Economic Operation and Control of Power System

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Week - 03

Lecture – 12

Very good morning. Welcoming all to the NPTEL course on Economic Operation and Control of Power System. Today we will be talking about formulation of AC power flow, lecture number 12. Now all of you please try to understand we discussed about the DC power flow in our previous lecture, where an easy way of identifying the power flow in each and every transmission or distribution corridor of a power network can easily be determined. However, that will be a solution, but not necessarily to be an accurate solution considering the reactive power flow. So, for a practical applications we always use AC power flow technology or techniques to determine both AC and DC power flow or real and reactive power flow in the transmission as well as distribution corridors.

Now one of the very common method that is popularly known as Newton-Raphson method, which is generally an optimizing tool, but being used to obtain load flow solution of a power network. The main objective of this AC load flow or AC power flow problem is the Newton-Raphson method, but which is also popularly known as Newton's point form method in which what we say the solution of a vector matrix which is nonlinear in nature, where

$\mathrm{F(X)} = 0$ …(12.1)

But F is the vector valued nonlinear function of a vector valued argumented x. We'll get into the details of the procedures and we'll try to solve a numerical example at the end to make sure or build confidence on our theoretical understanding. Now, what is Newton-Raphson method? Just a basic, when you say F of x equal to 0, that is equation number 12.2.

$\mathrm{F(X)} = 0 = \mathrm{F}(X^{(0)}) + \mathrm{J}\Delta X + \text{higher order terms}$ …(12.2)

which talks about majorly the F of x, its initial value as you could see, and then plus J times delta x and J is popularly known as the Jacobian matrix and delta x is the first order correction to x naught plus its higher order terms which are normally neglected because of its magnitude and J of ij which is the partial differentiation of f of i with respect to x of j.

Now, excluding the slack bus, now in any power network, I'll show you an example and then come back very quickly. In any power network let us look into this network. You could see it is a three bus network. This is my bus number one, this is my bus number two and bus number three. Now, each and every bus do possess four variables, okay, which is real power, reactive power, voltage and angle. Now, what happens in any given bus, only two parameters are known to me at a given point of time based on its nature and rest of the two parameters that need to be calculated. So, imagine if P and Q is known to me, then normally we call it as a PQ bus or a load bus, that is my bus number two. Now, if I say that P and V is known to me, then I have to calculate Q and delta and that is known as my PV bus which is my bus number two. And what is PV bus? Only for a generator, if a generator is connected to a particular location, then both real power output and voltage of that bus is known to me and hence a generator bus which is popularly known as PV bus and when P and Q are known to me, they are the load buses or known as PQ buses.

But moving to a slack bus where V and delta, when V is known to me and delta is known to me and I have to calculate P and Q, then that bus is known as slack bus which is my bus number one. So, in any power system or power network, especially to obtain the voltage solutions, we have to consider one bus which is slack bus where V and delta is known to me and rest of the buses are PQ buses or PV buses depending upon the parameters which are known to me at that particular bus, whether it is load connected or generator connected, we decide whether it is a PV bus or PQ bus. So, with this background, now I am going back to my original discussion, excluding the slack bus means if you ignore the bus where V and delta are actually known to me, there are usually two equations for each node of the following form. So, one is your Pi and the second one is actually delta Pi and delta Qi. So, what is delta Pi? Delta Pi is nothing but summation of partial differentiation of Pi with respect to dou J times delta J plus VJ delta Pi J upon VJ times delta VJ upon VJ.

