Economic Operation and Control of Power System

Prof Narayana Prasad Padhy

Department of Electrical Engineering

Director MNIT Jaipur and Professor IIT Roorkee

Week - 03

Lecture – 11

Very good morning. I welcome you all to the course on Economic Operation and Control of Power Systems. Today we will be focusing on lecture number 11, Power Flow Problems on DC Networks. As you all aware, when you are interested to analyze real and reactive power flow in any feeder as well as the current and voltage of a given network, we need to carry out power flow solutions. To start with, we will focus on DC network, which is quite simpler and then we will complicate the network and get into AC power flow solutions. Now, if you look into any power system.

In general, probably this is the geographic location that you could see and different substations and generators are being marked as you could see with the different notations. So, you could find there are few generators and you could find there are few substations and so and so. Now, when you translate this diagram into a one-line diagram, so one-line diagram of the power system now can be represented with a couple of generators located and all these areas are now being connected through different buses. So, this is almost a kind of a one, two, three, four, five, six. So, there are four buses and you can also see there are one, two, three, four, five, six, seven, eight, eight lines connected to those six buses and this is what actually to be a representative of a particular power system in a given geographic area. Now, let us also try to understand bit of representation of my one-lines with breakers and disconnected switches. So, this representation which talks about single bus system and we can also see sectionalized bus representation, where you can find breakers and switches. We can also see main and transfer bus arrangements as well as ring bus arrangement. So, probably you can see there is a circular arrangement like a ring.

So, different architectures are being adapted as per the requirement of a given distribution system or even a transmission system. Now, substation one-line diagram with breakers and disconnected switch also do have different breaker arrangements. So, one is very popular known as breaker and a half arrangement and double breaker double bus arrangement. So, in this network if you see the number of breakers and the buses are connected in a different way connected to my double breaker and double bus system.

These architectures are suitable to a given environment. Most likely it is a medium voltage level where breaker and half system is quite popular. Now, we can also see the breaker topology processing where you can see that the arrangement which is from the low voltage network to the high voltage side which has been represented by a model has one electrical bus with two transmission lines and two transformers attached. However, this representation if you translate with few close breakers then this is now represented with the model has two electrical buses, one and two with one transmission line and one transformer attached. So, depending upon the architecture of your breakers they can be simplified to a different bus system whether it is single bus or multiple bus elements. Now, when you talk about bus and branch model, so probably if you see this is my bus and which is connected to two different buses bus J as well as bus K and you can see there is a demand or sometime it is known as my load which is of the nature : $P + jQ$

and the generator which could be a slack generator for the time. So, this is ideally how my representation of the power system look like where you see there are n number of buses in the network and some of the generators and loads and the lines are connected at different buses or between buses. Now, when you talk about power flow applications there are power flow applications have been used for two different purposes or two different objectives. One is related to power flow for dispatch objectives and the other one is for the planning of power flows. So, when you talk about dispatched objective, there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity.

So, probably reorganize the power in such a manner that the devices are not overloaded and also during the So, when you talk about dispatched objective there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the One is related to power flow for dispatch objectives and the other one is for the planning of offers.

So, when you talk about dispatched objective there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the Now, when you talk about power flow applications there are power flow applications have been used for two different purposes or two different objectives. One is related to power flow for dispatch objectives and the other one is for the planning of offers. So, when you talk about dispatched objective there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the at different buses or between buses. Now, when you talk about power flow applications there are power flow applications have been used for two different purposes or two different objectives. One is related to power flow for dispatch objectives and the other one is for the planning of offers. So, when you talk about dispatched objective there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the n number of buses in the network and some of the generators and loads and the lines are connected at different buses or between buses. Now, when you talk about power flow applications there are power flow applications have been used for two different purposes or two different objectives. One is related to power flow for dispatch objectives and the other one is for the planning of offers. So, when you talk about dispatched objective there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the which is of the nature P + jQ and the generator which could be a slack generator for the time. So, this is ideally how my representation of the power system look like where you see there are n number of buses in the network and some of the generators and loads and the lines are connected at different buses or between buses. Now, when you talk about power flow applications there are power flow applications have been used for two different purposes or two different objectives. One is related to power flow for dispatch objectives and the other one is for the planning of offers. So, when you talk about dispatched objective there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the and which is connected to two different buses bus J as well as bus K and you can see there is a demand or sometime it is known as my load which is of the nature P + jQ and the generator which could be a slack generator for the time. So, this is ideally how my representation of the power system look like where you see there are n number of buses in the network and some of the generators and loads and the lines are connected at different buses or between buses. Now, when you talk about power flow applications there are power flow applications have been used for two different purposes or two different objectives. One is related to power flow for dispatch objectives and the other one is for the planning of offers. So, when you talk about dispatched objective there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the and which is connected to two different buses bus J as well as bus K and you can see there is a demand or sometime it is known as my load which is of the nature P + jQ and the generator which could be a slack generator for the time. So, this is ideally how my representation of the power system look like where you see there are n number of buses in the network and some of the generators and loads and the lines are connected at different buses or between buses. Now, when you talk about power flow applications there are power flow applications have been used for two different purposes or two different objectives. One is related to power flow for dispatch objectives and the other one is for the planning of offers. So, when you talk about dispatched objective there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the so probably if you see this is my bus which is bus I and which is connected to two different buses bus J as well as bus K and you can see there is a demand or sometime it is known as my load which is of the nature P + jQ and the generator which could be a slack generator for the time. So, this is ideally how my representation of the power system look like where you see there are n number of buses in the network and some of the generators and loads and the lines are connected at different buses or between buses. Now, when you talk about power flow applications there are power flow applications have been used for two different purposes or two different objectives.

One is related to power flow for dispatch objectives and the other one is for the planning of offers. So, when you talk about dispatched objective there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the Now, when you talk about bus and branch model, so probably if you see this is my bus which is bus I and which is connected to two different buses bus j as well as bus K and you can see there is a demand or sometime it is known as my load which is of the nature P + jQ and the generator which could be a slack generator for the time. So, this is ideally how my representation of the power system look like where you see there are n number of buses in the network and some of the generators and loads and the lines are connected at different buses or between buses. Now, when you talk about power flow applications there are power flow applications have been used for two different purposes or two different objectives. One is related to power flow for dispatch objectives and the other one is for the planning of offers. So, when you talk about dispatched objective there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the different bus system whether it is single bus or multiple bus elements. Now, when you talk about bus and branch model, so probably if you see this is my bus which is bus I and which is connected to two different buses bus J as well as bus K and you can see there is a demand or sometime it is known as my load which is of the nature P + jQ and the generator which could be a slack generator for the time. So, this is ideally how my representation of the power system look like where you see there are n number of buses in the network and some of the generators and loads and the lines are connected at different buses or between buses. Now, when you talk about power flow applications there are power flow applications have been used for two different purposes or two different objectives. One is related to power flow for dispatch objectives and the other one is for the planning of offers. So, when you talk about dispatched objective there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the different bus system whether it is single bus or multiple bus elements. Now, when you talk about bus and branch model, so probably if you see this is my bus which is bus I and which is connected to two different buses bus J as well as bus K and you can see there is a demand or sometime it is known as my load which is of the nature P + jQ and the generator which could be a slack generator for the time. So, this is ideally how my representation of the power system look like where you see there are n number of buses in the network and some of the generators and loads and the lines are connected at different buses or between buses. Now, when you talk about power flow applications there are power flow applications have been used for two different purposes or two different objectives. One is related to power flow for dispatch objectives and the other one is for the planning of offers. So, when you talk about dispatched objective there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the So, depending upon the architecture of your breakers they can be simplified to a different bus system whether it is single bus or multiple bus elements.

