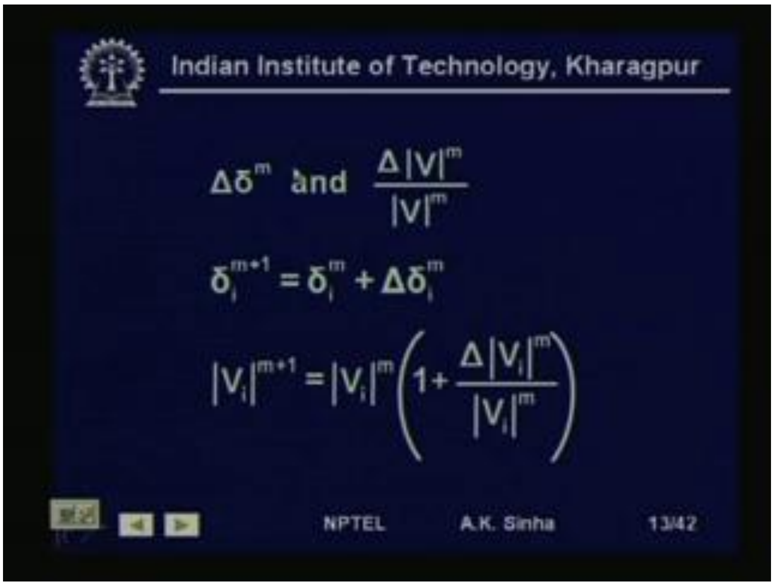

So, this is what we get. Then what happens is we have, now if you look at this we are calculating these terms. We know this we have got the values of this by substituting the value of state variables that is voltage magnitude and angle for the elements of the

Jacobian. Then solving this expression we can calculate delta delta m and delta V m by V m.

So, once we have calculated this, then we can get the updated value for m plus 1th iteration as delta I. That is delta at i th bus for m plus 1th iteration is equal to delta I at m th iteration plus delta delta I at m th iteration. And similarly the voltage magnitude is updated as V i at m plus 1th iteration is equal to V i at m th iteration into 1 plus delta V i by V i at m th iteration. So, this is the update that we do. Now, if you look at this, what we have done here is we have modified our Jacobian matrix terms in such a way that we do not need to compute all the terms.

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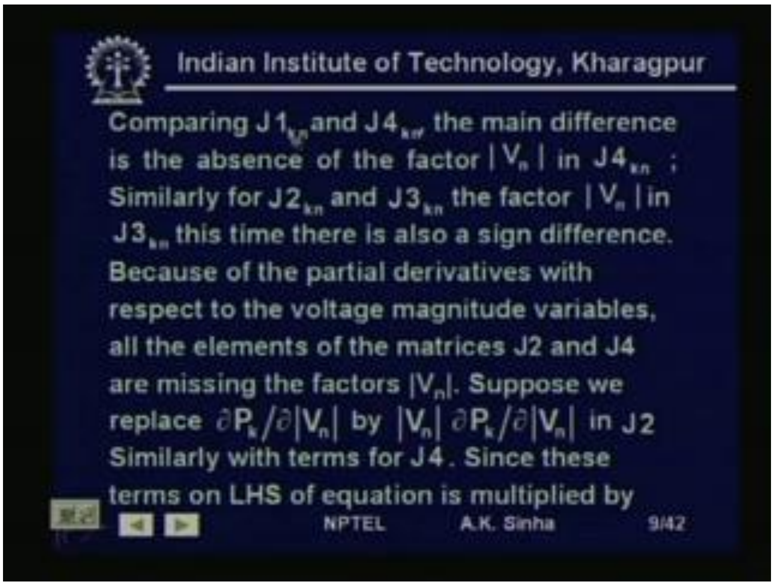

That is we have J 1, if you compute the J 1 terms we have also computed the J 4 terms.

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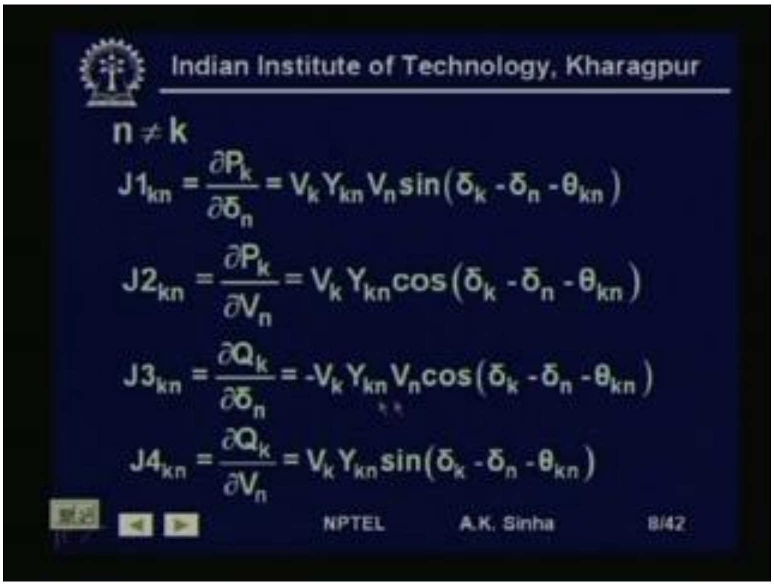

Now, similarly if we have computed the J 2 terms, then we also have computed the J 3 terms, here there is a mistake it should be J 3. This is J 2 terms, then we also have computed the J 3 terms if we have used this modification that is we have multiplied the J 2 and J 4 terms by the voltage magnitudes. So, this a great advantage, because you do not need to compute a large number of elements of the Jacobian matrix. So, this speeds up the computation for the Newton Raphson method considerably.

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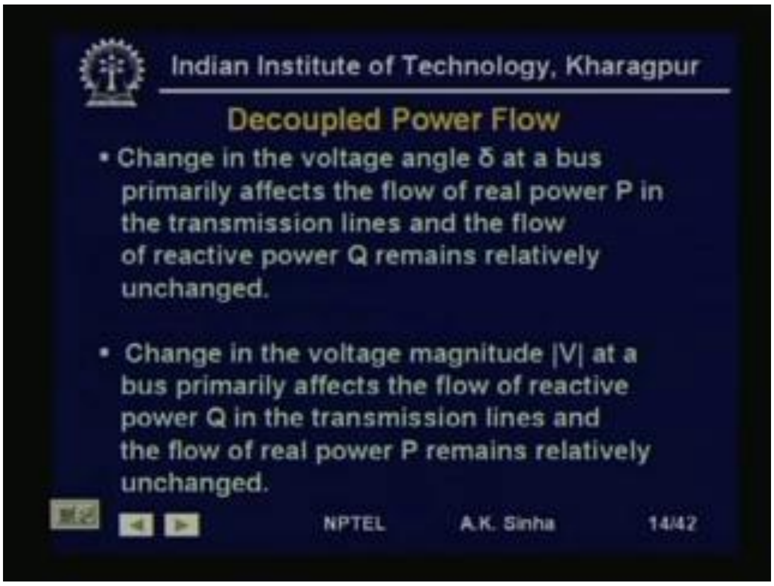

Now, still Newton Raphson method requires enormous amount of computation though we use techniques for improving the computational efficiency of the Newton Raphson method. Because we know that the Jacobian matrix there are large number of elements which will be zero. So, we use sparsity techniques for solving this. We will discuss some of the spars method techniques in the next lessons. There is still some chance for improving the computational aspect of the power flow problem. And these we can do by seek the some of the practical aspects associate with the power flow equations.

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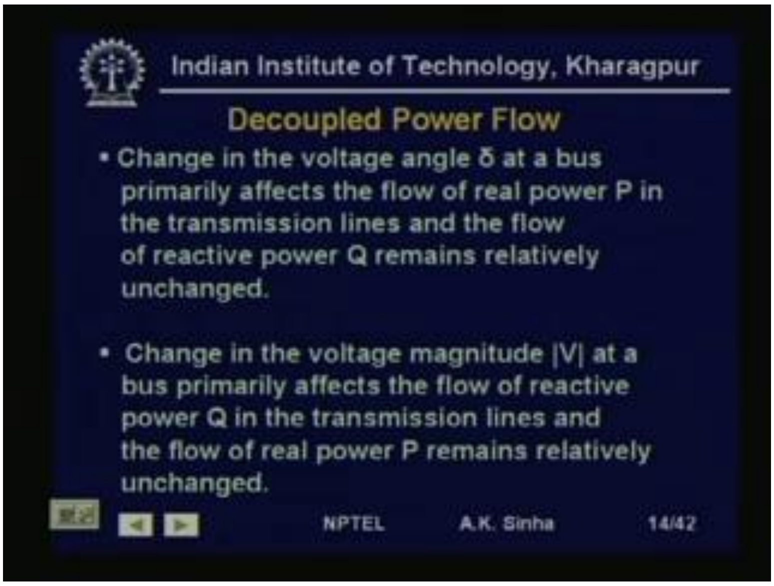

We know that change in voltage angle delta at a bus primarily affects the real power P in the transmission lines. That is delta primarily affects the real power flow in the transmission lines. Whereas the reactive power flows remain more or less unchanged. Same thing, if you see that, if you change the voltage magnitude. Then the reactive power flow on the transmission line get changed, but the real power flow remains more or less unchanged.

