Economic Operation and Control of Power System

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Week - 05

Lecture – 25

Hello and good morning everyone. Welcome you all for the NPTEL online course on Economic Operation and Control of Power Systems. Today's lecture will discuss about transmission system effects, mainly we will emphasis on load flow analysis and overview about it. So, the networks incremental power losses cause a bias in that optimal economic scheduling of the generators. Ultimately, we need to consider incremental power loss because unless if we ignore them, then we are not able to you know optimally find out the economic scheduling. So, the total real power loss increases the total generation demand.

The power flow forms the basis for the development of loss factors for predicting the real power loss. And the generation schedule may need to be adjusted by shifting the generation to reduce flows on the transmission circuits because they would otherwise becomes overloaded. So, transmission line effects means how optimally you design the scheduling of multiple generators considering the reduction in the transmission line losses and also the line circuits should not be overloaded, right. This is the constraint that need to be considered.

So, it is difficult to include the line limit in optimal dispatching. So, that is a difficult task and the power flow must be solved to check for violations. Means how do you check the violations because you need to know the different bus voltages and angles, right. So, then you will understand what is the line flow which is happening, then you will understand what is the thermal capacity of individual line for a given dispatch of generation. Then you ensure that this considered specified reactive power and active power generation will not be more than the limits that the transmission line can carry.

So, the power flow is the name given to a network solution that shows currents, voltages and active and reactive power flows at every bus within the system. Some assumptions we consider balance system, positive sequence solution only, right. So, often we find a negative sequence parameters. So, we consider positive sequence solution and it is a balanced system and in transmission level it is more or less balanced only. In distribution system you may find unbalance and simple generation and load models are considered.

So, it is a non-linear problem. It relates active and reactive power consumption and generation with voltage magnitudes. It uses design procedures, study unique operating problems and provide accurate calculations of loss penalty factors. So, the power flow problem consists of a given transmission network. Lines are represented by pi equivalent circuit.

There are two types of modeling you know I have already discussed in 330 course. It is T type and pi type. So, for medium line, so for short length line we consider it to be lumped, right. So, for medium length line it is T modeling or pi equivalent circuit. Now, the transformers are represented by a series impedance circuit.

Just represent the transformer with the series impedance circuit and generators and loads represent the boundary conditions. Loads are given as active and reactive power consumptions. Generators are usually described with the active power production and the terminal voltage. I will discuss about different types of buses, I will give an overview. So, the general power flow equation is one set of equations for each bus in the network.

So, basically P and Q. P injection is nothing but:

$$P_{inj-i} = \sum_{k=1}^{N} |E_i||E_k|\left(G_{ik}\cos(\theta_i - \theta_k) + B_{ik}\sin(\theta_i - \theta_k)\right)$$

$$Q_{inj-i} = \sum_{k=1}^{N} |E_i||E_k|\left(G_{ik}\sin(\theta_i - \theta_k) - B_{ik}\cos(\theta_i - \theta_k)\right)$$

▶ if a branch exists between nodes i and j

$Y_{ij} = -y_{ij}$

And $Y_{ii} = y_{i0} + \sum_j y_{ij}$

What is alpha ij? Alpha ij is the angle, angle of the admittance which is present between bus i and bus j, right. So, building the bus admittance matrix, this is very important to solve any road flow analysis bus admittance matrix need to be known. So, modelling the transmission network of complex impedance is as related to the system buses include the line transformer ancient element impedances. So, general construction rule if a branch exists between nodes i and j, then Yi j is nothing but this is admittance this is nothing but minus Yi j, right. So, negative and Yi i that means these are all off diagonal elements, these are all off diagonal and these are diagonal elements.

So, diagonal elements Vi i i is nothing but Yi 0 plus summation of j Yi j whatever the admittance which are connected to that specific bus simply added. So, in the case of off diagonal just take minus of it and represent it. So, where j is defined for all branches connected to it. This is simple because when we want let us say if there is node 1, node 2, node 3, right. So, this then what you will do? Simply if there is V1, V2, V3 and let us consider this to be V1, V2 ground let us say there is a ground here, this is grounded, right and this is also grounded.