Now, when you talk about bus and branch model, so probably if you see this is my bus which is bus I and which is connected to two different buses bus J as well as bus K and you can see there is a demand or sometime it is known as my load which is of the nature P + jQ and the generator which could be a slack generator for the time. So, this is ideally how my representation of the power system look like where you see there are n number of buses in the network and some of the generators and loads and the lines are connected at different buses or between buses. Now, when you talk about power flow applications there are power flow applications have been used for two different purposes or two different objectives. One is related to power flow for dispatch objectives and the other one is for the planning of offers. So, when you talk about dispatched objective there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the then this is now represented with the model has two electrical buses, one and two with one transmission line and one transformer attached. So, depending upon the architecture of your breakers they can be simplified to a different bus system whether it is single bus or multiple bus elements. Now, when you talk about bus and branch model, so probably if you see this is my bus which is bus I and which is connected to two different buses bus J as well as bus K and you can see there is a demand or sometime it is known as my load which is of the nature P + jQ and the generator which could be a slack generator for the time. So, this is ideally how my representation of the power system look like where you see there are n number of buses in the network and some of the generators and loads and the lines are connected at different buses or between buses. Now, when you talk about power flow applications there are power flow applications have been used for two different purposes or two different objectives. One is related to power flow for dispatch objectives and the other one is for the planning of offers. So, when you talk about dispatched objective there we are mainly focusing on what are the line and transformer load throughout the system we can understand as well as we can identify the voltages at different buses of the network and also we can understand what are the options to unload or overload a particular equipment if the equipment is loaded 95% to its rated capacity. So, probably reorganize the power in such a manner that the devices are not overloaded and also during the dispatch power flow we can also identify what are the actually options available to me if a device is really getting failed. So, contingent arrangements are available to me or not. So, they are very close to real time.

However, in case of planning of power flow, we are very much interested to know what are those new generator sites that need to be identified to be located in future. Even we can plan for the new transmission line to transfer power from a generating station to a remote location and if you like to consider a new proposed HVDC link then what would be the right location for that connection or if you wish to establish a FACT device in your system flexible AC transmission devices then what would be the right location for that devices and also we can understand if there is a demand growth or generation growth happening in a particular location then how do you plan your power system for future. So, as a whole what I wanted to emphasize my dear students, the power flow applications are used for two different objectives either it could be dispatcher power flow and the dispatch objective or power flow for planning objective. Now, let us focus bit on Tellegen's theorem that is conservation of energy. Now, the basic building blocks conservation of energy at a bus of the system, where you can all understand when you talk about conservation of energy at a bus is rewritten as:

$\sum_{j=k}^{l} S_{ij} = 0$…11.1

Complex power is summation of real and reactive power: $S = P + Q\sqrt{-1}$

Conservation of Energy can be written in terms of Real and Reactive Power as :

$$\sum_{j=k}^{l} P_{ij} = 0 \, , \sum_{j=k}^{l} Q_{ij} = 0$$

Similarly, all the input reactive power is equal to the output reactive power and as you all know S is given by the apparent power which is P + jQ which is can also be written as P + jQ. Now, as per the conservation of energy, we can rewrite the summation of the real power at a particular node is equal to 0 and similarly the summation of reactive power at a particular node connected to different branches is equal to 0. Using these statements, we can now write the complex form of bus which also at the point of i can be given as S generator at i equal to S demand i minus S ik minus Sij equal to 0. What does it mean? So, we are saying that all the power which has been generated at bus number i is equal to the load consumed at that same i as well as the power moving from bus i to bus k as well as bus i to bus j. So, it is something like that all of you please concentrate.

So, this is my a kind of generator am I right. So, this is my demand and probably this is moving to bus number k and this is moving to bus number j. So, we are saying this power which has been injected is equal to the summation of this load plus this plus this. So, at this bus summation of all the power equal to 0 or injected power is equal to outgoing power. So, if you separate it out both real and reactive power, we can rewrite that P generation at i bus minus P demand at i bus minus P ik minus P ij which is equal to 0.

We can also rewrite the similar equation for reactive power where Q generation i minus Q demand i minus Q ik minus Q ij is also equal to 0. So, 11.4 and 11.5 is very important with respect to real and reactive power:

$P_{gen,i} - P_{demand,i} - P_{ik} - P_{ij} = 0$ …11.4

$Q_{gen,i} - Q_{demand,i} - Q_{ik} - Q_{ij} = 0$ …11.5

and further what we can do if you are interested to generate the equations of P and Q in a network, we all know that the power S ok you must have learned from your first year basic electrical engineering where you have been taught that the power S Apparent power.

So, normally we say S. But now we need to say that Sk conjugate which is nothing but;

$S_k = V_k I_k^*$

So, the current which is nothing but the multiplication of admittance times voltage but the summation

which is V conjugate I, we can rewrite Sk conjugate equal to Vk conjugate ik and which is nothing but t
can be replaced by y ik j times vj. So, the current which is nothing but the multiplication of admittance times voltage where you have been taught that the power S Apparent power S equal to Vk ik conjugate. So, normally we see s s is given by vi conjugate all right at a bus number k it is represented as sk which is vk times ik conjugate all right. But now we need to say that sk conjugate which is nothing but s conjugate which is v conjugate i we can rewrite sk conjugate equal to vk conjugate ik and which is nothing but the summation j equal to 1 to n vk conjugate and ik can be replaced by y ik j times vj.

$$\sum_{j=1}^{N} |V|_k |V|_j (G_{kj} + jB_{kj}) \angle(\theta_k - \theta_j)$$

So, the current which is nothing but the multiplication of admittance times voltage where you have been taught that the power S apparent power S equal to Vk ik conjugate. So, normally we see s, s is given by vi conjugate all right at a bus number k it is represented as sk which is vk times ik conjugate all right. But now we need to say that sk conjugate which is nothing but s conjugate which is v conjugate i we can rewrite sk conjugate equal to vk conjugate ik and which is nothing but the summation j equal to 1 to n vk conjugate and ik can be replaced by y ik j times vj. So, the current which is nothing but the multiplication of admittance times voltage P and Q in a network, we all know that the power S ok you must have learned from your first year basic electrical engineering where you have been taught that the power s apparent power s equal to vk ik conjugate. So, normally we see s s is given by vi conjugate all right at a bus number k it is represented as sk which is vk times ik conjugate all right.