This shows that P delta, the P and delta are strongly length and Q and V are strongly length. And there is a weak coupling between P delta and Q V. And we can take advantage of this property of the power system in trying to improve the computational aspect of the power flow problem.

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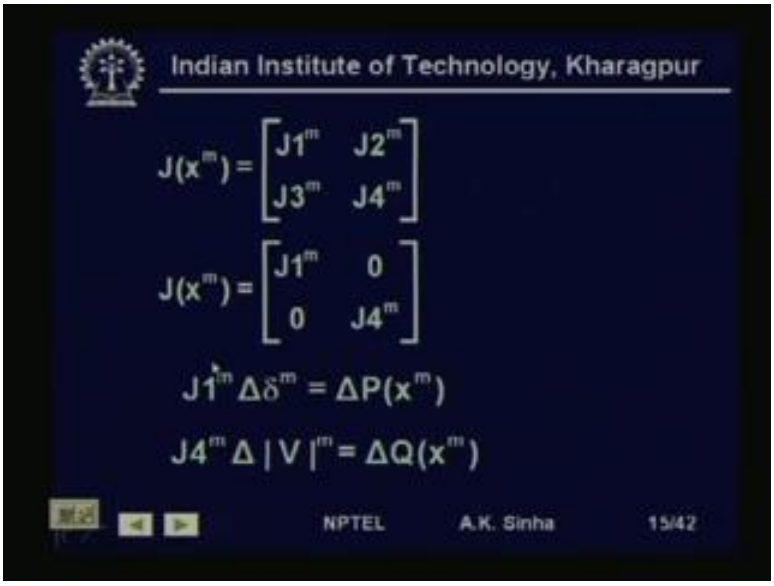

And if we do that, that is if we see the Jacobian matrix the Jacobian matrix J 1 J 2 J 3 J 4. If we see this we can also see since there is weak coupling between P and V that is the voltage magnitude. We find that the elements of this J 2 sub matrix which is basically providing the sensitivity of real power with respect voltage magnitude.

And similarly the elements of the J 3 sub matrix, which is providing which del Q by del delta. That is sensitivity of reactive power with respect to the voltage phase angle. These the elements of these sub matrices J 2 and J 3 are much smaller compared to the elements of J 1 and J 4.

This also tells us the same thing, that there is a strong coupling between P and delta and Q and V and a V coupling between P and V and Q and delta. And therefore, if we try to take advantage of this weak couplings, we can neglect the sub matrices J 2 and J 3 that is we can make them zero. So, we have now the Jacobian matrix consisting of sub matrix J 1 and J 4 only.

If that is the case, then we have the equations written as J 1 delta delta is equal to P delta P. That is if you look at this equation, since we have made these sub matrices 0. So, delta P is equal to H into delta delta H or J 1 into delta delta And delta Q is equal to L into delta V or J 4 into delta V or L into delta V by V.

So, what we see? Now, what has happened is the set of equation that is, if you assume that there is no PV bus. Then we have 2 into n minus 1 set of equations and the Jacobian matrices 2 into n minus 1 into 2 into n minus 1 matrix. Now, here what has happened is.

Now, this J 1 term is only there, which is n minus 1 into n minus 1 matrix. And J 4 term is there which is again n minus 1 into n minus 1 matrix if you assume no PV buses.

Then what we have seen is this whole problem, which was a 2 n 2 into n minus 1 simultaneous equation has been broken into 2 n minus 1 simultaneous equations. And this considerably reduces the computational aspect, because now our Jacobian matrices or much smaller and solving for these takes much less time. Because as we had talked about earlier, that the time taken for solving the X is equal to B matrix or the equation using Gauss elimination or some other method is proportional to n square additions and multiplications.

So, the time take is proportional to n square. So, now instead of 2 n square which is 4 n squared. Now, we are solving n squared plus n square that is 2 n squared. So, the computational aspect we again considerably; that is now we require only half the amount of computation in this case.

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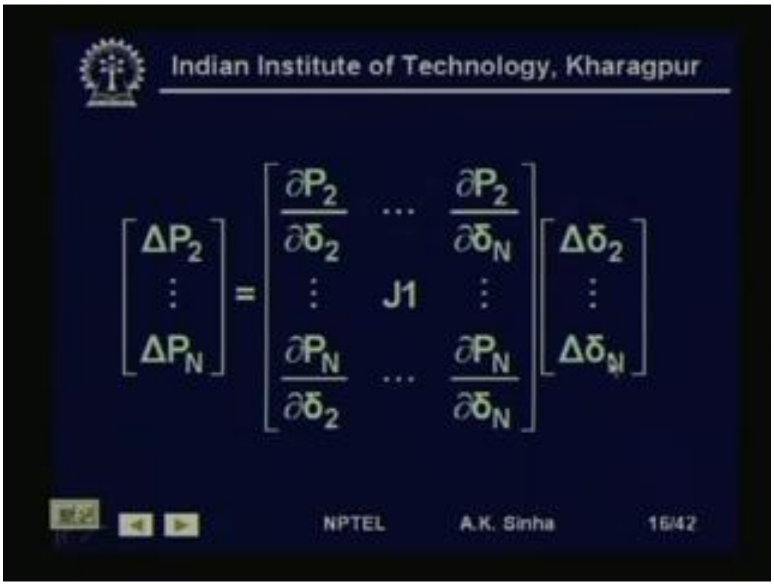

So, now we have the relationship for the decoupled equations as delta P from bus 2 to bus N is equal to this sub matrix J 1 into delta delta from delta 2 to delta delta N.

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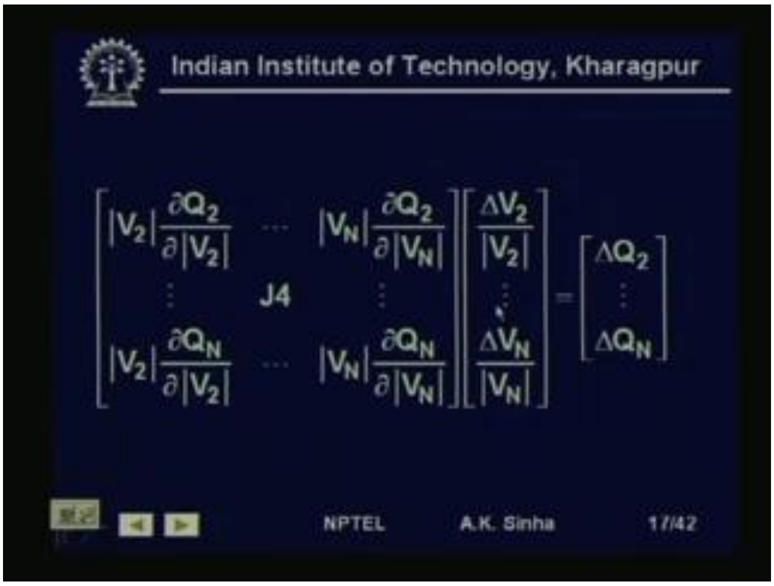

And for this the other set of equation is again this will be the sub matrix L, which we are using, because we have multiplied del Q by del V by V. So, here we have del V 2 by V 2 and del V N by V N and this is del Q. So, this is the other set of equation that we need to solve.

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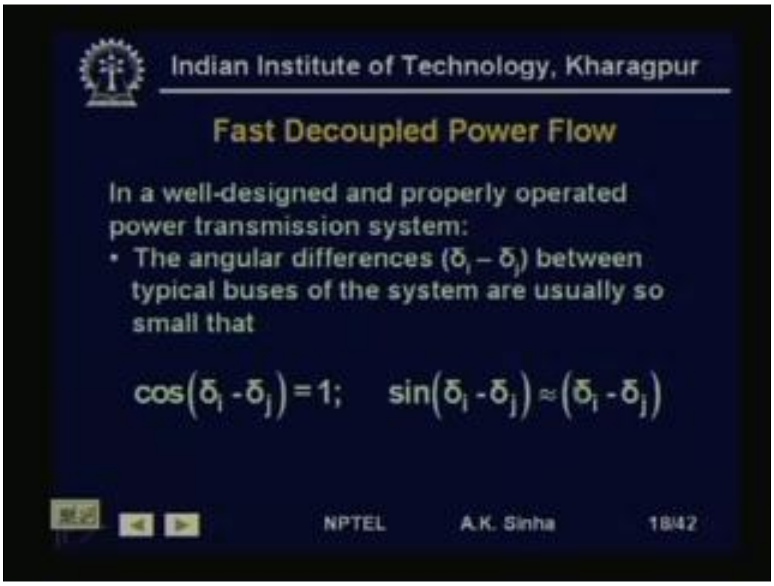

So, now the advantage of this method of decoupling has been that the computational aspect has been reduced considerably. But, we when trying to solve this we find that the number of iterations required for this, increases considerably and in many cases there are convergence difficulties. So, this does not really help much.

