Power System Dynamics, Control and Monitoring
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Lecture - 52
State estimation in power system

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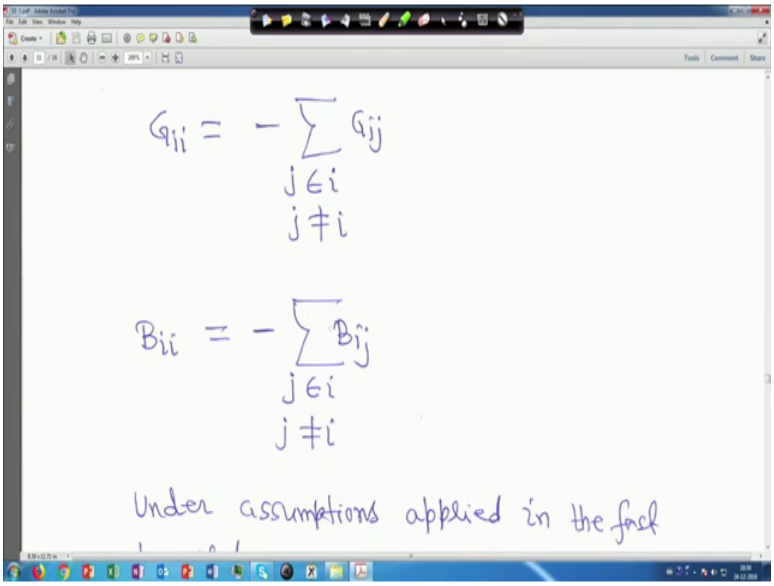

Ok. So, we are back again. So, this is actually G ii right. And then B ii will become although we will neglect this one, but mathematically you can write. Similarly, B ii will be minus sigma of j naught is equal to j belongs to i, but j naught is equal to i B ij right.

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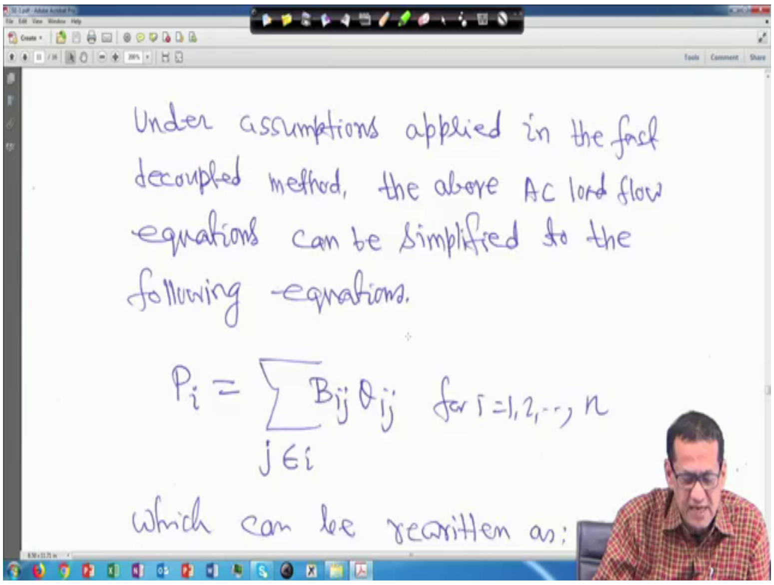

So, under assumptions applied in the fast decoupled method right, because fast decoupled load flow already you have studied, so nothing to be mentioned here right. If you if you have any doubt at the beginning that already that your power system analysis load flow studies I have covered, so there fast decoupled load flow or assumptions, I have been made. So, you can go through that or see any book no problem right. So, the above AC load flow equations can be simplified to the following equations, therefore P i is equal j belong to i B ij theta ij for i is equal to 1 to n.

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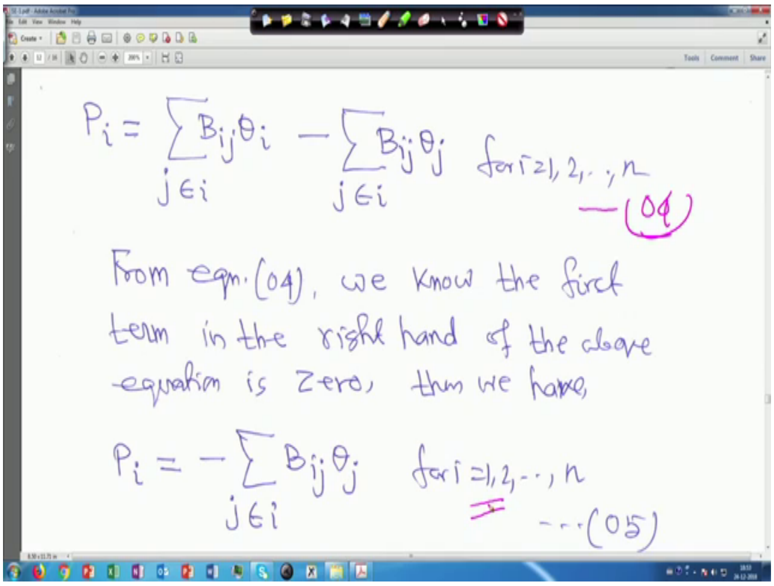