But now we need to say that sk conjugate which is nothing but s conjugate which is v conjugate i we can rewrite sk conjugate equal to vk conjugate ik and which is nothing but the summation j equal to 1 to n vk conjugate and ik can be replaced by y ik j times vj. So, the current which is nothing but the multiplication of admittance times voltage and further what we can do if you are interested to generate the equations of p and q in a network we all know that the power s ok you must have learned from your first year basic electrical engineering where you have been taught that the power s apparent power s equal to vk ik conjugate. So, normally we see s s is given by vi conjugate all right at a bus number k it is represented as sk which is vk times ik conjugate all right. But now we need to say that sk conjugate which is nothing but s conjugate which is v conjugate i we can rewrite sk conjugate equal to vk conjugate ik and which is nothing but the summation j equal to 1 to n vk conjugate and ik can be replaced by y ik j times vj. So, the current which is nothing but the multiplication of admittance times voltage similar equation for reactive power where q generation i minus q demand i minus q ik minus q ij is also equal to 0. So, 11.4 and 11.5 is very important with respect to real and reactive power and further what we can do if you are interested to generate the equations of p and q in a network we all know that the power s ok you must have learned from your first year basic electrical engineering where you have been taught that the power s apparent power s equal to vk ik conjugate. So, normally we see s s is given by vi conjugate all right at a bus number k it is represented as sk which is vk times ik conjugate all right. But now we need to say that sk conjugate which is nothing but s conjugate which is v conjugate i we can rewrite sk conjugate equal to vk conjugate ik and which is nothing but the summation j equal to 1 to n vk conjugate and ik can be replaced by y ik j times vj. So, the current which is nothing but the multiplication of admittance times voltage we can rewrite that p generation at i bus minus p demand at i bus minus p ik minus p ij which is equal to 0. We can also rewrite the similar equation for reactive power where q generation i minus q demand i minus q ik minus q ij is also equal to 0. So, 11.4 and 11.5 is very important with respect to real and reactive power and further what we can do if you are interested to generate the equations of p and q in a network we all know that the power s ok you must have learned from your first year basic electrical engineering where you have been taught that the power s apparent power s equal to vk ik conjugate. So, normally we see s s is given by vi conjugate all right at a bus number k it is represented as Sk which is Vk times Ik conjugate all right. But now we need to say that Sk conjugate which is nothing but S conjugate which is V conjugate I we can rewrite Sk conjugate equal to Vk conjugate Ik and which is nothing but the summation j equal to 1 to n Vk conjugate and Ik can be replaced by So, if you separate it out both real and reactive power we can rewrite that p generation at i bus minus p demand at i bus minus p ik minus p ij which is equal to 0. We can also rewrite the similar equation for reactive power where q generation i minus q demand i minus q ik minus q ij is also equal to 0. So, 11.4 and 11.5 is very important with respect to real and reactive power and further what we can do if you are interested to generate the equations of p and q in a network we all know that the power s ok you must have learned from your first year basic electrical engineering where you have been taught that the power S apparent power S equal to Vk Ik conjugate. So, normally we say S, S is given by Vi conjugate all right at a bus number k it is represented as Y ik j times Vj. So, the current which is nothing but the multiplication of admittance times voltage So, it is something like that all of you please concentrate. So, this is my a kind of generator am I right. So, this is my demand and probably this is moving to bus number k and this is moving to bus number j. So, we are saying this power which has been injected is equal to the summation of this load plus this plus this. So, at this bus summation of all the power equal to 0 or injected power is equal to outgoing power. So, if you separate it out both real and reactive power we can rewrite that p generation at i bus minus p demand at i bus minus p ik minus p ij which is equal to 0. We can also rewrite the similar equation for reactive power where q generation i minus q demand i minus q ik minus q ij is also equal to 0. So, 11.4 and 11.5 is very important with respect to real and reactive power and further what we can do if you are interested to generate the equations of p and q in a network we all know that the power s ok you must have learned from your first year basic electrical ok or voltage upon impedance. So, if you further expand this equation which is nothing but the Sk star is given by summation j equal to 1 to n Vk Vj and you can open it up which is G kj plus j Bk j angle theta k minus theta j. So, this is my polar representation or you can go for your relatively algebraic representation. So, finally the Sk star can be given by an equation which is Vk Vj and the Y component which has been distributed to G kj plus j Vk j and the voltage angle differences which has been represented by theta k and theta j. So, the angular component is now with reference to your voltages as well as because they are phasors ok. This voltages are my phasors. So, now they have been represented by V times angle and V times angle for both bus number k and j and Y kj is written represented by G kj plus j B kj. Now, out of this equation, I can now expand it to both real and reactive terms and further the real component can be my real power and the imaginary component is belongs to my reactive power. So, the 11.6 after breaking into the real and reactive components you can arrive with an equation which is Pk which is real power injected which is j equal to 1 to n Vk Vj G kj cos of theta k minus theta j minus of V kj sin of theta k minus theta j. So, if you expand that previous equation 11.6 you will get a real component plus j times an imaginary component. So, the real component is nothing but my because the left hand left half side S is nothing but my P plus j cube. So, when you expand the right hand side with you will get a real component plus j times an imaginary component. So, the real component is nothing but my because the left hand left half side s is nothing but my p plus j cube. So, when you expand the right hand side with which is j equal to 1 to n vk vj g kj cos of theta k minus theta j minus of v kj sin of theta k minus theta j. So, if you expand that previous equation 11.6 we get:

$$P_k = \sum_{j=1}^{N} |V|_k |V|_j \{ (G_{kj} \cos(\theta_k - \theta_j) - B_{kj} \sin(\theta_k - \theta_j) \} \ldots 11.7$$

You will get a real component plus j times an imaginary component. So, the real component is nothing but my because the left hand left half side s is nothing but my p plus j cube. So, when you expand the right hand side with a real component plus j times the reactive component and this real component is nothing but my p type ok. So, now moving further the equation number 11.7 there probably if you talk about a transmission line because we are carrying out this power flow equations or current and voltages at each and every line and buses can be obtained through a power flow analysis and if you are applying to a transmission system as you all know that the transmission line are actually the resistances are quite low compared to its reactances.