So, some other improvements looking at the physical aspects of the power system was suggested in form of a fast decoupled power flow method. Now, what how this method was developed is based on certain assumptions, which are valid for a properly operated power system. So, in a well designed and properly operated power transmission system the angular differences, that is delta I minus delta j between typical buses of a system are usually small.

They are small, so we have cos delta I minus delta j is equal to 1. Normally this angle difference will be of the order of 10 to 15 degrees maximum most of the time less then that also. So, we have therefore cos delta I minus delta j very nearly equal to 1. And sin delta I minus delta j is approximately equal to delta I minus delta j radiance.

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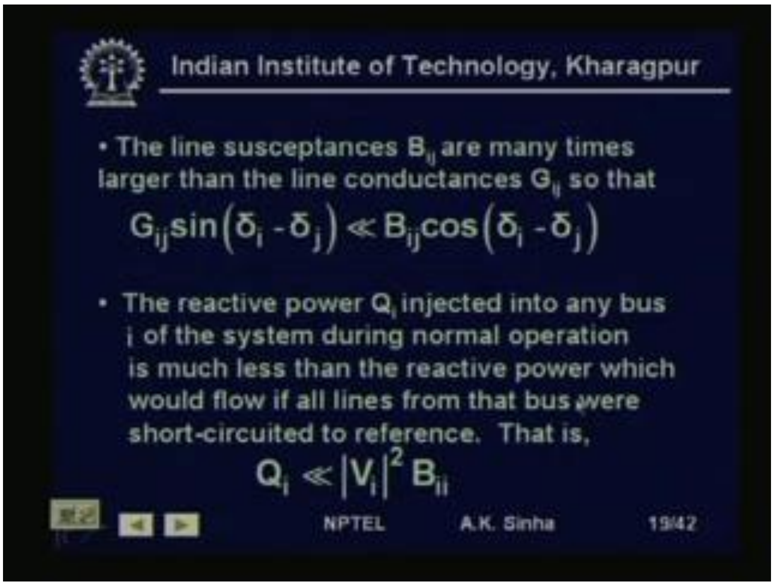

Also the line susceptances B i j are many times larger than the line conductance G i j. That is true, because we know that the inductance of the transmission line is much larger than the resistance; and therefore, B i j is much larger than G i j. Therefore we can say that G i j sin delta I minus delta j is much smaller than B i j cos delta I minus delta j. Because this term will be more or less very near to 1. So, this term will be B i j and G i j is much smaller and sin delta I minus delta j is equal to delta I minus delta j radiance only. Therefore this whole term is much smaller than this term and therefore, this can be neglected in comparison with this term.

Now, the reactive power Q i injected into a bus I of the system during normal operation is much less than the reactive power, which would flow if all the lines from that bus were short circuited to reference. That is if we short circuit that bus to the reference, what is the reactive power which will flow. It will be the voltage square multiplied by B i i.

So, V i square into B i i is what will be flowing when we short circuit that bus to the reference. Whereas Q I, which is the injected reactive power at that bus is certainly much smaller in normal operating time. Therefore Q i is much smaller than V i square into B i i.

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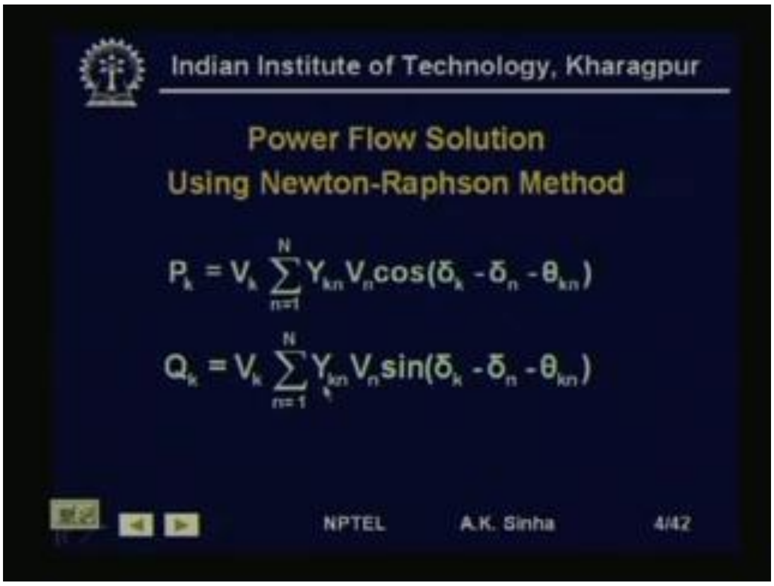

In fact, this we can also see from this relationship where Q k is given as V k into Y k n V n sin delta k minus delta n minus. Now, this Y k n into sin delta k n terms will give me the V terms. Whereas let me go back and see this from another equation.

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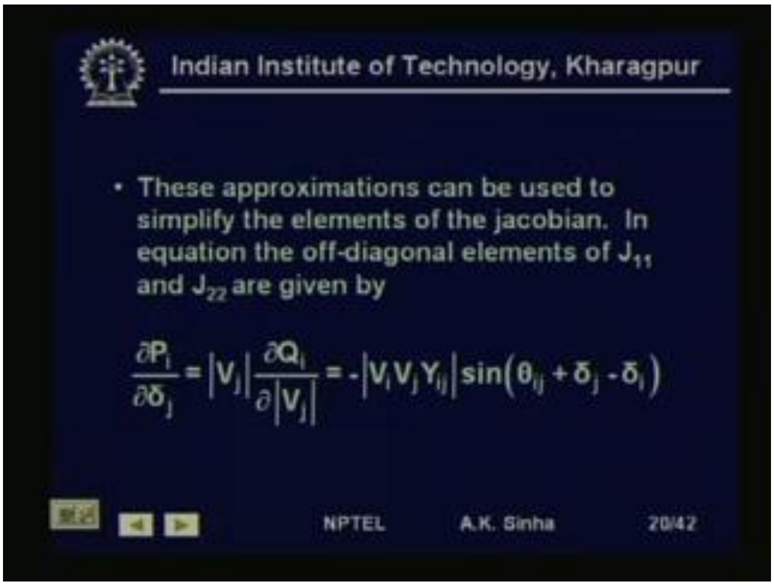

Now, if we see this term for Q i it will be V i V j into Y i j sin theta i j plus delta j minus delta i. Now, here what happens is this term will be a summation of all these terms. Whereas we know that the term for Y i j is a negative term of Y i j the actual admittance between the for the line connecting bus I and j. And B i i is a term, which is sum of all the susceptances for connected to that line; that is connected to that bus.

So, susceptances for all the transmission lines connected to that bus, when we add them we get B i i. And B i j is negative of the susceptance which is connected to that between bus I and j. Therefore if we look at this the Q i since it is summation of all those terms with summation B i j V i into V j.

Therefore V i and V j magnitude values will be very nearly equal to 1. And therefore, what we find is the total summation is going to be much smaller, because there are all B i j terms, which are negative terms will be subtracted from B i i. And the total value of Q i therefore, is going to be much smaller than this.

Now, these approximations can be used to simplify the elements of the Jacobian matrix. In equation the off diagonal elements J 1 1 and J 2 2 that is J 1 and J 2 are given by del P i by del del delta j is equal to V j del Q i by del V j. This is equal to minus V i V j into Y i j sin theta i j plus delta j minus delta i.

Using the identity sin alpha plus beta is equal to sin alpha cos beta plus cos alpha sin beta in the equation gives us del P i by del delta J is equal to V j del Q i by del V j. This is equal to minus V i V j B i j cos delta j minus delta I plus G i j sin delta j minus delta I, where we have used this B i j as Y i j sin theta i j this the susceptance part. And G i j is equal to Y i j cos theta i j, which is the conductance part. The approximations listed above yields the off diagonal elements.

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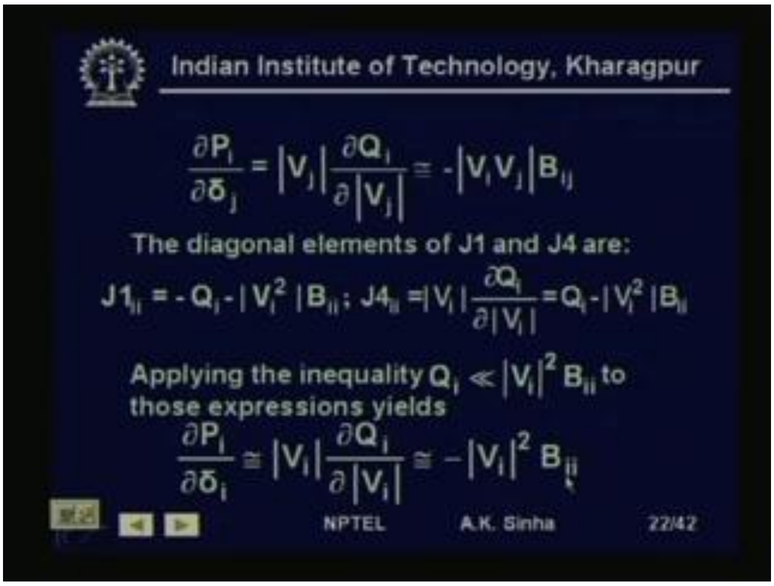

As minus V i V j B i j, the diagonal elements of J 1 and J 4 are J 1 i i is equal to minus Q i into V i square into B i i. And J 4 i i is equal to V i into del Q i by del V I, which is equal to Q i minus Vi square B i i. So, if we see these elements applying the Q i is much smaller than V i square B i i; that means, this term much smaller than this term. So, the expression for del Pi by del delta I will be approximately equal to V i into del Q i by del V i. And both will be approximately equal to V i square into B i i. So, this is what we see that the diagonal elements will be given by this; whereas, the off diagonal elements will be given by this.