Let us say there are you need to find out the voltage between the current flowing between V1 and V2. So, how do you find out? I say this is I1, this I1 is nothing but V1 minus V2 by R1, right. This is let us say this is R1, V1 minus V2 by R1. So, what you are doing here? V1 by R1 minus V2 by R1. So, this what is happening? And if this is I1 which is flowing from node 1 to node 2, so that means this is positive and whatever is though there is a positive impedance present, when we express with respect to the second bus this is always 1 minus 1 by R1 negative.

This is the thing. If you want to you know do it for the second bus, what we will do is V2 minus V1 by R1. So, then it will be V2 by R1 minus V1 by R1. When we have to consider the current flowing between bus 2 to bus 1, it will be exactly opposite. So, this is very simple thing. So, define bus characteristics based on typical information available.

So, power flow bus specifications are three types of bus.

Bus Type	Specified	Unknown
Slack Bus	V, θ	No unknown
P-V Bus	P	θ
P-Q Bus	P, Q	V, θ

Slack bus, PV bus and PQ bus, right. Slack bus, PV bus and PQ bus. So, slack bus where voltage and angle is known and unknown parameters are P and Q. Unknown parameters are actually P and Q that you will find out after solving all the node flow analysis.

Initially to start with we ignore slack bus consideration, henceforth we have considered no unknown. So, we ignore in any Gauss Seidel or any Newton Raphson or any of the methods, we simply ignore the calculation of slack bus. But ultimately when you find out the voltage and angle for all the buses, then we will find out P and Qs generated by the slack bus because that will also include the losses. And there is PV bus. In PV bus what is known? PQ bus power is known and voltage is known.

Whereas, unknown is theta, Q. Whereas, in PQ bus P and Q is known and voltage and angle is unknown. So, that means what happens? Let us say there is a N bus system. And then this includes N bus means this represents slack bus, PV bus and there is a PQ bus. Because slack bus for the entire system there will be only one slack bus, one reference bus basically where we consider voltage and angle as a reference.

And then PV bus means active power is known, voltage is known. So, let us consider the total M generator buses. M generator buses in among N buses if there are M generator buses, then how many PQ buses will be there? It will be just N minus M. These are all load buses. PQ bus is nothing but load bus.

So if N is the total number of bus, M is generator bus and N minus M is the PQ bus. That means how many PV buses will be there? It will be N M minus 1. M minus 1. M are the generator buses.

One is slack bus. Slack bus plus PV bus is equal to generator bus. So PV bus is nothing but total generator bus minus slack bus which is M minus 1. This is M. This is nothing but your N minus M. N number of buses, M total generator buses.

It will be N minus M load buses. So that means in a system how many unknown variables is there that many known parameters should be there. So that means known equations, then you unknown variables. It should be same. Then only you can solve. So let us say in slack bus as I already told, let us ignore the slack bus and PV bus.

P is there. P which we know. So P we know, V also we know. So what are the parameters we know? P is equal to how many P we know totally which is equal to N minus 1. Because you understand we are ignoring slack bus. For PV bus we know P, for PQ bus also we know P. So total known variables is N minus 1 P.

And how many known Q will be there? No, how many known Q will be there? In PV bus and slack bus we do not know P, sorry Q. So it will be N minus M. So how many known parameters are there? N minus 1 plus N minus M. So it will be 2N minus M minus 1. These are the things we know, active and reactive power.

So in case how many unknowns we know, how many unknowns that we need to determine? So basically voltage and angle. So in how many angles we do not know basically? How many angles that we do not know? Angles we do not know in PV bus, angles we do not know in PQ bus also. So it will be N minus 1 theta we do not know, unknown. And how many V we do not know? In PV bus we know what is voltage. In slack bus, slack bus anyway is not considered.

So it will be N minus M voltages that we do not know. So N minus 1 angle we do not know, N minus M voltage we do not know. Whereas N minus 1 active power we know and N minus M reactive power we know. This put together it will be 2N minus M minus 1. So we know 2N minus N minus 1 known things, 2N minus M minus 1 unknown things.

So it is same. We can solve the load flow equations basically. So the AC power flow, let us say the first approach is Gauss-Seidel method. So in Gauss-Seidel first AC power flow method developed for digital computers method as linear convergence governing, this is the governing equation. So this is basically how we get it. Current injection at every bus is equal to summation of k is equal to 1 to N, yik Vk.