So, this equation is basically representing your series expansion of my P and similarly, I can generate one more equation for Q. Now, the question here, what is delta Pi and what is delta Qi? So, delta Pi is nothing but the specified value at a particular bus which is known to me and something that I have calculated through my numerical equation. So, the difference between specified and calculated is given by delta So, delta Pi is nothing but the specified value at a particular bus which is known to me and something that I have calculated through my numerical equation. So, the difference between specified and calculated is given by delta Now, the question here, what is delta Pi and what is delta Qi? So, delta Pi is nothing but the specified value at a particular bus which is known to me and something that I have calculated through my numerical equation. So, the difference between specified and calculated is given by delta of my P and similarly, I can generate one more equation for Q. Now, the question here, what is delta Pi and what is delta Qi? So, delta Pi is nothing but the specified value at a particular bus which is known to me and something that I have calculated through my numerical equation. So, the difference between specified and calculated is given by delta of my P and similarly, I can generate one more equation for Q. Now, the question here, what is delta Pi and what is delta Qi? So, delta Pi is nothing but the specified value at a particular bus which is known to me and something that I have calculated through my numerical equation. So, the difference between specified and calculated is given by delta So, this equation is basically representing your series expansion of my P and similarly, I can generate one more equation for Q. Now, the question here, what is delta Pi and what is delta Qi? So, delta Pi is nothing but the specified value at a particular bus which is known to me and something that I have calculated through my numerical equation. So, the difference between specified and calculated is given by delta So, this equation is basically representing your expansion series expansion of my P and similarly, I can generate one more equation for Q. Now, the question here, what is delta Pi and what is delta Qi? So, delta Pi is nothing but the specified value at a particular bus which is known to me and something that I have calculated through my numerical equation. So, the difference between specified and calculated is given by delta second one is actually delta Pi and delta Qi. So, what is delta Pi? Delta Pi is nothing but summation of partial differentiation of Pi with respect to dou J times delta J plus VJ delta Pi J upon VJ times delta VJ upon VJ. So, this equation is basically representing your expansion series expansion of my P and similarly, I can generate one more equation for Q.

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So, the aii element which is the partial differentiation of Pii upon delta I, Vi times Pii upon Vi and Qii upon delta I as well as Qi upon delta b. So, you have taken the partial differentiation of Pii with respect to delta i and Vi. Similarly, you've taken the partial differentiation of Q with respect to delta i and Vi. Now, in the case of aij, you have take the partial differentiation of actually Pij with respect to delta j and Pij with respect to the Vj and similarly Qij with respect to delta j and Qij with respect to Vj. Now, with this fundamental, now let us try to understand the basics of a transmission line model.

So, you have a physical system. We need to model each and every line and each and every device, the buses we have understood. Now, let us focus a little bit on transmission line models. As you know, transmission line models are either Pi models or they are actually T models, but considering it is a purely pi model as you could see, the line resistance is known to me, line reactance is known to me and you can also experience bit of capacitance between transmission line and ground. So, you could see this capacitance which are present here. Now, this is my transmission line representation. Now, if I have to understand what is voltage at each end of the transmission line, so I can experience some Vi here and we can experience some Vj here as well as some angle delta i and delta j and similarly, we can also experience the series impedance of the line as well as shunt impedance of the line which is Yij and Yij with different magnitudes of series as well as shunt elements. Now, once you understand the series impedance, shunt impedance and the angle and voltage at each bus, so that represents my transmission line. So, then you can easily calculate what is the current flowing between ij, you can calculate the current model which is ij. Theoretically, as you could see from the equation number 12.11:

$$I_{ij} = V_i y_{ii} + (V_i - V_j) y_{ij}$$

$$= V_i(y_{ii} - y_{ij}) - V_j y_{ij} \quad \ldots(12.11)$$

The current which is flowing in the line iij, the current between bus number i to j which is Vi, Yii plus Vi minus Vj times Yij. So, the initial the current which is being injected plus the current which has been created because of voltage difference upon the admittance. So, once you know the current, we can also calculate the apparent power using the expression Sij which is Vi Iij conjugate. Now, iij is known to me, Vi is known to me, so I can apply and get my equation 12.13 which is given by:

$$S_{ij} = |V_i|^2 y_{ii}^* + |V_i|^2 y_{ij}^* - V_i V_j^* y_{ij}^* \ldots 12.13$$

for my apparent power. So, once I get my apparent power, I can expand it, get the real component and reactive component that will give me the real power flow as well as the reactive power flow through equation number 12.14 and 12.15 given by:

$$P_{ij} = |V_i|^2 |y_{ii}| \cos(y_{ij}) - |V_i||V_j||y_{ij}| \cos(\delta_i - \delta_j - \gamma_{ij}) \quad \ldots(12.14)$$

$$Q_{ij} = -|V_i|^2 |y_{ii}| - |V_i|^2 |y_{ij}| \sin(y_{ij}) - |V_i||V_j||y_{ij}| \sin(\delta_i - \delta_j - \gamma_{ij}) \ldots(12.15)$$