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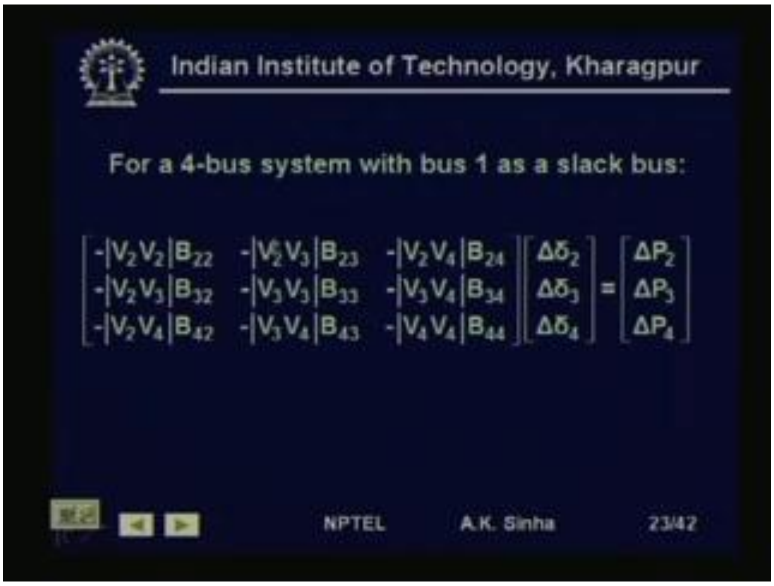

Now, if we take a 4 bus system where bus 1 is a slack bus then we can write the expression for J 1 into delta is equal to delta P in this form as V 2 into V 2 B 2 2 minus V 2 into V 3 B 2 3 minus V 2 into V 4 B 2 4. And similarly V 2 V 3 into B 3 2 V 3 V 3 into B 3 3, this that is what we have if got is V 2 V 2 into B 2 2 into delta 2, delta deta 2 minus V 2 into V 3 B 2 3 into delta delta 3 and so on. So, this is the expression that we have got these are the Jacobian element, Jacobian matrix elements.

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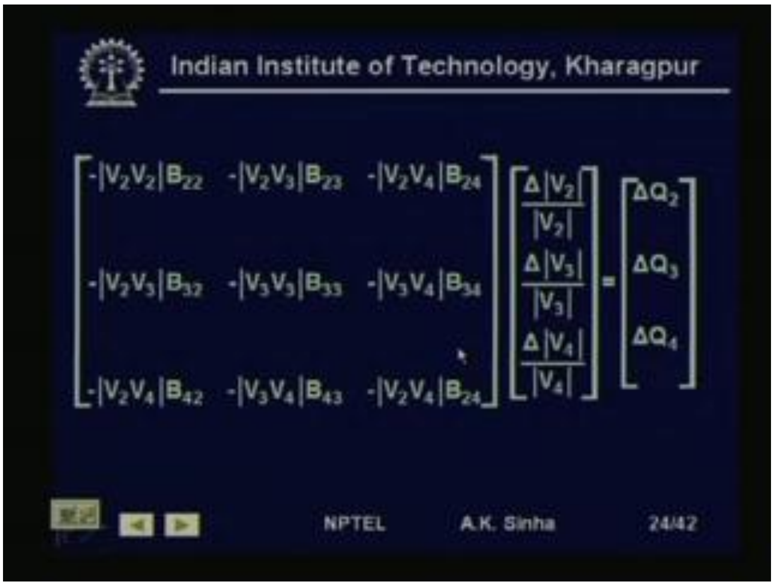

Similarly, for the other expression that is for L into delta V by V is equal to delta Q expression we have got like this which is V 2 into V 2 B 2 2 in this form.

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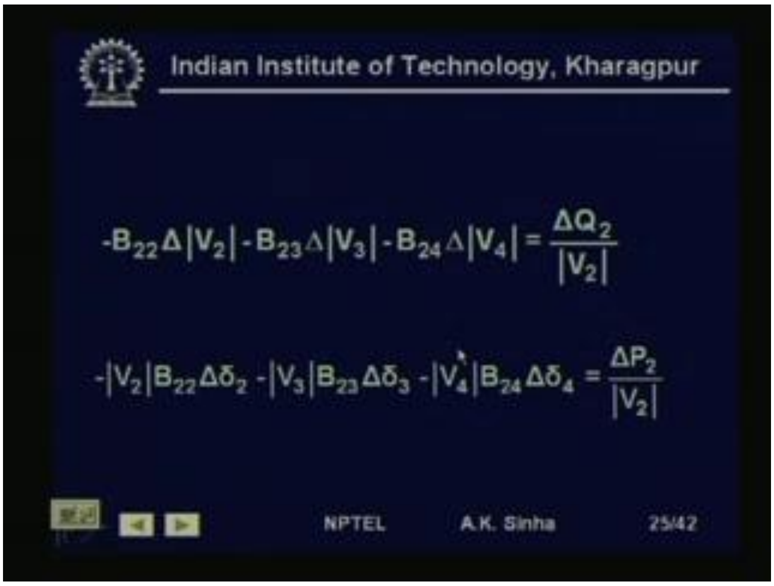

So, now if we take up 1 equation then we have say this equation for the first row that is delta Q 2 is equal to B 2 2 minus B 2 2 delta V 2 minus B 2 3 delta V 3 minus B 2 4 delta V 4 this is what we will get. Here we had this term V 2 2, V 2 into V 2 V 2 into V 3 V 2 into V 4. So, what we have done is we have taken out that V 2 term and divided it here.

Similarly, for the expression from here again ((Refer Time: 35:56)) we will get V 2 2 V 2 into V 2 B 2 2 minus V 2 into V 3 B 2 3 minus V 2 into V 4 B 2 4 into this term into delta 2 this term into delta 3 this term into delta 4 is equal to delta P 2. Now, these V 2 terms in this if we take out and divide on this side, this equation remains same. So, what, that is what is we have done. So, we have minus V 2 into B 2 2 delta delta 2 minus V 3 into B 2 3 delta delta 3 minus V 4 B 2 3 into B 2 4 into delta, delta 4 is equal to del P 2 by V 2.

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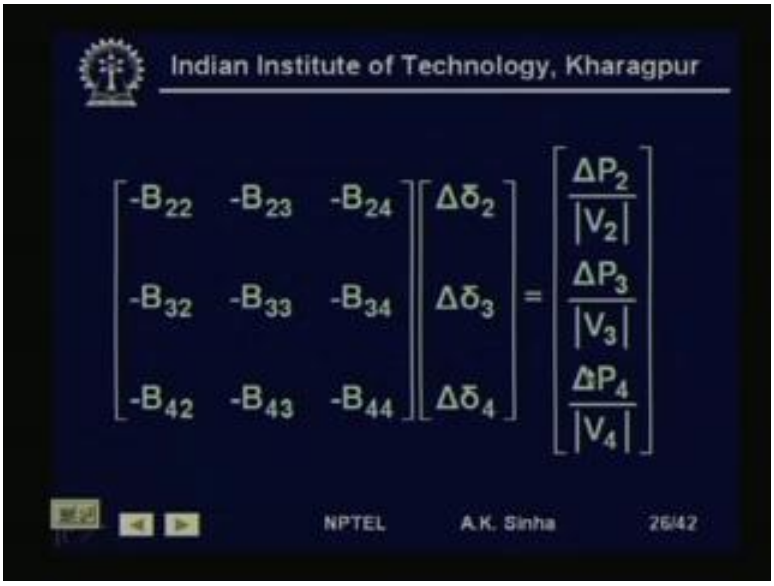

So, from here we can, now see we can write this expression here like this, minus B 2 2 minus B 2 3 minus B 2 4 and so on; into delta delta 2 delta delta 3 delta delta 4 is equal to delta P 2 by V 2 delta P 3 by V 3 delta P 4 by V 4 in this way.