This is admittance yik into Vk. So this can be expressed as yii Vi plus summation of k is equal to 1 to N, k is not equal to i, yik Vk. So then by using this expression now we will come out with this expression. What we would like to know? Ek is nothing but:

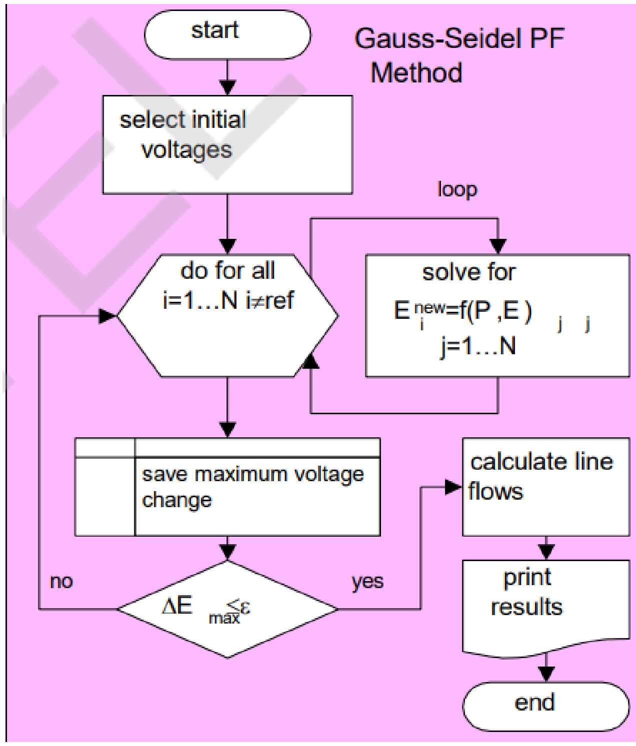
$$E_k^{[\xi]} = \frac{1}{Y_{kk}} \left[\frac{P_k^{[sch]} - jQ_k^{[sch]}}{E_k^{[\xi-1]*}} - \sum_{j<k} Y_{kj}\, E_j^{[\xi]} - \sum_{j>k} Y_{kj}\, E_j^{[\xi-1]} \right]$$

So what is i? P minus jQ divided by V star. That is what is this here. This is current. The current divided by admittance is the voltage. That is what we are getting here, voltage. Current divided by the admittance is the voltage and this is for j is equal to k.

And for j less than k, ultimately j varies from 1 to N total. So for j less than k, found out the voltages. That means you are in the same iteration level. Now you replace with the initial values with the updated values.

So what you are getting? Ykj into Ej zeta. If you know this is nothing but the Ykj into Ej is nothing but current, admittance into voltage is current. Now current divided by the admittance again is the voltage. So you will get the same expression. Minus summation of j is greater than k, Ykj Ej you can see here is zeta minus 1.

Zeta minus 1 means we do not know the future one. After j comes k, right? After j comes k. So that means when we are in the kth level of iteration, then we know that you know previous level of voltages we know already. So that is why we consider zeta. After j is greater than k, we do not know. The flowchart of Gauss Seidal Power flow is given by:



So we consider the assumed initial values. So it is zeta minus 1. So by this we will get the voltages and then this is the overall flowchart. Start select the initial voltages. Why we need to select? Because for the PV bus we know the voltages already.

But for the PQ bus you do not know the voltage. What we will do is we go for the flat start. Flat start means angle voltage is considered to be 1 per unit and angle is considered to be 0, right? So because even in real time the voltages will be close to 1 per unit and angle will be you know 5 degree to 10 degree variation maximum. So this assumption is valid. So select initial voltages and for all the this thing for i is equal to 1 to n solve for the voltages again, right? As per the previous expression that I have given.

Then once you know, then save the maximum voltage change. Then ensure that the change in voltage is less than the tolerance limit. Then calculate the line flow otherwise in one doing keep on do the iteration basically. This is for the first iteration and then you go for the next iteration with the updated values, right? But the issue with the Gauss-Seidel takes like lot of time. So non-linear system solution techniques come then we go for Newton-Raphson method. Instead of treating each bus individually in each iteration, the correction is found for the whole system.