So, the transmission lines are mainly dominated by inductive effects. So, they are actually reactance is more compared to resistance or indirectly I can say the X by R ratio is not too small actually it is quite actually a reasonably between 2 and 10 and hence I can say that X is 2 to 10 times more than the resistance and because of which one can assume the value of G is very very close to 0 because the resistance and reactance ratio is reactance upon resistance ratio is very very high. So, if you substitute G equal to 0 then probably the equation Pk now can convert to this one ignoring the negative sign which will identify the reverse real power flow. So, now P assuming the reactance is very dominating compared to resistance now Pk which is given by j equal to 1 to n Vk Vj Bkj sine of theta k minus theta j. So, that is by equation number 11.8:

$$P_k = \sum_{j=1}^{N} |V|_k |V|_j \{(B_{kj} \sin(\theta_k - \theta_j)\} \quad \ldots 11.8$$

Now, one more interesting part the theta k and theta j what is theta k and theta j if you go back to my original slide the theta k and theta j they are nothing but the angles with respect to my V the voltage at bus number k and the voltage at bus number j. So, they are the angle at which those voltages are being defined and in general the voltages do not oscillate too much with their angles be respective of the buses. So, the angle difference between two different buses are very very small and maximum it could be 10 to 15 degrees. So, when my theta is very very small and then my sine theta will be also very very equal to my theta when theta is very small then sine theta equal to theta and if you substitute that assumption then the equation 11.8 now can be expressed as 11.9 with this assumption the 11.10 become the real power P.

$$\text{Sin}(\theta_k - \theta_j) \approx (\theta_k - \theta_j) \quad \ldots (11.9)$$

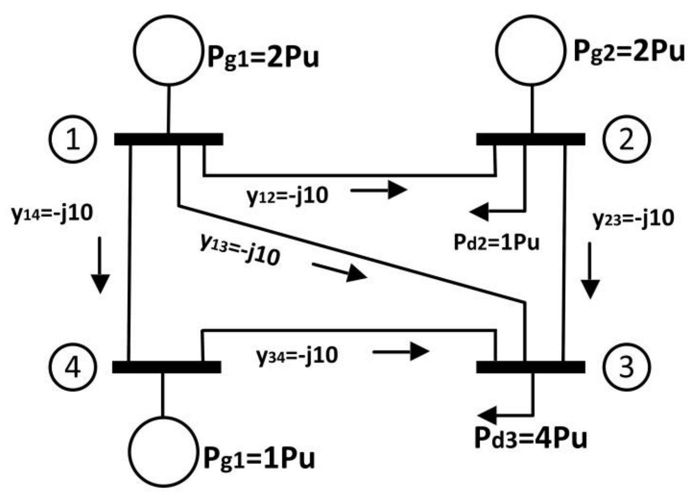
$$P_k = \textstyle\sum_{j=1}^{N} |V|_k |V|_j \{(B_{kj}(\theta_k - \theta_j)\} \quad \ldots (11.10)$$

So, sine of theta k minus theta j has been replaced by theta k minus theta j. So, hope you are able to follow it up. So, if not please try to repeat it and one more interesting assumption that we have to consider those voltages you know V at k as well as V at j two different buses they are also kind of actually one per unit once very close to for example, 33 kV each or 66 kV each or maybe 230 kV each whatever it is they are very close to one per unit and maybe with small oscillations of actually you know 0.95 to 1.05 variation. So, if you consider them to be close to unity then further the equation can be simplified the Pk which is given by summation equal to j equal to 1 to n Bkj theta k minus theta j. So, this is one of the wonderful equation that will help us for the DC network significantly where we are seeing the real power flow in a particular line can easily be considered or at a particular bus can be determined by simply multiplying the pkj times the difference in angles theta k minus theta j. further the equation can be simplified the Pk which is given by summation equal to j equal to 1 to n vkj theta k minus theta j. So, this is one of the wonderful equation that will help us for the DC network significantly where we are seeing the real power flow in a particular line can easily be considered or at a particular bus can be determined by simply multiplying the pkj times the difference in angles theta k minus theta j. So, if you consider them to be close to unity then further the equation can be simplified the pk which is given by summation equal to j equal to 1 to n vkj theta k minus theta j. So, this is one of the wonderful equation that will help us for the DC network significantly where we are seeing the real power flow in a particular line can easily be considered or at a particular bus can be determined by simply multiplying the pkj times the difference in angles theta k minus theta j. So, if not please try to repeat it and one more interesting assumption that we have to consider those voltages you know v at k as well as v at j two different buses they are also kind of actually one per unit once very close to for example, 33 kV each or 66 kV each or maybe 230 kV each whatever it is they are very close to one per unit and maybe with small oscillations of actually you know 0.95 to 1.05 variation. So, if you consider them to be close to unity then further the equation can be simplified the pk which is given by summation equal to j equal to 1 to n vkj theta k minus theta j. So, this is one of the wonderful equation that will help us for the DC network significantly where we are seeing the real power flow in a particular line can easily be considered or at a particular bus can be determined by simply multiplying the pkj times the difference in angles theta k minus theta j. theta k minus theta j. So, hope you are able to follow it up. So, if not please try to repeat it and one more interesting assumption that we have to consider those voltages you know v at k as well as v at j two different buses they are also kind of actually one per unit once very close to for example, 33 kV each or 66 kV each or maybe 230 kV each whatever it is they are very close to one per unit and maybe with small oscillations of actually you know 0.95 to 1.05 variation. So, if you consider them to be close to unity then further the equation can be simplified the pk which is given by summation equal to j equal to 1 to n vkj theta k minus theta j. So, this is one of the wonderful equation that will help us for the DC network significantly where we are seeing the real power flow in a particular line can easily be considered or at a particular bus can be determined by simply multiplying the pkj times the difference in angles theta k minus theta j. and if you substitute that assumption then the equation 11.8 now can be expressed as 11.9 with this assumption the 11.10 become the real power p which is summation j equal to 1 to n vk vj vkj theta k minus theta j. So, sine of theta k minus theta j has been replaced by theta k minus theta j. So, hope you are able to follow it up. So, if not please try to repeat it and one more interesting assumption that we have to consider those voltages you know v at k as well as v at j two different buses they are also kind of actually one per unit once very close to for example, 33 kV each or 66 kV each or maybe 230 kV each whatever it is they are very close to one per unit and maybe with small oscillations of actually you know 0.