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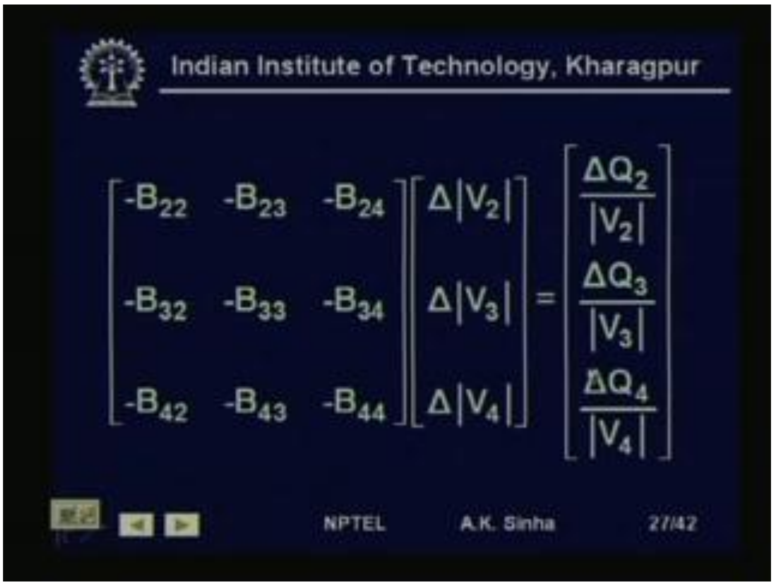

And similarly for the other expression we have again minus B 2 2 minus B 2 3 minus B 2 4. So, this matrix we have this matrix which is containing terms of susceptance only this is delta V 2. Now, this term that we had multiplied V 2 here and we have divided V 2 V 3 here. So, this we have taken out. So, this again now a constant term this is delta V 2 delta V 3 and delta V 4.

And this V 2 we had divided, so we are getting del Q 2 by V 2 del Q 3 by V 3 and del Q 4 by V 4.

Now, what we have seen from these two sets of equation that the matrix Jacobian matrix here is only the susceptance elements. And therefore, these are constants, they are not depend on the state variables. And therefore, these remain constant throughout the different iterations. So, they do not say with the iterations.

Now, if they do not change with the iterations means we do not need to compute these elements each time. that is one advantage. The other advantage is once we have triangularized these matrices, we can keep the matrix elements stored. Because they are not going to the change and what we need to change is only do a forward operation on this vector. And then using a back substitution we can calculate the value of the unknown's delta V and delta delta. So, this is a great advantage that we get because the matrix is now a constant matrix, we can store the factors of this matrix or triangularized matrix. And we can use them in each iteration.

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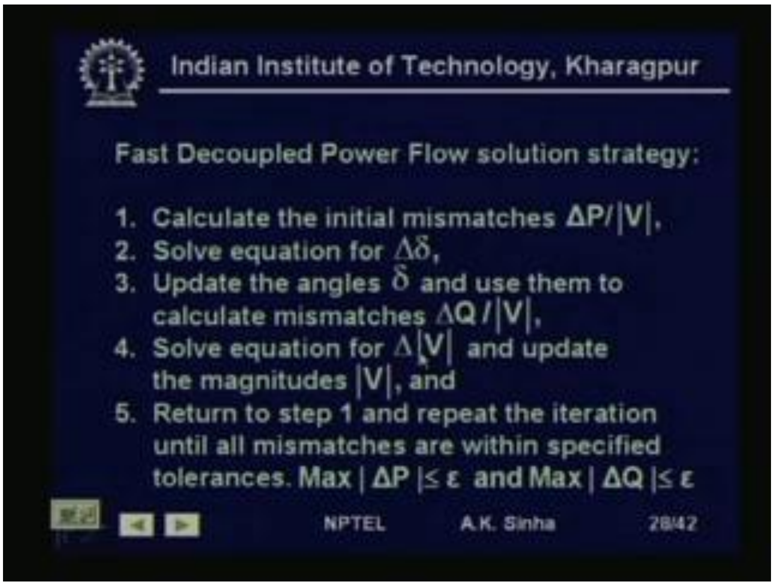

This considerably reduces the computational requirement for this method and this is why this method is called a fast decoupled power flow method, because this is much faster and it uses a decoupled relationship. That is P delta and Q V relations are decoupled, that is P is decoupled from V and Q is decoupled from delta.

Now, the algorithm for fast decoupled power flow is as such, calculate the initial mismatches del P by V. Solve for delta delta. Update the angles delta and use them to calculate mismatches del Q by V. Solve the equation for delta V and update the magnitudes of V. And return to step one and repeat the iteration until all mismatches are within specified tolerances.

That is maximum delta P is less than some tolerance value that we have and maximum delta Q is less than some tolerance value. So, what we need to do is, if we see here ((Refer Time: 41:02)) what we do is this matrix is already available, because we know the susceptances for the system.

We compute these elements and solve for this. Once we get these values, we add it to the pervious values of delta, and so we get the new values of delta. Once we have got these values of delta, using this we will compute the elements of this vector that is del Q by V vector right, and since this matrix is already known. So, we will compute this by solving this equation. So, we once we get this delta V's, we add it to the previous value previous iteration values of V and we get the new values of V. And then we go back and again compute these values with the new values of V obtained and solve for delta delta.

And this way we keep on repeating the iteration till we find that, the value of delta P for all the elements or all the buses and delta Q for all the buses or with the limits. So, if wells that happens, then we have got the values of B and delta and using this we can calculate all the power flows in the transmission lines slack bus powers and P V bus Q values.

Now, if we have any P V bus in the system, then the row and column for that bus will not be there in the matrix for this expression. So, the two matrices this matrix is generally termed as a B dash matrix that is B dash into delta delta is equal to del P by V. And this matrix is called B double dash matrix. So, B double dash into delta V is equal to del Q by V. So, this is the expression that we have and this is the algorithm that we use for solving the power flow using fast decoupled power flow method.

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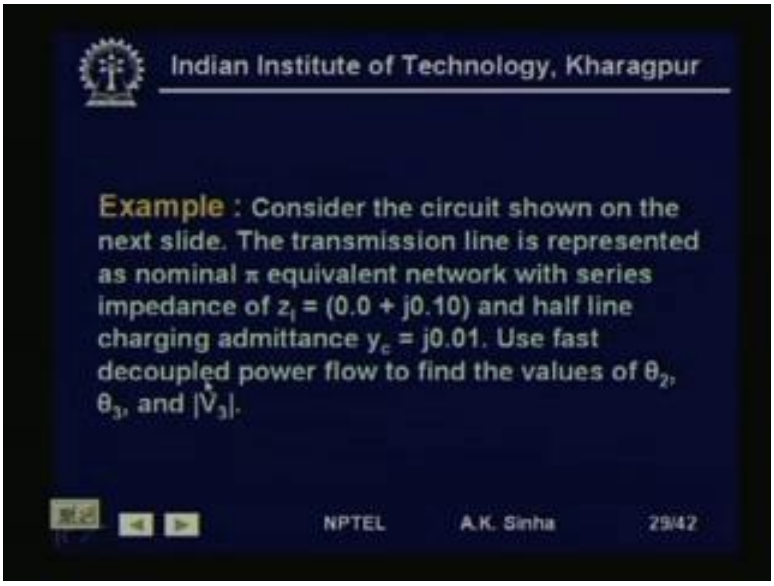

Now, we will take one example for solving a power flow using fast decoupled method. So, consider the circuit shown on the next slide the transmission line is represented as nominal pi equivalent network with series impedance Z l is equal to 0.0 plus j 0.1 and half line charging admittance Y c is equal to j 0.01. Using fast decoupled power flow find the values of theta 2 theta 3 and V 3.

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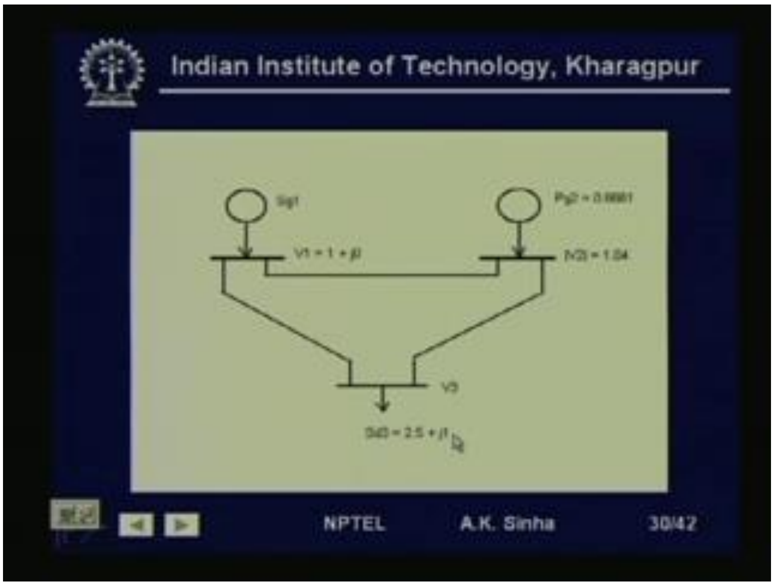

Now, if you see this system this is a 3 bus system. This bus 1 is a slack bus, where the voltage is specified as 1 angle 0 that is 1 plus j 0. Bus 2 is a PV bus where we have the real power injection given as 0.6661 per unit. And the voltage magnitude at this bus is given as 1.04 per unit. Bus 3 is a PQ bus, where the load value is given as 2.5 plus j 1.