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So, it is almost similar to my transmission line model, but this end point instead of connecting to the directly bus number j, now it is connecting to a variable coil. So, the voltage can easily be varied. Now, the flow as measured at each end of the transformer is given by the following equation. As you could see, now the potential at the Vm which is now slightly different which is alpha times Vj depending upon your tap ratio in the transformers. So, you can calculate what is your series impedance, the tap ratio, the series impedance is given by this, the tap ratio is also known to me which is a phasor mainly and once you know the series impedance and phase tap ratio, then you can calculate the current Iij in a different way. So, finally 12.18 represent the current in the transmission line between bus i to j is given by:

$$I_{ij} = (V_i - V_m)y_{ij} \quad \ldots(12.16)$$

$$I_{ij} = V_i y_{ij} - V_m y_{ij} \quad \ldots(12.17)$$

$$I_{ij} = V_i y_{ij} - \alpha_{ij} V_j y_{ij} \quad \ldots(12.18)$$

Even for the same equation, the current is known to you, the voltage is known to you. So, you can calculate Sij for the transformer modeling 12.19, then you get two components separate them out, you get real power and reactive power.

So, for separate for any bus actually for ij and for the real power and reactive power, you derive what is 12.20 and 12.21.

$$P_{ij} = |V_i|^2|y_{ij}|\cos(y_{ij}) - |\alpha_{ij}||V_i||V_j||y_{ij}|\cos(\delta_i - \delta_j - \theta_t - \gamma_{ij}) \quad \ldots(12.20)$$

$$Q_{ij} = -|V_i|^2|y_{ij}|\sin(\theta_{ij}) - |\alpha_{ij}||V_i||V_j||y_{ij}|\sin(\delta_i - \delta_j - \theta_t - \gamma_{ij}) \quad \ldots(12.21)$$

where you can easily understand having a transformer modeling into in a mathematical expression, the real power flow and reactive power flow can easily be calculated. So, once you have the transformer real and reactive power equation as well as transmission line real and reactive power equations, the probability is easy to move for the Newton-Raphson model because the real power is known to me, reactive power is known to me. Now, to differentiate to create the Jacobian. Now, I am connecting.

So, when you move here, when you get into this equation, please try to understand. So, what you are doing to solve this equation? So, for me, once I know the delta and once I know the V, then probably I know everything and so these variables need to be calculated. So, X need to be calculated by inversing A times B assuming B is known to me and A is known to me, then only I can calculate X. So, to calculate X actually I need to know what is A and B. So, B is known to me, but what is A? A is nothing but my Jacobian for an example. So, where actually I have to substitute these elements, so what is partial differentiation of P ii upon delta i? So, for that I must know what is P i i.

So, once I know P ii, I can also understand the partial differentiation of P ii with respect to delta i. Similarly, if I know what is P ij, I can differentiate with respect to delta j and get this element and that is the only reason. Now, you are very confident the moment you have this 12.14 and 15, where P ij, Q ij is known to me, I can easily partially differentiate with respect to any variable that is either voltage or angle. Similarly, for transformer flow equations also, I can do similar job by differentiating these equations.

Now, sometimes you may have a model like a DC link model, so this is what this because the transmission line do have HVDC corridors because for huge power transmission, instead of having overhead lines, we go underground cables or sometimes we go for HVDC transmission for huge power transformer, where all the energy is being transmitted in a DC form. So, what we do, we get the power at AC, we convert into DC, take it to 500 miles or 5000 kilometers and then we convert DC to AC and then So, what we do, we get the power at AC, we convert into DC, take it to 500 miles or 5000 kilometers and then we convert DC to AC and then where all the energy is being transmitted in a DC form. 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For example, if I do have a HVDC corridor between Delhi to Mumbai, so what I can do, I can generate the power in AC, no doubt. Once it is available to me, I convert them into DC, take that corridor till Mumbai and then convert that power DC to AC and then cater the Mumbai city without any AC transmission. So, there is the advantage of that actually, you know, you need not put any physical transformers here and there and then probably you can avoid, you know, the overhead lines which is certainly a challenging as of now, because we do not have any more space, so we need to move to a HVDC corridor in the near future or near the gate. So, this is what the DC link model look like, where you have Vdc plus and minus which could be any range, probably it is 500 kilovolt plus or minus and then you have different configurations. Now, assuming you have transmission line, transformers and HVDC corridors, these are the maximum three things that you can experience in a transmission system and then you have generator buses, load buses and slack buses, so that is how the overall system will look like physically and those physical system need to be converted into mathematical equations and then solved so that the voltage and angle each and every bus will be known to me.