can be simplified the pk which is given by summation equal to j equal to 1 to n vkj theta k minus theta j. So, this is one of the wonderful equation that will help us for the DC network significantly where we are seeing the real power flow in a particular line can easily be considered or at a particular bus can be determined by simply multiplying the pkj times the difference in angles theta k minus theta j. when theta is very small then sine theta equal to theta and if you substitute that assumption then the equation 11.8 now can be expressed as 11.9 with this assumption the 11.10 become the real power p which is summation j equal to 1 to n vk vj vkj theta k minus theta j. So, sine of theta k minus theta j has been replaced by theta k minus theta j. So, hope you are able to follow it up. So, if not please try to repeat it and one more interesting assumption that we have to consider those voltages you know v at k as well as v at j two different buses they are also kind of actually one per unit once very close to for example, 33 kV each or 66 kV each or maybe 230 kV each whatever it is they are very close to one per unit and maybe with small oscillations of actually you know 0.95 to 1.05 variation. So, if you consider them to be close to unity then further the equation can be simplified the pk which is given by summation equal to j equal to 1 to n vkj theta k minus theta j. So, this is one of the wonderful equation that will help us for the DC network significantly where we are seeing the real power flow in a particular line can easily be considered or at a particular bus can be determined by simply multiplying the pkj times the difference in angles theta k minus theta j.

$$P_k = \sum_{\substack{j=1 \\ j \neq k}}^{N} B_{kj}(\theta_K - \theta_j) \qquad \ldots (11.11)$$

Now, let us apply this equation number 11.11 to further understand the power flow real power network assuming a very standard network shown in diagram number 11.8 which is a four bus very standard expression.



So, what you could see from this diagram you could see there is there are actually three generators generator number one two and probably then you can see also one more generator here and you could see there are two loads this is one as well as two. So, the generators generations if you could see there is two per unit two per unit one per unit. So, total there are five per unit of generation and you could see the load which is four per unit and one per unit. So, almost the load and generation they are balanced and one interesting part you please So, almost the load and generation they are balanced and one interesting part you please two per unit one per unit. So, total there are five per unit of generation and you could see the load which is four per unit and one per unit.

So, almost the load and generation they are balanced and one interesting part you please observe the admittance of each and every line is equal to j10, this means they are all of similar lines similar lines means similar admittances means they are of the same distances. Though in the diagram they look different, but theoretically it has been assumed the distances between each and every bus remain same. And with that assumption, we can see there is no real power component real real component your admittance means resistances have been completely ignored. So, we say that they are purely inductive in nature. Now, considering this and applying the DC power flow we will see how DC power can be determined in this diagram.

Now, if you are interested to compute the real power flow if you are interested to continue the real power flow. Now, what we need to do yes. Now, in the previous diagram as you could see if I am interested to know what is P 1 that means at this bus at this bus I am interested to know what is P 1 means real power injection at bus number 1 which is nothing, but B 12 theta 1 minus theta 2 plus B 13 theta 1 minus theta 3 plus B 14 theta 1 minus theta 4. That means you please remember this bus number 1 which has been connected to bus number 2 this line which has been connected to bus number 3 which has been connected to bus number 4. So, as per my previous equation using this expression I can rewrite the P1 which is B12 theta 1 minus theta 2 plus B13 theta 1 minus theta 3 plus B14 theta 1 minus theta 4. Now, if you rearrange you can multiply and then you rearrange you get a new equation very interesting equation that is P1 which has been given by B12 plus B13 plus B14 times theta 1 minus B12 theta 2 minus B13 theta 3 minus B14 theta. Means the P1 which is and coefficient multiplied by theta 1 minus theta 2 multiplied by a coefficient theta 3 multiplied by another coefficient and theta 4 multiplied by another coefficient. We will understand more detail in the next slide, but before that I wanted to highlight that if you express P2 also similar to P1 you will get a very interesting equation that is my 11.15 and if you proceed further P3 and P4 you will get this equation 11.16, 17, 18, 19. You can observe a very interesting phenomenon, the diagonals they look different and that is the elements they look different. So, if you arrange in a matrix form then my P1, P2, P3, P4 is now expressed as a matrix where the diagonals are the positive sum of all the B matrices at which the lines are connected to that particular bus. Means if you see P1 means all the lines connected to bus number 1 the B element of those lines are being summed up and rest of them are negative. Similarly, when you go to P2 you could see the second element which is the summation of all the B elements connected to the bus number 2 and similarly bus number 3 and bus number 4. So, this is a very interesting matrix for us and once you have this matrix equation probably we can also rewrite that to get the matrix it is helpful to first write down the Y bus, the Y bus which can be formed in any network and once you form the Y bus, Y matrix then probably you can rewrite the whole matrix which is similar to the same thing. So, this is what we have derived and then now we are saying this is nothing but my Y bus matrix. So, what is Y bus matrix is nothing but the summation of all the admittances connected to a particular bus and they will represent my diagonal elements and rest will be represented with a negative element. But because it is a DC power flow we are considering only real power flow here. So, we are considering only the B element of that admittance not the other component and hence you can see it is completely represented by B3. Now how do I form the Y bus here? If you go to the original network you can easily see. So, this is Y bus actually given to be j10 the imaginary components are given to me which is because Y is given by G actually given to be J 10 the imaginary components are given to me which is because Y is given by G Now how do I form the Y bus here? If you go to the original network you can easily see.

So, this is Y bus actually given to be J 10 the imaginary components are given to me which is because Y is given by G it is completely represented by B3. Now how do I form the Y bus here? If you go to the original network you can easily see. So, this is Y bus actually given to be J 10 the imaginary components are given to me which is because Y is given by G other component and hence you can see it is completely represented by V 3. Now how do I form the Y bus here? If you go to the original network you can easily see. So, this is Y bus actually given to be J 10 the imaginary components are given to me which is because Y is given by G other component and hence you can see it is completely represented by V 3. Now how do I form the Y bus here? If you go to the original network you can easily see. So, this is Y bus actually given to be J 10 the imaginary components are given to me which is because Y is given by G only real power flow here. So, we are considering only the b element of that admittance not the other component and hence you can see it is completely represented by V 3. Now how do I form the Y bus here? If you go to the original network you can easily see. So, this is Y bus actually given to be J 10 the imaginary components are given to me which is because Y is given by G the admittances connected to a particular bus and they will represent my diagonal elements and rest will be represented with a negative element.