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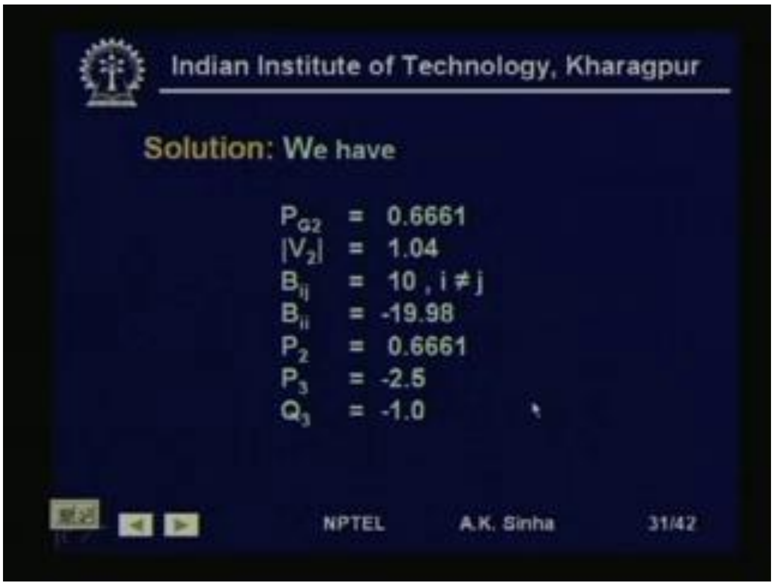

Now, using the transmission line impedance values, we have got B i j is equal to 10 for I not equal to j that is B 1 2, B 1 3, B 2 3, B 3 2 all these terms will be equal to 10, because it is equal to 1 by 0.1 j 0.1. So, that becomes minus j 10. And B i i is equal to minus 19.98, because we add all the susceptances connected to the bus plus the half line charging of the 2 lines at that bus.

This we had already calculated in the previous lesson. So, I am just substituting those values. We have been given PG 2 is equal to 0.6661 and V 2 as 1.04. We have, therefore P 2 the real power injection at bus 2 is equal to PG 2 minus PD 2, the demand at that bus. Since the demand at that bus is 0 or the load at bus is 0.

So, P 2 is equal to 0.6661. P 3 is P G 3 minus P D 3. So, P G 3 is 0. So, P D 3 is 2.5. So, P G 3 minus P D 3. So, P 3 is equal to minus 2.5. Similarly, Q 3 is equal to Q G 3 minus Q D 3. So, Q G 3 is zero and Q D 3 is 1.0. So, Q 3 is equal to 0 minus 1.0 which is minus 1.0.

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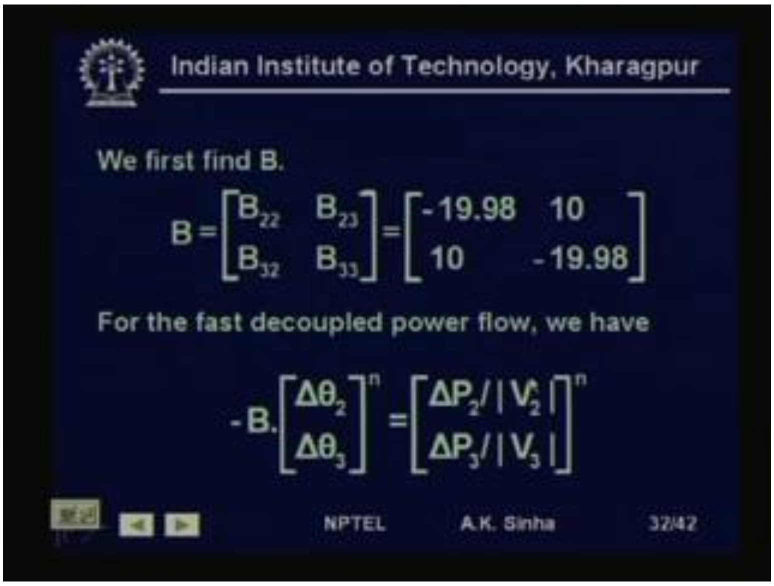

Now, we have to find B matrix. So, B matrix is B 2 2 B 2 3 B 3 2 B 3 3, because bus 1 this is slack bus. So, here we have the values substituted. Now, for fast decoupled power flow we have minus B into delta theta or delta delta is equal to del P by del V.

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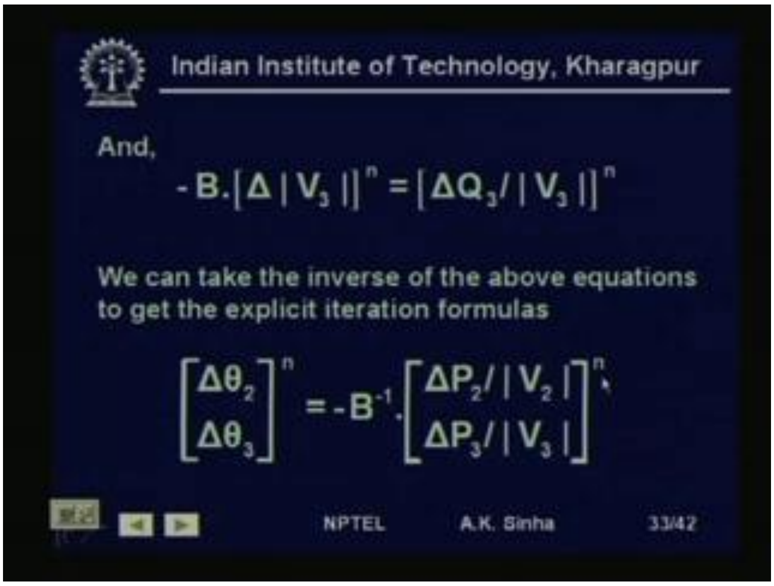

So, and we have minus B into del V is equal to del Q by V. Now, we can take the inverse of above equations to get, that is we can solve this by using minus B inverse into this will give me this. And similarly minus B inverse into this will give me this that is delta theta or delta delta. Whatever you write at nth iteration is equal to minus B inverse into delta P by V at nth iteration or we can write delta theta 2 delta theta 3 at nth iteration, this is the value of B inverse.

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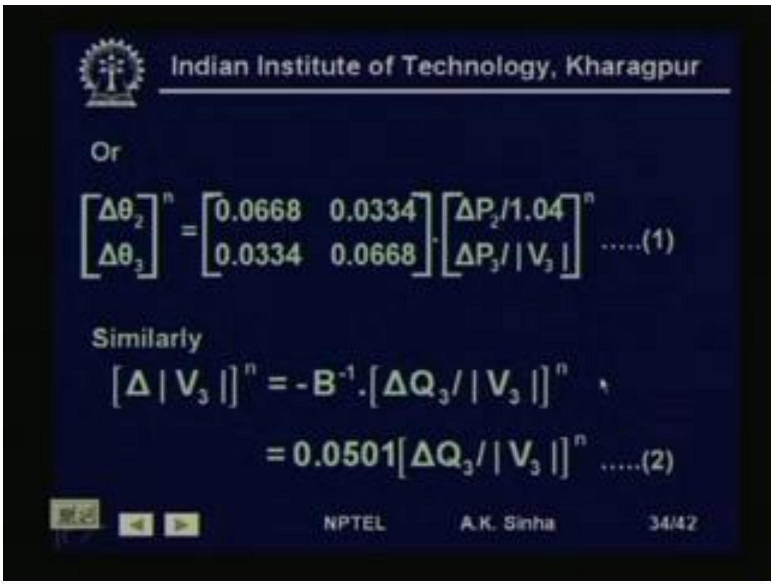

So, this into this will give me the value of this. Similarly, del V 3 at n is minus B inverse into del Q 3 by del V 3. Now, here this, since we have only V 3 that is bus 3 terms available. So, the in this case minus B inverse will be only the inverse of this term. So, B is given like this and for the Q equation, we have only for bus 3. So, bus 2 row and column is eliminated and we have only B 3 available. So, we using this we get del V 3 as this much.

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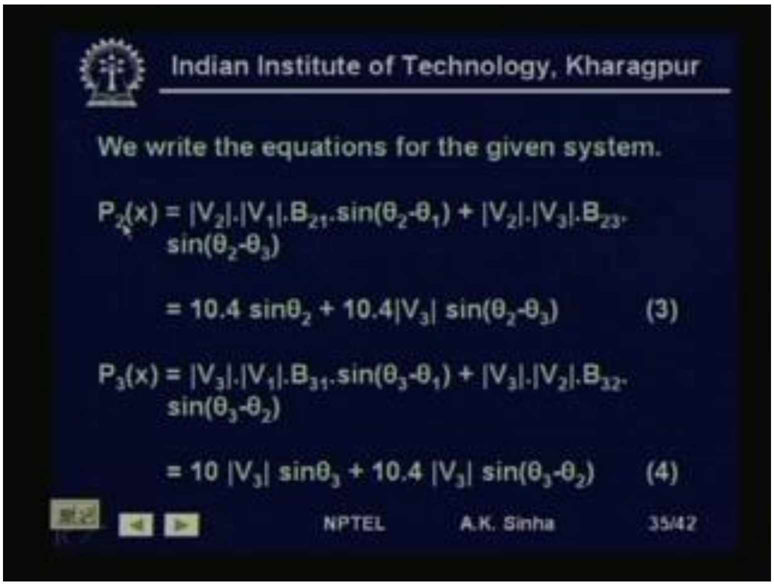

Now, we can calculate the value of injection at bus 2 and bus 3 using the value of V and theta or delta, that is the phase angle using the expression for real power injection at bus 2 and 3.