Newton's method is based on the idea of driving the error of a function to 0 by making a correction on all the independent variables. So, we can write:

- setting up the equation: $f(x) = k$
- pick a starting point x^0 : $f(x^0) + \varepsilon = k$
- use Taylor expansion about x^0 : $f(x^0) + (df(x^0)/dx)\Delta x + \varepsilon = k$
- setting the error to zero: $\Delta x = [df(x^0)/dx]^{-1}[k - f(x^0)]$

So Newton's method is an iterative process for a non-linear system of equations but it possesses quadratic convergence to a solution.

The set of first order partial differential equation is called the Jacobian. Now we will find out Jacobian. The set of power flow equations for each bus in the network, so this is the same expression that we have discussed earlier. So the injected powers on the left hand side are the knowns for a load bus, P and Q are known for the load bus. Now obtain the power mismatch or error is the difference between the left hand and the right hand side with a particular guess of voltages.

$$\Delta P_i^{[\xi]} = P_{inj-i} - \sum_{k=1}^{N} \left|E_i^{[\xi]}\right| \left|E_k^{[\xi]}\right| \left(G_{ik}cos\left(\theta_i^{[\xi]} - \theta_k^{[\xi]}\right) + B_{ik}sin\left(\theta_i^{[\xi]} - \theta_k^{[\xi]}\right)\right)$$

$$\Delta Q_i^{[\xi]} = Q_{inj-i} - \sum_{k=1}^{N} \left|E_i^{[\xi]}\right| \left|E_k^{[\xi]}\right| \left(G_{ik}sin\left(\theta_i^{[\xi]} - \theta_k^{[\xi]}\right) - B_{ik}cos\left(\theta_i^{[\xi]} - \theta_k^{[\xi]}\right)\right)$$

- the incremental correction is defined as
- $\Delta P_i^{[\xi]} = \sum_{k=1}^{N} \frac{\partial P_i}{\partial \theta_k} \Delta \theta_k^{[\xi]} + \sum_{k=1}^{N} \frac{\partial P_i}{\partial |E_k|} \Delta \left|E_k^{[\xi]}\right|$
- $\Delta Q_i^{[\xi]} = \sum_{k=1}^{N} \frac{\partial Q_i}{\partial \theta_k} \Delta \theta_k^{[\xi]} + \sum_{k=1}^{N} \frac{\partial Q_i}{\partial |E_k|} \Delta \left|E_k^{[\xi]}\right|$

Now there is something called as P specified and something called as P calculated. We are finding delta P and delta Q. So this is nothing but P injected minus this expression, this is calculated one. Q injected minus calculated one. Now the incremental correction is defined as delta Pi, delta Qi is nothing but dou P by, you can see here, four Jacobians are seen here.

dou P by dou theta represented by dou P by dou Ek, dou Q by dou theta, dou Q by dou Ek. That means J1, there are four Jacobians J1, J2, J3, J4. These are nothing but the partial differential equations of each variables known things P with respect to theta and P with respect to Ek, Q with respect to theta and Q with respect to Ek. Ultimately, there are four variables, P, Q, theta, voltage. I have already told these are known, these are unknown that need to be found out.

So each known is expressed with respect to each unknown, partially differentiated. So J1 is a matrix where you find terms in terms of dou P by dou theta. And what is the size of this matrix? dou P by dou theta. So I have already told N buses, M generator bus, M minus 1, PV bus, N minus M, PQ bus. Now how many knowns are there? N minus 1, that means it will be N minus 1 into how many? Theta that we do not know.

Again N minus 1. So this is a matrix of size N minus 1 into N minus 1. So J2 means it is nothing but dou P by dou V. This is dou P by dou V. J1 is active power with respect to angle, change in active power with respect to change in angle. Now J2 is nothing but change in active power with respect to change in voltage. So what is the size of this matrix? Then P, how many we know? N minus 1.

And then how many V that we do not know? N minus M, correct. Because it is nothing but PQ bus. PQ bus voltage that we do not know.

And J3 is nothing but again same thing. Now P is done. Go for Q. Dou Q by dou theta. And J4 is nothing but dou Q by dou V. Dou Q by dou theta is nothing but N minus M into N minus 1. This is nothing but N minus M into N minus M. So total put together, if there are let us say if there are four matrix J1, J2, J3, J4.