But because it is a DC power flow we are considering only real power flow here. So, we are considering only the b element of that admittance not the other component and hence you can see it is completely represented by V 3. Now how do I form the Y bus here? If you go to the original network you can easily see. So, this is Y bus actually given to be J

10 the imaginary components are given to me which is because Y is given by G the admittances connected to a particular bus and they will represent my diagonal elements and rest will be represented with a negative element. But because it is a DC power flow we are considering only real power flow here. So, we are considering only the b element of that admittance not the other component and hence you can see it is completely represented by V 3. Now how do I form the Y bus here? If you go to the original network you can easily see. So, this is Y bus actually given to be J 10 the imaginary components are given to me which is because Y is given by G the whole matrix which is similar to the same thing. So, this is what we have derived and then now we are saying this is nothing but my Y bus matrix. So, what is Y bus matrix is nothing but the summation of all the admittances connected to a particular bus and they will represent my diagonal elements and rest will be represented with a negative element. But because it is a DC power flow we are considering only real power flow here. So, we are considering only the b element of that admittance not the other component and hence you can see it is completely represented by V 3. Now how do I form the Y bus here? If you go to the original network you can easily see. So, this is Y bus actually given to be J 10 the imaginary components are given to me which is because Y is given by G once you form the Y bus, Y matrix then probably you can rewrite the whole matrix which is similar to the same thing. So, this is what we have derived and then now we are saying this is nothing but my Y bus matrix. So, what is Y bus matrix is nothing but the summation of all the admittances connected to a particular bus and they will represent my diagonal elements and rest will be represented with a negative element. But because it is a DC power flow we are considering only real power flow here. So, we are considering only the b element of that admittance not the other component and hence you can see it is completely represented by V3. Now how do I form the Y bus here? If you go to the original network you can easily see. So, this is Y bus actually given to be J 10 the imaginary components are given to me which is because Y is given by G we can also rewrite that to get the matrix it is helpful to first write down the Y bus, the Y bus which can be formed in any network and once you form the Y bus Y matrix then probably you can rewrite the whole matrix which is similar to the same thing. So, this is what we have derived and then now we are saying this is nothing but my Y bus matrix. So, what is Y bus matrix is nothing but the summation of all the admittances connected to a particular bus and they will represent my diagonal elements and rest will be represented with a negative element. But because it is a DC power flow we are considering only real power flow here. So, we are considering only the b element of that admittance not the other component and hence you can see it is completely represented by V 3. Now how do I form the Y bus here? If you go to the original network you can easily see. So, this is Y bus actually given to be J 10 the imaginary components are given to me which is because Y is given by G all the B elements connected to the bus number 2 and similarly bus number 3 and bus number 4. So, this is a very interesting matrix for us and once you have this matrix equation

probably we can also rewrite that to get the matrix it is helpful to first write down the Y bus, the Y bus which can be formed in any network and once you form the Y bus Y matrix then probably you can rewrite the whole matrix which is similar to the same thing. So, this is what we have derived and then now we are saying this is nothing but my Y bus matrix. So, what is Y bus matrix is nothing but the summation of all the admittances connected to a particular bus and they will represent my diagonal elements and rest will be represented with a negative element. But because it is a DC power flow we are considering only real power flow here. So, we are considering only the b element of that admittance not the other component and hence you can see it is completely represented by V 3. Now how do I form the Y bus here? If you go to the original network you can easily see. So, this is Y bus actually given to be J 10 the imaginary components are given to me which is because Y is given by G go to P2 you could see the second element which is the summation of all the B elements connected to the bus number 2 and similarly bus number 3 and bus number 4. So, this is a very interesting matrix for us and once you have this matrix equation probably we can also rewrite that to get the matrix it is helpful to first write down the Y bus, the Y bus which can be formed in any network and once you form the Y bus Y matrix then probably you can rewrite the whole matrix which is similar to the same thing. So, this is what we have derived and then now we are saying this is nothing but my Y bus matrix. So, what is Y bus matrix is nothing but the summation of all the admittances connected to a particular bus and they will represent my diagonal elements and rest will be represented with a negative element. But because it is a DC power flow we are considering only real power flow here. So, we are considering only the b element of that admittance not the other component and hence you can see it is completely represented by V 3. Now how do I form the Y bus here? If you go to the original network you can easily see. So, this is Y bus actually given to be J 10 the imaginary components are given to me which is because Y is given by G at which the lines are connected to that particular bus. Means if you see P 1 means all the lines connected to bus number 1 the b element of those lines are being summed up and rest of them are negative. Similarly, when you go to P 2 you could see the second element which is the summation of all the b elements connected to the bus number 2 and similarly bus number 3 and bus number 4. So, this is a very interesting matrix for us and once you have this matrix equation probably we can also rewrite that to get the matrix it is helpful to first write down the Y bus, the Y bus which can be formed in any network and once you form the Y bus Y matrix then probably you can rewrite the whole matrix which is similar to the same thing. So, this is what we have derived and then now we are saying this is nothing but my Y bus matrix. So, what is Y bus matrix is nothing but the summation of all the admittances connected to a particular bus and they will represent my diagonal elements and rest will be represented with a negative element.

But because it is a DC power flow we are considering only real power flow here. So, we are considering only the b element of that admittance not the other component and hence you can see it is completely represented by V 3. Now how do I form the Y bus here? If you go to the original network you can easily see. So, this is Y bus actually given to be J 10 the imaginary components are given to me which is because Y is given by G if you arrange in a matrix form then my P 1 P 2 P 3 P 4 is now expressed as a matrix where the diagonals are the positive sum of all the b matrices at which the lines are connected to that particular bus. Means if you see P 1 means all the lines connected to bus number 1 the b element of those lines are being summed up and rest of them are negative. Similarly, when you go to P 2 you could see the second element which is the summation of all the b elements connected to the bus number 2 and similarly bus number 3 and bus number 4.

So, this is a very interesting matrix for us and once you have this matrix equation probably we can also rewrite that to get the matrix it is helpful to first write down the Y bus, the Y bus which can be formed in any network and once you form the Y bus Y matrix then probably you can rewrite the whole matrix which is similar to the same thing. So, this is what we have derived and then now we are saying this is nothing but my Y bus matrix. So, what is Y bus matrix is nothing but the summation of all the admittances connected to a particular bus and they will represent my diagonal elements and rest will be represented with a negative element. But because it is a DC power flow we are considering only real power flow here. So, we are considering only the b element of that admittance not the other component and hence you can see it is completely represented by V 3. Now how do I form the Y bus here? If you go to the original network you can easily see. So, this is Y bus actually given to be J 10 the imaginary components are given to me which is because Y is given by G plus jB. So, the B components which are available to me based on this expression. So, B is nothing but 10 for me. So, if you say this is 10 if you go this is 10 in each line. So, then this summation of all the three will now be minus 10 minus 10 minus 10 this become you know become minus 30 and rest of the minus of minus 10 become plus 10 and similarly there are two lines connected to bus number 2 let us check it. If you check it out bus number 2 and there are two lines yes this line and this line. So, it become 20 and similarly some of the cases it is 30. So, you get this Y bus which is minus 30 minus 20 minus 30 minus 20 and rest of the elements are minus of minus 10 become plus 10. So, once you have this Y matrix which is available to me now I can substitute the P1 P2 P3 P4 is known to me. So, you may have bit of doubt.

So, I am just going bit slow going back what is P 1 what is my P1? P1 means the power injected at bus number 1. What is power injected? 2 per unit . Am I right. So, the P become 2 for me am I right excluding the load points load points you could see.