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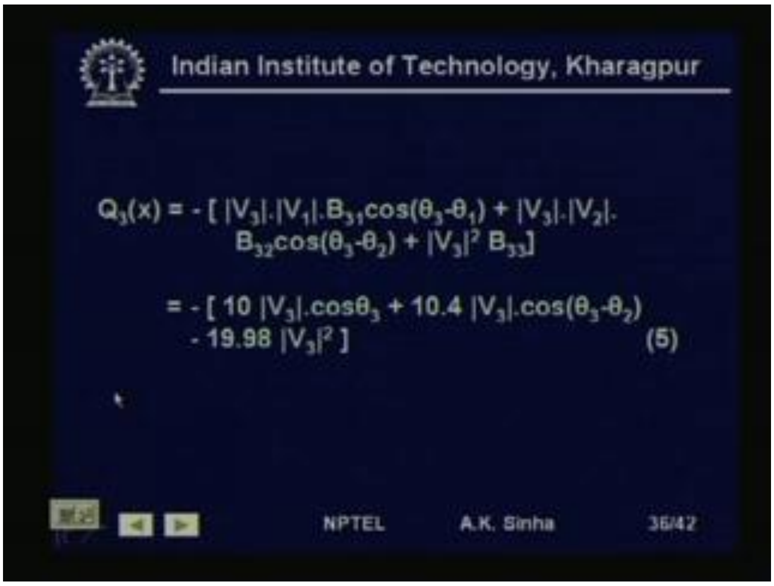

And similarly the reactive power injection at bus 3.

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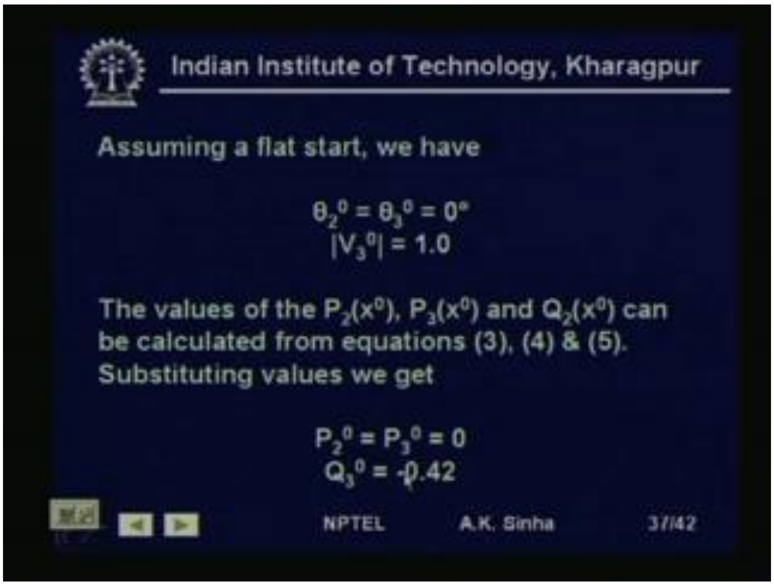

So, once we take or assume a starting value the starting value normally as we said earlier we assume as a flat start. So, theta 2 and theta 3 at the starting point is 0 degrees and V 3 at starting point is 1 per unit. The values of P 2 at the starting point P 3 at the starting point and Q 2 oh Q 3 at the starting point can be calculated this should be Q 3 at the starting point can be calculated from these equations. Substituting the values we get P 2 is equal to P 3 is equal to 0 and Q 3 is equal to minus 0.42.

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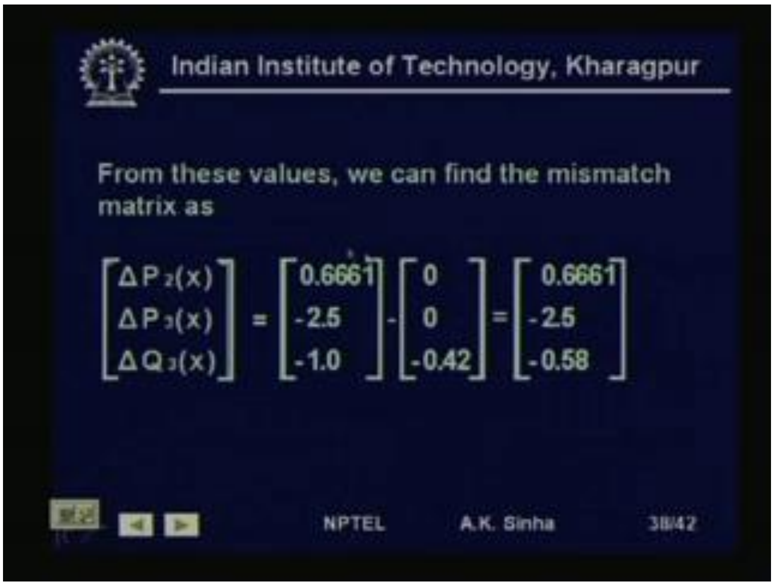

Now, now substituting these we can find the mismatches like this. So, we will have the mismatch values as 0.6661 minus 2.5 and 0.58. That is delta P 2 is 0.6661 minus 0, delta P 3 is minus 2.5 minus 0, delta Q 3 is minus 1 minus 0.42. So, this will give you delta P 2 is equal to 0.6661, sdelta P 3 is minus 2.5. Delta Q 3 is minus 0.58.

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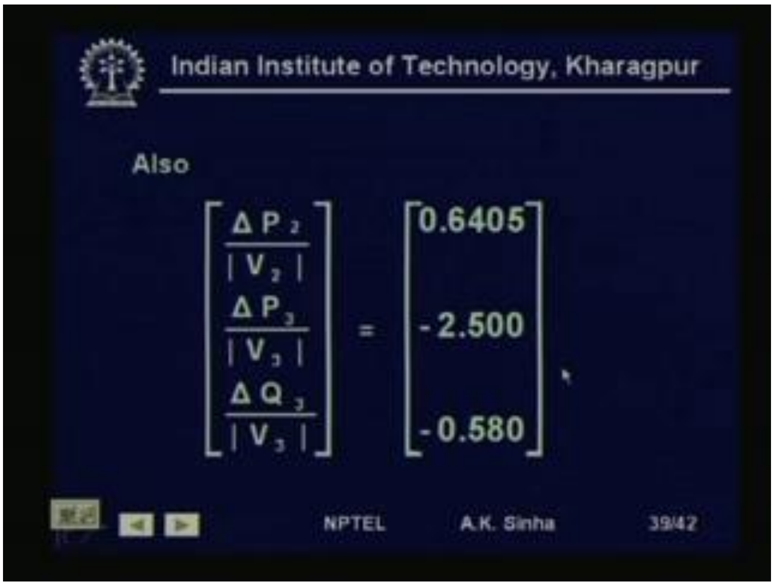

So, once we have that then we have this del P 2 by del V 2. So, V 2 is given as 1.04. So, 0.6661 divided by 1.04 gives me this. Del P 3 by del by V 3, now V 3 is 1.0. So, we get this same as 2.5 minus 2.5 by 1, which is same as minus 2.5. Del Q 3 by V 3 as minus 0.580 by 1, which is same as 0.5 is a minus 0.580.

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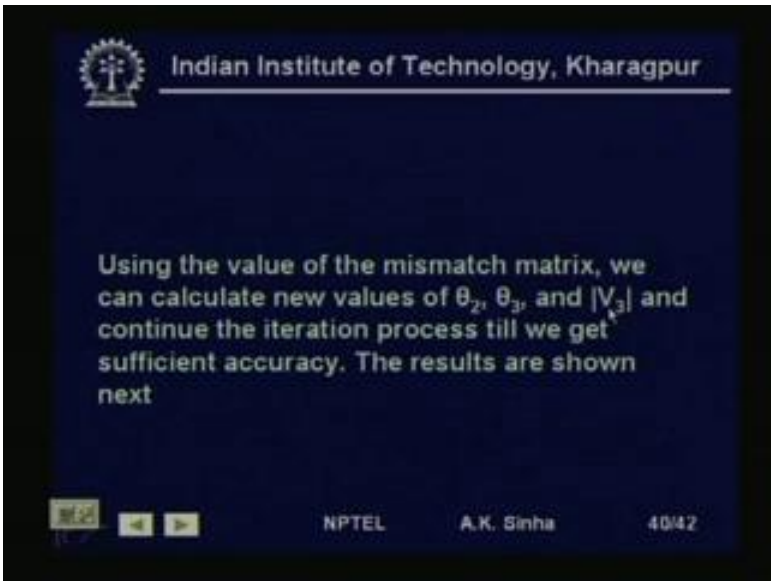

Using the value of mismatch matrix, we can calculate the value of theta 2 theta 3 and V 3 and continue the iteration process till we get sufficient accuracy.