What is the size of this matrix one can guess? So ultimately there is Jacobian matrix J1, J2, J3, J4. The size of this is you see here. This is N minus 1 into N minus 1.

- The matrix representation of the incremental corrections

$$\begin{bmatrix} \Delta P_1 \\ \Delta P_2 \\ \vdots \\ \Delta Q_{n-1} \\ \Delta Q_n \end{bmatrix} = \begin{bmatrix} \partial P_1/\partial\theta_1 & \partial P_1/\partial\theta_2 & \cdots & \partial P_1/\partial|E_{n-1}| & \partial P_1/\partial|E_n| \\ \partial P_2/\partial\theta_1 & \partial P_2/\partial\theta_2 & \cdots & \partial P_2/\partial|E_{n-1}| & \partial P_2/\partial|E_n| \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \partial Q_{n-1}/\partial\theta_1 & \partial Q_{n-1}/\partial\theta_2 & \cdots & \partial Q_{n-1}/\partial|E_{n-1}| & \partial Q_{n-1}/\partial|E_n| \\ \partial Q_n/\partial\theta_1 & \partial Q_n/\partial\theta_2 & \cdots & \partial Q_n/\partial|E_{n-1}| & \partial Q_n/\partial|E_n| \end{bmatrix} \begin{bmatrix} \Delta\theta_1 \\ \Delta\theta_2 \\ \vdots \\ \Delta|E_{n-1}| \\ \Delta|E_n| \end{bmatrix}$$

- Deriving the Jacobian terms
  - Off-diagonal terms

$$\frac{\partial P_i}{\partial\theta_k} = |E_i||E_k|\left(G_{ik}sin(\theta_i - \theta_k) - B_{ik}cos(\theta_i - \theta_k)\right)$$

$$\frac{\partial P_i}{\partial|E|_k/|E|_k} = |E_i||E_k|\left(G_{ik}cos(\theta_i - \theta_k) + B_{ik}sin(\theta_i - \theta_k)\right)$$

$$\frac{\partial Q_i}{\partial\theta_k} = -|E_i||E_k|\left(G_{ik}cos(\theta_i - \theta_k) + B_{ik}sin(\theta_i - \theta_k)\right)$$

This is N minus 1 into N minus M. This is N minus M into N minus 1. This is N minus M into N minus M. So, how many rows are there? N minus 1 plus N minus M. These are N minus 1 rows. And then there are N minus M rows.

So, columns are divided into N minus 1 plus N minus M. So, this will be 2N minus 1 minus M into 2N minus 1 minus M. This is the size of the Jacobian matrix. Right? This is what we have expressed here.

So ultimately you get J into, this is Jacobian. This entire thing is Jacobian. J into delta x, let us denote this as x, x is state variables, theta and voltages. Right? So, what is the size of this matrix can somebody tell? Size of this matrix? This is equal to delta M. M is calculated. That is the specified minus calculated error.

That is delta P and delta Q will be there. Here what you will get? This is nothing but J1, J2, J3, J4 into delta x. x is nothing but what are there here? Delta theta and delta V. Here what you get? Delta P, delta Q. Delta P and delta Q. So, what is the size of this matrix? J1, J2, J3, J4 it is 2N minus 1 minus M into 2N minus 1 minus M. What is the size of this matrix? So, how many theta are there that we do not know? It is N minus 1. And how many voltages that we do not know? It is N minus M. Right? This is single one column matrix.

Then it will be 2N minus N 1 minus M into 1. This is your delta x. And delta M again is same thing. How many knowns we have? That means 2N minus N minus 2N minus 1 minus M into 1.

This is a column matrix. These two are column matrix. This is a square matrix. Got it? So, this is not just nothing but you know I have done some derivation that one can do. Dau P by dau theta, dau Q by dau theta and dau P by dau V and dau Q by dau V. So, the diagonal terms you get will be in terms of dau P by dau theta is nothing but minus Qi minus Bii Ei square. Bii is nothing but the susceptance.