So, this is injected we can consider it is positive. So, P1 become 2 and P2 become injected to load 1. So, net injection will be 1 at bus number 2. So, again it is positive bus number 3 it is negative minus 4 because it is 1 and bus number 4 it is positive because it injected 1. So, based on this, now I can claim my P matrix which is 2 1 minus 4 and 1 and this B matrix we have already defined and theta I have substituted all right. So, from that you can calculate theta is nothing but inverse of that B matrix multiplied by P.

If you solve it now you get the value for theta 2 theta 3 and theta 4 ok. So, probably which I will interest to me ok which is quite interest to me. So, any angle theta now can be determined by taking the inverse of B matrix and multiplied by its P matrix ok and that is all. So, we know the value of thetas. So, once you know the value of theta, how do you calculate P1 2? For example, if I am interested to know the real power flow between bus number 1 and 2 BP12 is nothing but B12 multiplied by theta 1 minus theta 2 ok.

Assuming the theta 1 which is 0 to me theta 2 theta 3 theta 4 is known to me. So, P12 is nothing but B12 what is B12 which is 10 multiplied by theta 1 minus theta 2 theta 1 is known to me theta 2 is known to me. So, finally, I can get it is 0.25 per unit is the real power flow between line number 1. Similarly, the power flow at each and every line can easily be determined and that is known as a real power flow solution of a network of a power system using DC concept. Now, when you talk about DC power flow, if I like to you know generalize this concept. So, we assume there are totally n number of buses and m number of branches and we consider bus number 1 is identified as a reference that is what you got theta 1 equal to 0 and real power injection at all the buses except bus number 1 and so you need to have a topology and admittance for all branches need to be considered. Now, if you further go the P which is given by B dash theta the DC power flow equation based on Matrix form can also be written as P equal to B dash theta, but P is the nodal injections ok it is a vector and theta is the vector of nodal phase angles and B dash is nothing but B prime matrix ok previously was in the B matrix which is a B prime matrix in this case. Now, if you again go for development of B prime matrix so what is B prime matrix to be because you know the P which is B times of theta and the Y matrix which is given by your B matrix and to calculate the P prime what we normally do from the previous slide we can develop a procedure to obtain the B prime matrix from the Y bus itself. So, B prime can be obtained very interestingly remove the G from the Y bus replace the diagonal element B dash k k with the sum of the non diagonal elements in row k alternatively subtract B k the sum term from B k k and multiply by 1 if there is no B k then just multiply by minus 1. So, multiply all of diagonals by minus 1 remove row 1 and column 1 and that will give me the B prime matrix. So, in this case as you could see the Y bus matrix I have already taught you that is minus 30 10 10 10 10 minus 20 10 0 10 10 minus 30 10 10 0 10 minus 20. Now, if you are interested to know what is B prime so what you have done if you very carefully observe we have actually taken out this row and column all right and rest what you have done actually the diagonals we have multiplied made it positive and rest of the terms we multiplied by minus term. So, what has happened this 20 minus 10 0 minus 10 30 minus 10 20 become my B prime matrix. So, once you have the B prime so then you can apply the concept in a different way hence there are some questions that need to be answered from the above analysis let's 20 become my B prime matrix. So, once you have the B prime so then you can apply the concept in a different way hence there are some questions that need to be answered from the above analysis let's So, B prime can be obtained very interestingly remove the G from the Y bus replace the diagonal element B dash k k with the sum of the non diagonal elements in row k alternatively subtract B k the sum term from B k k and multiply by 1 if there is no B k then just multiply by minus 1. So, multiply all of diagonals by minus 1 remove row 1 and column 1 and that will give me the B prime matrix. So, in this case as you could see the Y bus matrix I have already taught you that is minus 30 10 10 10 10 minus 20 10 0 10 10 minus 30 10 10 0 10 minus 20. Now, if you are interested to know what is B prime so what you have done if you very carefully observe we have actually taken out this row and column all right and rest what you have done actually the diagonals we have multiplied made it positive and rest of the terms we multiplied by minus term. So, what has happened this 20 minus 10 0 minus 10 30 minus 10 20 become my B prime matrix. So, once you have the B prime so then you can apply the concept in a different way hence there are some questions that need to be answered from the above analysis let's and to calculate the P prime what we normally do from the previous slide we can develop a procedure to obtain the B prime matrix from the Y bus itself. So, B prime can be obtained very interestingly remove the G from the Y bus replace the diagonal element B dash k k with the sum of the non diagonal elements in row k alternatively subtract B k the sum term from B k k and multiply by 1 if there is no B k then just multiply by minus 1. So, multiply all of diagonals by minus 1 remove row 1 and column 1 and that will give me the B prime matrix. So, in this case as you could see the Y bus matrix I have already taught you that is minus 30 10 10 10 10 minus 20 10 0 10 10 minus 30 10 10 0 10 minus 20. Now, if you are interested to know what is B prime so what you have done if you very carefully observe we have actually taken out this row and column all right and rest what you have done actually the diagonals we have multiplied made it positive and rest of the terms we multiplied by minus term. So, what has happened this 20 minus 10 0 minus 10 30 minus 10 20 become my B prime matrix. So, once you have the B prime so then you can apply the concept in a different way hence there are some questions that need to be answered from the above analysis let's Now, if you again go for development of B prime matrix so what is B prime matrix to be because you know the P which is B times of theta and the Y matrix which is given by your B matrix and to calculate the P prime what we normally do from the previous slide we can develop a procedure to obtain the B prime matrix from the Y bus itself. So, B prime can be obtained very interestingly remove the G from the Y bus replace the diagonal element B dash k k with the sum of the non diagonal elements in row k alternatively subtract B k the sum term from B k k and multiply by 1 if there is no B k then just multiply by minus 1.

So, multiply all of diagonals by minus 1 remove row 1 and column 1 and that will give me the B prime matrix. So, in this case as you could see the Y bus matrix I have already taught you that is minus 30 10 10 10 10 minus 20 10 0 10 10 minus 30 10 10 0 10 minus 20. Now, if you are interested to know what is B prime so what you have done if you very carefully observe we have actually taken out this row and column all right and rest what you have done actually the diagonals we have multiplied made it positive and rest of the terms we multiplied by minus term. So, what has happened this 20 minus 10 0 minus 10 30 minus 10 20 become my B prime matrix. So, once you have the B prime so then you can apply the concept in a different way hence there are some questions that need to be answered from the above analysis let's flow equation based on Matrix form can also be written as P equal to B dash theta, but P is the nodal injections ok it is a vector and theta is the vector of nodal phase angles and B dash is nothing but B prime matrix ok previously was in the B matrix which is a B prime matrix in this case. Now, if you again go for development of B prime matrix so what is B prime matrix to be because you know the P which is B times of theta and the Y matrix which is given by your B matrix and to calculate the P prime what we normally do from the previous slide we can develop a procedure to obtain the B prime matrix from the Y bus itself.