So, these are the input data and then we do bit of process and then output. So, this table will help you to understand more in detail how the process actually moves theoretically. This is one important part, the step by step procedure of Newton Raphson. Here I will go little slow to make you understand why these steps are important? First of all, what you have to do, given a system you have to immediately calculate the bus admittance matrix.

You have been taught how to calculate bus admittance matrix. In my previous lecture, it is quite simple. So, why bus? You can easily determine for a given matrix. Previously, we had only admittances, now we have the resistance plus admittances, so they become impedances. So, you can calculate the bus admittance matrix. Once the bus admittance matrix is available to me, that is step number one, then you move to step number two. Step number two, you have to set initial values of variables, they are delta I and VI, at each and every bus, wherever possible, you have to set the initial values delta I and VI, with zero, super suffix kind of representation, they are the initial values.

So, with this, Y is known to me, initial with zero, so for suffix zero kind of representation, they are the initial values. So, with this, Y is known to me, initial initial values of variables, they are delta I and VI, at each and every bus, wherever possible, you have to set the initial values delta I and VI, with zero, so for suffix zero kind of representation, they are the initial values. So, with this, Y is known to me, initial Previously, we had only admittances, now we have the resistance plus admittances, so they become impedances. So, you can calculate the bus admittance matrix. Once the bus admittance matrix is available to me, that is step number one, then you move to step number two. Step number two, you have to set initial values of variables, they are delta I and VI, at each and every bus, wherever possible, you have to set the initial values delta I and VI, with zero, so for suffix zero kind of representation, they are the initial values. So, with this, Y is known to me, initial so they become impedances. So, you can calculate the bus admittance matrix. Once the bus admittance matrix is available to me, that is step number one, then you move to step number two. Step number two, you have to set initial values of variables, they are delta I and VI, at each and every bus, wherever possible, you have to set the initial values delta I and VI, with zero, so for suffix zero kind of representation, they are the initial values. So, with this, Y is known to me, initial lecture, it is quite simple. So, why bus? You can easily determine for a given matrix. Previously, we had only admittances, now we have the distance plus admittances, so they become impedances. So, you can calculate the bus admittance matrix. Once the bus admittance matrix is available to me, that is step number one, then you move to step number two. Step number two, you have to set initial values of variables, they are delta I and VI, at each and every bus, wherever possible, you have to set the initial values delta I and VI, with zero, so for suffix zero kind of representation, they are the initial values. So, with this, Y is known to me, initial First of all, what you have to do, given a system you have to immediately calculate the bus admittance matrix. You have been taught how to calculate bus admittance matrix. In my previous lecture, it is quite simple. So, why bus? You can easily determine for a given matrix. Previously, we had only admittances, now we have the distance plus admittances, so they become impedances. So, you can calculate the bus admittance matrix. Once the bus admittance matrix is available to me, that is step number one, then you move to step number two. Step number two, you have to set initial values of variables, they are delta I and VI, at each and every bus, wherever possible, you have to set the initial values delta I and VI, with zero, so for suffix zero kind of representation, they are the initial values. So, with this, Y is known to me, initial lecture, it is quite simple. So, why bus? You can easily determine for a given matrix. Previously, we had only admittances, now we have the distance plus admittances, so they become impedances. So, you can calculate the bus admittance matrix. Once the bus admittance matrix is available to me, that is step number one, then you move to step number two. Step number two, you have to set initial values of variables, they are delta I and VI, at each and every bus, wherever possible, you have to set the initial values delta I and VI, with zero, so for suffix zero kind of representation, they are the initial values.