Some of the susceptance present at that specific bus itself. These are all diagonal elements. That is why you see Ii. If there is IK, then it is off diagonal. So for diagonal terms:

- Off-diagonal terms

$$\frac{\partial Q_i}{\partial |E|_k / |E|_k} = |E_i||E_k|\left(G_{ik} sin(\theta_i - \theta_k) - B_{ik} cos(\theta_i - \theta_k)\right)$$

- Diagonal terms

$$\frac{\partial P_i}{\partial \theta_i} = -Q_i - B_{ii}|E_i|^2$$

$$\frac{\partial P_i}{\partial |E_i| / |E_i|} = P_i + G_{ii}|E_i|^2$$

$$\frac{\partial Q_i}{\partial \theta_i} = P_i - G_{ii}|E_i|^2$$

$$\frac{\partial Q_i}{\partial |E_i| / |E_i|} = Q_i - B_{ii}|E_i|^2$$

You get these expressions. If you do the partial differential equation, you will get to it. And then solving the incremental equation. Ultimately, you need to find out theta and voltages. What you will do is find out Jacobian into delta X that we do not know and delta M that you find out P specified minus P calculated. So you know delta M, find out Jacobian, then obtain delta X.

$$\begin{bmatrix} \Delta\theta_1 \\ \Delta\theta_2 \\ \vdots \\ \Delta|E_{n-1}|/|E_{n-1}| \\ \Delta|E_n|/|E_n| \end{bmatrix} = [J]^{-1} \begin{bmatrix} \Delta P_1 \\ \Delta P_2 \\ \vdots \\ \Delta Q_{n-1} \\ \Delta Q_n \end{bmatrix}$$

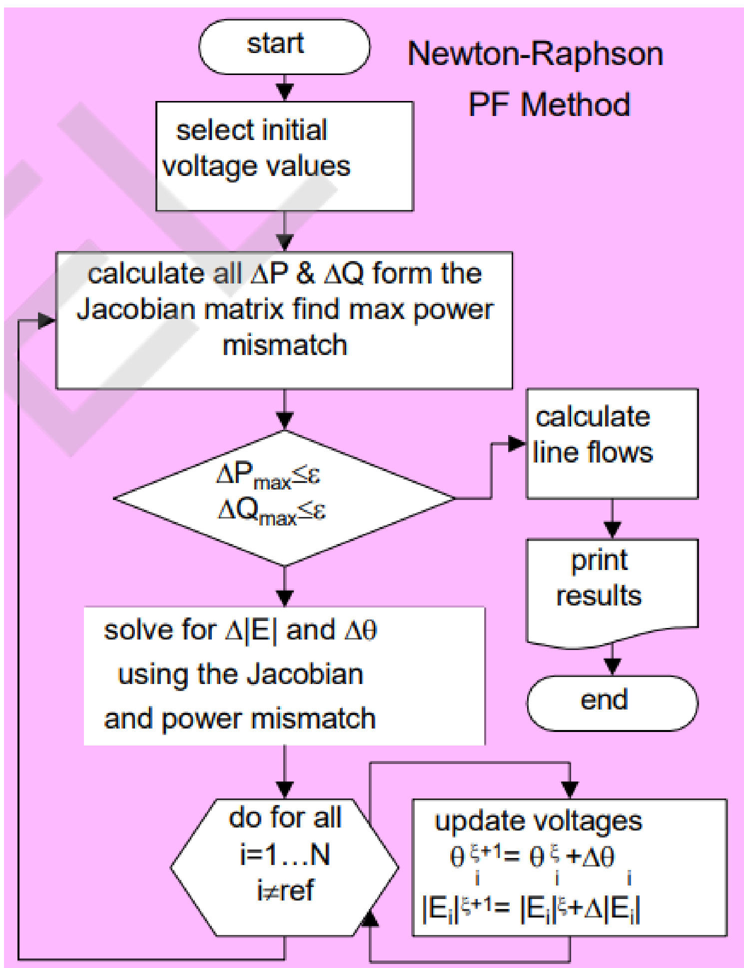
This is nothing but J inverse into delta M. Once you get delta X, that is updated angle and voltages. Then there is already previous voltages and angle, you add with that. Theta plus delta theta, voltage plus delta V. This is the updated values of voltages and this thing.