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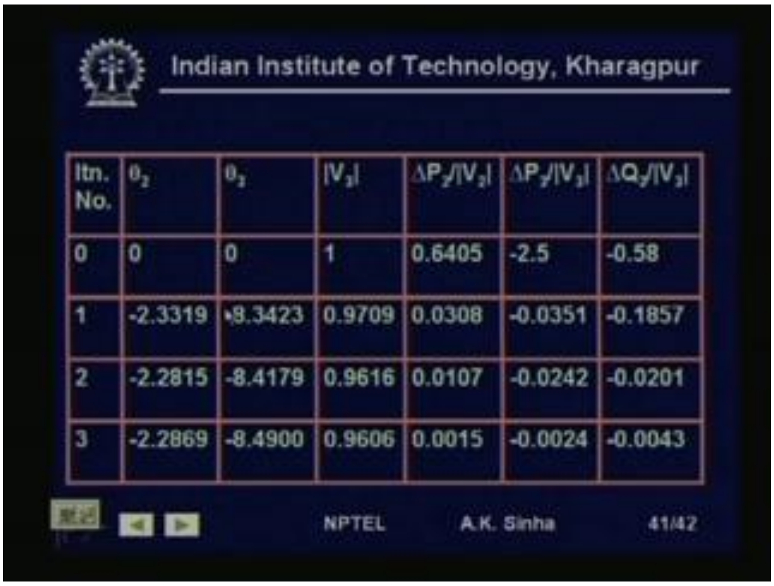

Itn. No.	θ_2	θ_3	$\lvert V_3\rvert$	$\Delta P_2/\lvert V_2\rvert$	$\Delta P_3/\lvert V_3\rvert$	$\Delta Q_3/\lvert V_3\rvert$
0	0	0	1	0.6405	-2.5	-0.58
1	-2.3319	-9.3423	0.9709	0.0308	-0.0351	-0.1857
2	-2.2815	-8.4179	0.9616	0.0107	-0.0242	-0.0201
3	-2.2869	-8.4900	0.9606	0.0015	-0.0024	-0.0043

The results are shown here. That is the initial values we have theta 2 theta 3 as 0 and V 3 as 1 and these are the value of P 2 by V 2 P 3 delta P 2 by delta P 3 by V 3 and delta Q 3 by V 3. After first iteration the values of theta 2 theta 3 and V 3 come out like this.

And then when we calculate the new values we get the new values like this. Again using these values when these compute we get theta 2 theta 3 and V 3 like this. And when we again we find mismatches we are getting like this. Again substituting those values we will get these values of as the angles and the voltage magnitude. And here we find that the mismatches have reduced considerably and since we have used our tolerance value to be of the order of 0.005. So, these have converged. So, these are the final value of theta 2 theta 3 and P 3.

Thank you very much.

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Welcome to lesson 21. In this session we will continue with the Power Flow problem.

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In this lesson we will first take up a power flow problem for large power systems how you implement it what are the implementation aspects. One of the aspects which we will look at will be sparse matrix methods and it is application to power flow problem. And then we will also look into the modeling of regulating transformers in power flow problem.

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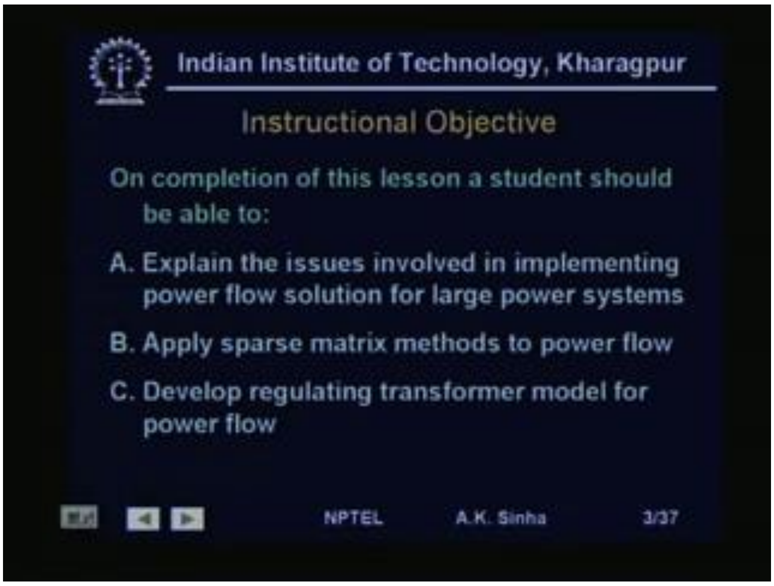

On the completion of this lesson you should be able to explain the issues involved in implementing power flow solution for large power systems. Apply sparse matrix methods to power flow and develop regulating transformer model for power flow solution.

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Now, what are the types of power flow methods that we have learnt earlier. We have discussed about the Gauss Seidel method for solution of power flow problem, then we looked into the Newton Raphson method. Then we tried to take advantage of the physical property of the power system; where the real power and voltage phase angle close association. And reactive power and the voltage magnitude closer association was taken into a account. And the power flow equations were decoupled into P delta and Q V chooses a problems. And then we saw that by taking certain physical characteristics of the power system.

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Now, let us see if we the factorization for this kind of a matrix what happens. Now, if we take a matrix like this, that we have used earlier the same matrix, and if you try to use the gauss elimination method for factorizing this matrix then.

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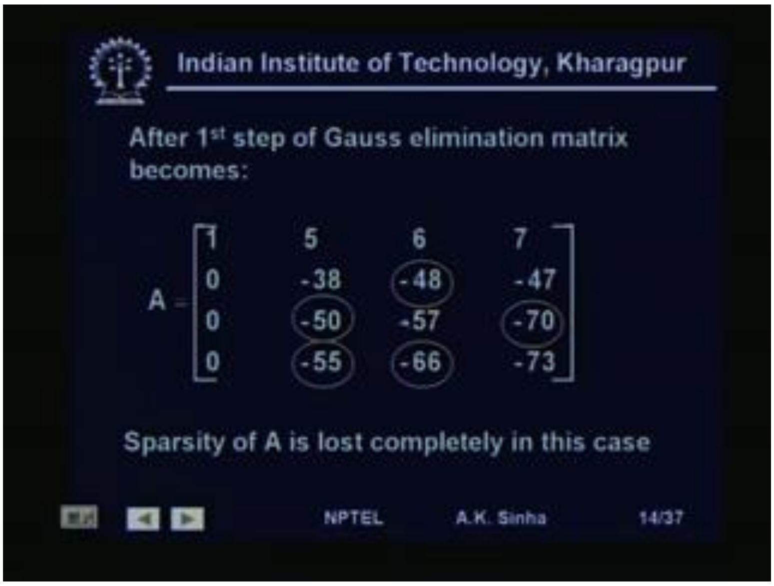

After the first step of Gauss elimination that is reducing all the elements in the first column as 0's what we will have is all these elements which were zero or now getting filled in. That is instead of a Gauss matrix now we have a completely full matrix. That means sparsity is lost, because we get large number of fill in's in this case.

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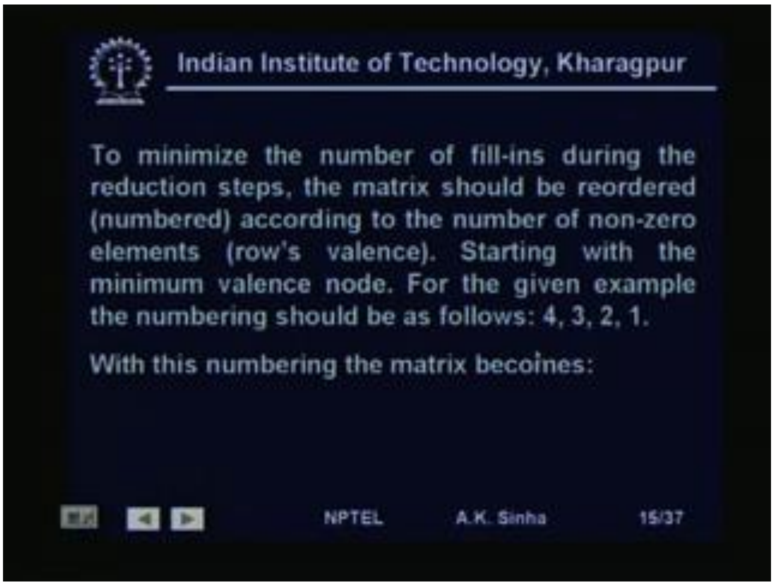

Now, let us see what we can do about it. So, if we are trying to advantage of sparse matrix and we want to use this sparse matrix method. If we go through the factorization just like that for the given matrix, then we find that this sparsity is no longer maintained because large number of fill in's will come. So, what we do to minimize these fill in's.

So, to minimize these fill in's during the reduction step the matrix needs to be re ordered or re numbered according to the number of non zero elements, which in each row, which we call the rows valance. So, if we take any row and see how many non zero elements are there in that row and we call that as the rows valence.

So, if we pick up the rows, which have minimum number of non zero elements or the rows with minimum valance or ordered as row number 1 and so on. We go tell we reached the last row which will have the largest number of non zero elements. Then we will talk about the regulating transformers and how we can model them in a power flow solution.

And then we will see some comparison of the Newton Raphson load flow and fast decoupled load flow algorithms. So, with this we will stop today. And we will take up in the next lesson, the other things as I discussed just now.

Thank you very much.