So, with this, Y is known to me, initial values of delta and V is known to me, now I can calculate Pi and Qi at each load bus from the following. So, the Pi, that is real power injected at a particular bus i, the reactive power injected at a particular bus i, can be calculated based on this parameter. So, we have assumed, delta you have assumed , Y buses are known to me, so YiK, Yi, all the elements are known to me, so you can easily calculate Pi and Qi. Compute the schedule error, once you calculate, then you calculate what is delta P, based on the known parameters and calculated parameters, take the difference, calculate delta P, calculate delta Q, using the equation number 12.6 and 12.7. Once they are known, then you move to the Jacobian matrix. So, once you can calculate Jacobian matrix, so what has happened now, the Jacobian matrix is ready with me and the errors are also available with me, schedule errors and once they are known, obtain the value of delta delta P, using the equation number 12.8, 9, 10. So, you can use the Jacobian matrix and the error delta P delta Q will give you the value of delta delta and delta P. Now, using the step number 6, modify the voltage magnitude and phase angle at each load bus. So, you had a initial value, you calculated for example, delta Io you have assumed, now you calculated delta delta, then you can go for a new, the initial set of delta I, which is the previous value plus delta delta.

So, you set a new value and repeat next iteration from the point number 2 to point number actually 6 continuously and see to that, the delta delta and delta P you keep on calculating till they fall between a very tolerable margin. So, once they are there, then you can say the last iteration will give me all the voltage and angle solutions. Now, we will also try to see a very simple example and try to solve how the, you know, using Newton Raphson, we can obtain voltage and angle at each and every bus as well as the power flow and reactive and real power flow in each and every line. Now, already I discussed this diagram, where we know there are three buses, one is slack bus, then bus number 2, which is a PQ bus and bus number 3 is a PV bus. Don't get confused, it is very simple. For a load bus, the both P and Q is known to me and hence we call it as a PQ bus and you're supposed to calculate the V and delta at that particular bus. For a generator bus, P and V is known to me, you have to calculate actually Q and delta. Similarly, for a slack bus, V and delta is known to me, you have to calculate the P and Q at that particular bus. Each and every bus out of four variables, two are known to me and two need to be calculated. The impedances of each line is known to me. So, what is the step number one? If you have been asked to solve using Newton Raphson, the voltage solutions of this diagram, the step number one is formulate the Y bus matrix, okay, step number one. You form the Y bus, all the line impedances are given to you, you can form the Y bus. So, first is, first step is your Y bus, so you can calculate Y bus. Please check whether the solutions that we have provided and your solution they do match and if it is not matching, probably you can put me questions through your inquiry chat where actually why there is an error that will be corrected.

I'm confident that the solution must be right. And once you calculate Y bus, then you have to assume delta and V. Now, please tell me, so if you look into delta 2 and delta 3, so the first bus, the delta is known. Only the second and third bus, the delta is not known to me and hence you have to assume, okay, the delta is known to you, then no need to assume. So, bus number two, bus number one, the delta is known to me. Bus number two, delta is not known, so assume delta 2 equal to 0. Ideally, we assume 0 angle for delta and 1 per unit for voltage, okay. So, delta 2 is 0 and if you move to delta 3, delta is not known, so the bus number 3 again, delta 3 equal to 0. So, delta 1 is known to me, delta 2 you have assumed to 0, delta 3 you have assumed to 0. What about voltages? Voltages bus number one is known to me, voltage at bus number two is not known to me, okay, that I have to assume because what need to be calculated, we have to assume to So, delta 1 is known to me, delta 2 you have assumed to 0, delta 3 you have assumed to 0. What about voltages? Voltages bus number one is known to me, voltage at bus number two is not known to me, okay, that I have to assume because what need to be calculated, we have to assume to delta is not known, so the bus number 3 again, delta 3 equal to 0.