Then again you go for next iteration if it is not converged. So Gauss elimination is often used to solve directly for the changes in voltage magnitudes and angles instead of finding the matrix inverse of the Jacobian explicitly. The changes in voltage magnitudes and angles are added to the values that were used at the beginning of the iteration. Now this is the procedure. Select initial voltages values and calculate all delta P and delta Q from the Jacobian matrix and find maximum power mismatch.

P specified minus P calculated. And then if this within the tolerance limit, delta M is in the tolerance, then it is already converged. Then calculate line losses, line flows, print results. Otherwise solve for angle and voltages. Obtain Jacobian and with this obtain J inverse, then find out delta X that I have already told, which is J inverse into delta M.

Delta M is nothing but delta P, delta Q matrix that we have already calculated with the previous step. And then once this is done, then you update angle and voltages. Theta is nothing but previous theta plus change in theta. And voltages is nothing but previous initial voltage plus change in voltage delta E.

And then go for the next iteration. Find out delta P, delta Q and then check. So, this is just a problem that one can solve. I do not have solution here. Now there is something called as fast decoupled power flow, which is even updated one. So, here the Newton Raphson is the most robust algorithm that that is well used even in present day.



But if you need quick results, so then convergence time of fast decoupled is even I mean faster. So, you get the faster results compared to the Newton Raphson. The Jacobian matrix must be recalculated for each iteration. These are some of the drawbacks of this thing. The set of linear equations must be resolved for each iteration.

A faster method was sought after that is fast decoupled. So, what is the assumption? Because usually in transmission line X by R ratio is very very high, more than 10 or more than 20, then we can ignore resistance or conductance basically. Because X is greater than R that means, acceptance is only considered and conductance is ignored. And bus angles values are relatively close in value. So that is why we can consider cos of this is this theta change in angle is almost 0.

So sine angle is 0, cos is 1. So the simplification what basically several of the off diagonal terms tends towards 0 by doing this. And ultimately there is a relation established between p and theta, q and v. And the relation between p and v is ignored and relation between q and theta is ignored. Because usually decoupled means what? There is decoupled between active and voltage active and angle, active power and angle and reactive power and voltage.

So that is what we are doing actually here. So then you get dou p by dou e, dou q by dou theta, this is 0 basically, dou q by dou theta. And then you get dou p by dou theta and dou q by dou v. This is expressed in terms of susceptance only. And you get something like this, dou q by dou theta is p i minus g i i e i square which is 0. Then the remaining diagonal terms can also be reduced as dou p by dou theta is minus b i i e i square and dou q by dou e i by e i, this is normalized, this is nothing but minus b i i e i square.

So you get this, consider the 0 terms, incremental corrections can be rewritten as dou p i is, J 1 matrix will be there here, this is J 1 matrix. Dou q i is nothing but this is J 4 matrix basically. So in overall Jacobian will now reduce to J 1 0 0 J 4. Substituting in the reduced terms then you get this expression and dou q as, dou p with respect to angle and dou q with respect to delta q with respect to the voltage.

Then finally you get this expression. When you normalize with respect to e i, so you will get this delta p by delta e is nothing but minus b i k delta theta and delta q by e i is nothing but minus b i k delta e k. Then what you get? Now this is the expression similarly. So this is the Jacobian matrix J 1 and J 4. So resulting we express in terms of two matrix B dash and B double dash, this is a sub-tense matrix basically.

So this comes from the bus admittance matrix only. That means in the bus admittance matrix we consider only the imaginary parts, we ignore the real parts. So whatever is the admittance matrix Y, we consider N minus 1 terms for this theta, the dou p by dou e. So N minus 1 first diagonal elements will be considered and for here N minus M terms will be considered for the B double dash. This is for B dash.

So what is the advantage? So B dash and B double dash are constant because it is once calculated it is already there. It is a constant matrix. Line parameters will not change. So B dash and B double dash are constant. That means once you obtain this B double dash, B dash, B double dash, inverse it and keep it stored.