So, B prime can be obtained very interestingly remove the G from the Y bus replace the diagonal element B dash k k with the sum of the non diagonal elements in row k alternatively subtract B k the sum term from B k k and multiply by 1 if there is no B k then just multiply by minus 1. So, multiply all of diagonals by minus 1 remove row 1 and column 1 and that will give me the B prime matrix. So, in this case as you could see the Y bus matrix I have already taught you that is minus 30 10 10 10 10 minus 20 10 0 10 10 minus 30 10 10 0 10 minus 20. Now, if you are interested to know what is B prime so what you have done if you very carefully observe we have actually taken out this row and column all right and rest what you have done actually the diagonals we have multiplied made it positive and rest of the terms we multiplied by minus term.

So, what has happened this 20 minus 10 0 minus 10 30 minus 10 20 become my B prime matrix. So, once you have the B prime so then you can apply the concept in a different way hence there are some questions that need to be answered from the above analysis let's theta 1 equal to 0 and real power injection at all the buses except bus number 1 and so you need to have a topology and admittance for all branches need to be considered. Now, if you further go the P which is given by B dash theta the DC power flow equation based on Matins form can also be written as P equal to B dash theta, but P is the nodal injections ok it is a vector and theta is the vector of nodal phase angles and B dash is nothing but B prime matrix ok previously was in the B matrix which is a B prime matrix in this case. Now, if you again go for development of B prime matrix so what is B prime matrix to be because you know the P which is B times of theta and the Y matrix which is given by your B matrix and to calculate the P prime what we normally do from the previous slide we can develop a procedure to obtain the B prime matrix from the Y bus itself. So, B prime can be obtained very interestingly remove the G from the Y bus replace the diagonal element B dash k k with the sum of the non diagonal elements in row k alternatively subtract B k the sum term from B k k and multiply by 1 if there is no B k then just multiply by minus 1. So, multiply all of diagonals by minus 1 remove row 1 and column 1 and that will give me the B prime matrix. So, in this case as you could see the Y bus matrix I have already taught you that is minus 30 10 10 10 10 minus 20 10 0 10 10 minus 30 10 10 0 10 minus 20. Now, if you are interested to know what is B prime so what you have done if you very carefully observe we have actually taken out this row and column all right and rest what you have done actually the diagonals we have multiplied made it positive and rest of the terms we multiplied by minus term. So, what has happened this 20 minus 10 0 minus 10 30 minus 10 20 become my B prime matrix. So, once you have the B prime so then you can apply the concept in a different way hence there are some questions that need to be answered from the above analysis let's generalize this concept. So, we assume there are totally n number of buses and m number of branches and we consider bus number 1 is identified as a reference that is what you got theta 1 equal to 0 and real power injection at all the buses except bus number 1 and so you need to have a topology and admittance for all branches need to be considered.

Now, if you further go the P which is given by B dash theta the DC power flow equation based on Matins form can also be written as P equal to B dash theta, but P is the nodal injections ok it is a vector and theta is the vector of nodal phase angles and B dash is nothing but B prime matrix ok previously was in the B matrix which is a B prime matrix in this case. Now, if you again go for development of B prime matrix so what is B prime matrix to be because you know the P which is B times of theta and the Y matrix which is given by your B matrix and to calculate the P prime what we normally do from the previous slide we can develop a procedure to obtain the B prime matrix from the Y bus itself. So, B prime can be obtained very interestingly remove the G from the Y bus replace the diagonal element B dash k k with the sum of the non diagonal elements in row k alternatively subtract B k the sum term from B k k and multiply by 1 if there is no B k then just multiply by minus 1. So, multiply all of diagonals by minus 1 remove row 1 and column 1 and that will give me the B prime matrix.

So, in this case as you could see the Y bus matrix I have already taught you that is minus 30 10 10 10 10 minus 20 10 0 10 10 minus 30 10 10 0 10 minus 20. Now, if you are interested to know what is B prime so what you have done if you very carefully observe

we have actually taken out this row and column all right and rest what you have done actually the diagonals we have multiplied made it positive and rest of the terms we multiplied by minus term. So, what has happened this 20 minus 10 0 minus 10 30 minus 10 20 become my B prime matrix. So, once you have the B prime so then you can apply the concept in a different way hence there are some questions that need to be answered from the above analysis let's check what they are. Now, once you apply the B prime matrix probably we will try to solve a simple problem using B prime matrix and see whether it is working or not. Now, the same example that we have discussed in the past we obtain the power flow in each and every line using a different concept B times theta i minus theta j Bij multiplied by theta i minus theta j is my B.

The same concept we are extending to another form where you can see the DC power flow in a generalized form we can create a nodal matrix node-arc incident matrix A. So, based on the topology the same diagram can be expressed in the form of A where we can say how the nodes and arcs are being represented the D matrix formed by placing the negative of the susceptance of each branch along with the diagonal of M cross M matrix where M equal to 5. So, you can form a D matrix and once we have the incidence matrix and D matrix then probably we can write it down combining AD and theta we can rewrite P which is D cross A times theta. So, the P is given by D cross this is another approach to find your power flow where you can write P equal to D cross A into theta.

So, this is D this is A this is theta and based on which I can multiply actually A into theta I get this element and then finally, I get this element. So, what is happening the value P is known to me and once the P is known to me, I can solve theta 1 theta 2 theta 3 theta 4 and we are very happy to say that the theta 2 theta 3 theta 4 is minus 0.025 0.15 is plus minus 0.025 which is almost saying that we obtained in the past.

So, we discussed almost three different methods one is based on prime matrix, one is based on incident matrix, one is based on classical real power flow method. So, then you can further calculate the real power flows of different lines. I think this is all about DC power flow expressions and solutions of a given power network which is a very simplified way of doing it. But if I would not have ignored some of my real power components as well as some serious simplification that we have assumed in our network because we have not considered reactive power at all. So, if you consider reactive power then this problem become very very complex and that we will see in our next lecture about AC load flow where we respect both real and reactive power and we do not ignore anything out of it. So, the final solution of DC power flow in a very generalized form is you could see that the power injection is given to you the line flows are given to you. So, at the end of the day what we like to highlight through a particular process the real power flow in any line can be determined. But using this procedure if someone asked me what is the reactive power flow in this particular line between 1 and 2 probably I will be not in a position to answer. And that we can answer when you go to the AC power flow concept.

So, at this point of time you will be very comfortable in identifying the real power flow in any given line at any given point of time. So, with this we stop here. Thank you. So, at this point of time you will be very comfortable in identifying the real power flow in any given line at any given point of time. So, with this we stop here. Thank you.