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Bus number two, delta is not known, so assume delta 2 equal to 0. Ideally, we assume 0 angle for delta and 1 per unit for voltage, okay. So, delta 2 is 0 and if you move to delta 3, delta is not known, so the bus number 3 again, delta 3 equal to 0. So, delta 1 is known to me, delta 2 you have assumed to 0, delta 3 you have assumed to 0. What about voltages? Voltages bus number one is known to me, voltage at bus number two is not known to me, okay, that I have to assume because what need to be calculated, we have to assume to first step is your Y bus, so you can calculate Y bus. Please check whether the solutions that we have provided and your solution they do match and if it is not matching, probably you can put me questions through your inquiry chat where actually why there is an error that will be corrected. I'm confident that the solution must be right. And once you calculate Y bus, then you have to assume delta and V. Now, please tell me, so if you look into delta 2 and delta 3, so the first bus, the delta is known. Only the second and third bus, the delta is not known to me and hence you have to assume, okay, the delta is known to you, then known it was you. So, bus number two, bus number one, the delta is known to me.

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You form with the Y bus, all the line impedances are given to you, you can form the Y bus. So, first is, first step is your Y bus, so you can calculate Y bus. Please check whether the solutions that we have provided and your solution they do match and if it is not matching, probably you can put me questions through your inquiry chat where actually why there is an error that will be corrected. I'm confident that the solution must be right. And once you calculate Y bus, then you have to assume delta and V. Now, please tell me, so if you look into delta 2 and delta 3, so the first bus, the delta is known.

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Ideally, we assume 0 angle for delta and 1 per unit for voltage, okay. So, delta 2 is 0 and if you move to delta 3, delta is not known, so the bus number 3 again, delta 3 equal to 0. So, delta 1 is known to me, delta 2 you have assumed to 0, delta 3 you have assumed to 0. What about voltages? Voltages bus number one is known to me, voltage at bus number two is not known to me, okay, that I have to assume because what need to be calculated, we have to assume to you have to calculate actually Q and delta. Similarly, for a slack bus, V and delta is known to me, you have to calculate the P and Q at that particular bus.

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Ideally, we assume 0 angle for delta and 1 per unit for voltage, okay. So, delta 2 is 0 and if you move to delta 3, delta is not known, so the bus number 3 again, delta 3 equal to 0. So, delta 1 is known to me, delta 2 you have assumed to 0, delta 3 you have assumed to 0. What about voltages? Voltages bus number one is known to me, voltage at bus number two is not known to me, okay, that I have to assume because what need to be calculated, we have to assume to Q and delta. Similarly, for a slack bus, V and delta is known to me, you have to calculate the P and Q at that particular bus.

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Ideally, we assume 0 angle for delta and 1 per unit for voltage, okay. So, delta 2 is 0 and if you move to delta 3, delta is not known, so the bus number 3 again, delta 3 equal to 0. So, delta 1 is known to me, delta 2 you have assumed to 0, delta 3 you have assumed to 0. What about voltages? Voltages bus number one is known to me, voltage at bus number two is not known to me, okay, that I have to assume because what need to be calculated, we have to assume to start the iteration and then you land with a solution. So, V2 which is 1 per unit at bus number two, but fortunately at bus number three, the voltage is known to me. So, the voltage at bus number one is known to me, at bus number three is known to me, bus number two is not known to me and hence I have assumed the voltage at bus number two is 1 per unit. So, now the problem is clear, we know very well that delta P2, delta P3, delta Q2 which is Jacobian times delta 2, delta Q3 and delta V2. Using this equation, using this equation, you can calculate what is P2, the value of P2 is known to me, the previous expressions if you substitute the bus 2, you will get this equation and once P2 is known to me, you can calculate what is delta P2, substitute different assumed values and you will get the initial value of P2 which changes, that is delta P20 which has been calculated as minus 1.13 per unit. Similarly, you can calculate what is change in P3 that is delta P3 initial value which is 0.5616. Before you start the delta P3 initial value which is 0.5616. Before you start the minus 1.13 per unit. Similarly, you can calculate what is change in P3 that is delta P3 initial value which is 0.5616. Before you start the that is delta P20 which has been calculated as minus 1.13 per unit. Similarly, you can calculate what is change in P3 that is delta P3 initial value which is 0.5616. Before you start the substitute different assumed values and you will get the initial value of P2 which changes, that is delta P2 0 which has been calculated as minus 1.13 per unit. Similarly, you can calculate what is change in P3 that is delta P3 initial value which is 0.5616. Before you start the Using this equation, using this equation, you can calculate what is P2, the value of P2 is known to me, the previous expressions if you substitute the bus 2, you will get this equation and once P2 is known to me, you can calculate what is delta P2, substitute different assumed values and you will get the initial value of P2 which changes, that is delta P2 0 which has been calculated as minus 1.13 per unit. Similarly, you can calculate what is change in P3 that is delta P3 initial value which is 0.5616. Before you start the Using this equation, using this equation, you can calculate what is P2, the value of P2 is known to me, the previous expressions if you substitute the bus 2, you will get this equation and once P2 is known to me, you can calculate what is delta P2, substitute different assumed values and you will get the initial value of P2 which changes, that is delta P2 0 which has been calculated as minus 1.13 per unit. Similarly, you can calculate what is change in P3 that is delta P3 initial value which is 0.5616. Before you start the Using this equation, using this equation, you can calculate what is P2, the value of P2 is known to me, the previous expressions if you substitute the bus 2, you will get this equation and once P2 is known to me, you can calculate what is delta P2, substitute different assumed values and you will get the initial value of P2 which changes, that is delta P2 0 which has been calculated as minus 1.