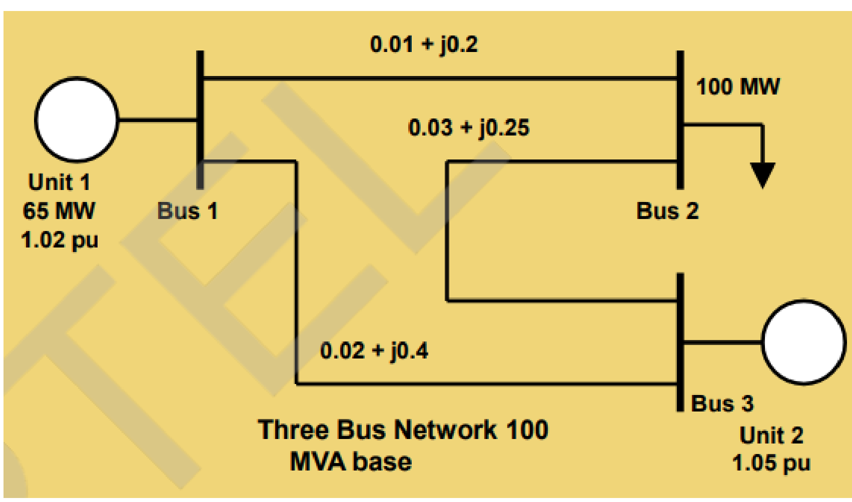
So you need not have to calculate the Jacobian inverse for all the iteration. So that will save lot of time. And calculate only once and only B double dash may need to change resulting from a generator where limit value. If there is a where limit value that may change because the B double dash is relevant to reactive power the last term and about one fourth of the number of terms found in the Jacobian.

So because the matrix will become very sparse. It is many zero entries will be there. So calculations will be very easy. So the disadvantage is solution convergence failure when underlying assumptions do not hold. That means if X by R ratio is less than 10 or 20 and angle is not within the limit. So there is something called as DC power flow.

Even if you can make it even more faster by ignoring voltage and reactive power totally. DC means there is no reactive power. So it is only active power. So what we express is active power with respect to theta is expressed here.

That is it. And only B dash is there. B double dash also matrix is ignored. So this is basically you get p i k is 1 by x i k theta i minus theta k because sine theta i minus theta k minus theta k is close to theta i minus theta k. And the power injection at each node is p i is equal to this expression.

B i k dash into theta i minus theta k. There is one problem. Solve for the megawatt flows. This is the system unit 1 65 megawatt and 3 bus system and flows calculated by the DC power flow. Then you get this.



The system equations are expressed and solution will come out to be angle like 0.02N minus 0.1 by using DC power flow. Then basically then the transmission losses if you consider, then generating units are identical if you consider two generator system and production costs are modeled using a quadratic equation. F1 of p1 is equal to F2 of p2 is equal to this quadratic expression is there. And the losses on the transmission line are proportional to the square of the power flow.

That both units are be loaded to 250 megawatt, the load would be underserved by 12.5 megawatt. Why? Because there is a loss which is happening. Then you obtain this is a Lagrangian equation. Cost of generator 1, cost of generator 2 Lagrangian multiplied divided by into constraint and loss expression is also there.

You remember we have discussed about penalty factor and all. So, that also need to be considered. So, finally, you get loss as this much and the overall cost will also include the loss. Note optimum dispatch tends to towards supplying the losses from the unit close to the load resulting a lower value of losses. The best economics are not necessarily attained at minimum losses also.

If you try to minimize the losses that does not ensure that you reduce overall economic cost. So, so minimum loss solution is this much. You see here minimum loss you are getting cost higher than the previous cost 4623.15. Here the objective was to reduce the overall cost, losses could be higher.

Here the losses is 2.08 megawatt, losses is less whereas cost is higher. Here losses is higher, cost is less. What is your objective? If you want to if even if you are okay having lesser loss, but increased cost then you can take up suitable call. But generally economic load dispatch includes we reduce the overall cost of operation. So, then there is something called as B matrix loss formula. Practically we can it is a simplified approach for loss and incremental cost calculations.

So, this is expressed in terms of PTBP, loss is expressed in terms of PTBP plus B0TP plus B00. What are they? P is the vector of all generator bus net power injections, B is a square loss factor matrix of the same dimension as P, B0 is a loss factor vector, loss factor vector of the same length as P and B00 is a loss factor constant. So, the right form of the loss equation is this one.

I am not detailing much. So, one can look into this reference if you have much interest. So, with this we will conclude this week. Thank you very much.