13 per unit. Similarly, you can calculate what is change in P3 that is delta P3 initial value which is 0.5616. Before you start the iteration, these values need to be calculated. So, once you know, so what you know, voltage at each bus, delta at each bus, delta P2 initial, delta P3 initial and also you can calculate Q2. As you know, the initial value for Q2. Once you know this, then you can calculate what is delta P2 initial. So, what is delta P2 initial which is delta P2 specified minus delta P2 initial calculated. So, you get this value which is delta P2 initial, delta P3 initial and delta Q2 initial. So, these three values delta is known to me. So, what is happening, slowly if you go to this equation, so the first delta P20, delta P30, delta Q0 you have calculated. If you multiply that with Jacobian inverse, then you will get actually delta 2, delta 3, delta V2 and repeat this and then you go back to initial values, update them with new deltas, new Vs and then you come back, repeat the cycle. You keep on doing it until unless you land with a solution. I am very confident in Jacobian Newton-Raphson load flow solution, maximum there will be two to three iterations, and repeat this and then you go back to initial values, update them with new deltas, new Vs and then you come back, repeat the cycle.

You keep on doing it until unless you land with a solution. I am very confident in Jacobian Newton-Raphson load flow solution, maximum there will be two to three iterations, with Jacobian inverse, then you will get actually delta 2, delta 3, delta V2 and repeat this and then you go back to initial values, update them with new deltas, new Vs and then you come back, repeat the cycle. You keep on doing it until unless you land with a solution. I am very confident in Jacobian Newton-Raphson load flow solution, maximum there will be two to three iterations, equation, so the first delta P2 0, delta P3 0, delta Q0 you have calculated. If you multiply that with Jacobian inverse, then you will get actually delta 2, delta 3, delta V2 and repeat this and then you go back to initial values, update them with new deltas, new Vs and then you come back, repeat the cycle. You keep on doing it until unless you land with a solution. I am very confident in Jacobian Newton-Raphson load flow solution, maximum there will be two to three iterations, you will get your solution. However, in Gauss-Seidel, it takes multiple iterations. So, once you know this, please look into this equation, delta P20, delta P30, delta Q20, this is my Jacobian times delta 2. So, I can calculate each and every Jacobian elements now and then these nine elements I can calculate and then once they are known to me, all the elements have been calculated and then you take Jacobian inverse as I told you and then multiply with delta P2, delta P3, delta Q2 and which will give you the value for delta 20, delta 30 and delta V0. Once you know the value of delta 20, delta 30, delta V0, you can move to the first iteration by using this equation.

What you will do? You will say for the first iteration, delta 2 1 1 1 or delta 21, delta 31, delta V21 will be your initial assumed values plus your calculated value, just now you have calculated above and you will get a new initial set. Use this set, you again calculate the same equation and repeat it till you get the final solution. So, this is what all about Newton-Raphson load flow for AC networks for obtaining power flows in a transmission or distribution lines or systems. So, with this we stop today. So, probably we will get into decoupled and other new load flow solutions during the next class. Thank you very much.

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