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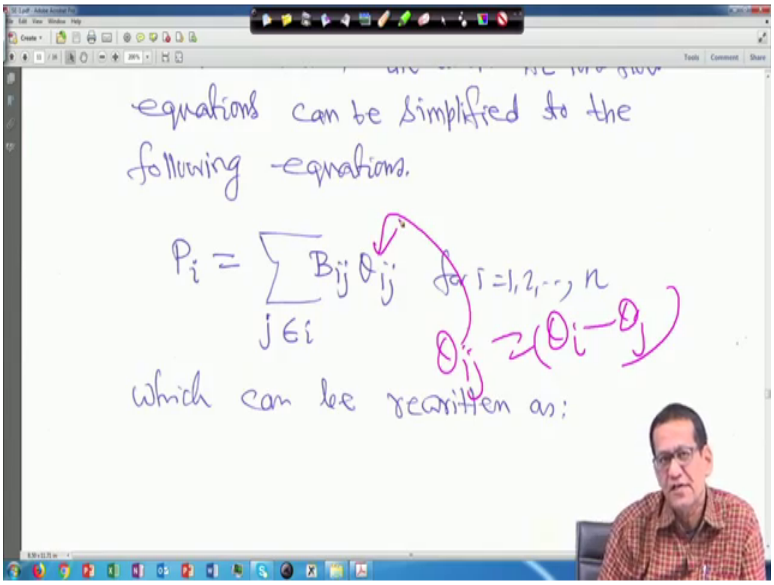

In this case, what we are doing is that your resistance is neglected that is why, we are writing like this, which can be re written as that P i and your theta ij, and your theta ij is equal to theta i minus theta j. So, this one you substitute here, you just substitute here right, then you make two terms.

So, P i that is power injection and bus i that j belongs to i B ij theta i minus sigma j belongs to i that B ij theta j, for i is equal to 1, 2 up to n right. So, equation 04 from equation 04, we know that first term in the right hand of the above equation is zero right. So, this is your thus we have that P i is equal to minus your j belongs to i B ij theta j for i is equal to your 1 to n right.

So, this is a simple thing from equation your 4, we know that first term in the right hand of the above equation is zero. Because, if we come back to equation-4, let me see right, this is equation-3, 4 is this one right, I forgot to mark equation-4 right. So, your this thing this is actually, it should have been question number-4, I am making it for you right 04 right. So, therefore, then we have that your minus sigma j belongs to i, it will B ij theta ij, for i is equal to your 1 to n right.

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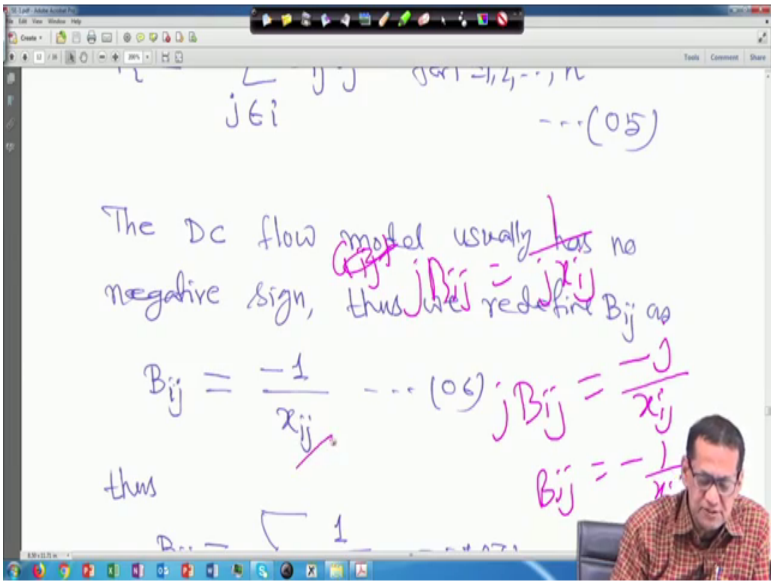

So, therefore this is actually P i is equal to this one. So, the DC load flow model you usually has no negative sign, thus B ij is equal to your what you call, it will be minus 1 upon x x ij.

Actually, what we will do now, DC load flow has no negative sign, therefore we can write like this say G ij, I will just forget about that that B ij is equal to actually your 1 upon j x ij, this will because this thing. Therefore, B ij can be written as minus j your later I will j B ij equal to minus j upon x ij that means, jj cancel both side, so B ij will be minus 1 upon x ij. So, this conventional we will use, same as before although we took minus 1, but DC load flow usually has no negative sign. Therefore, we use this one.

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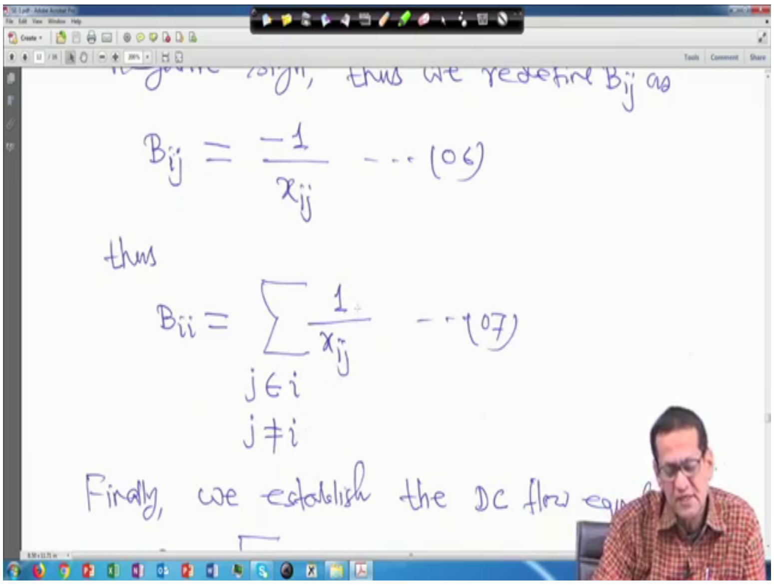

So, if you do so if you do so, then thus you can make it that B ii will be just j belongs to i, j not is equal to i, 1 upon x ij, this equation-7.

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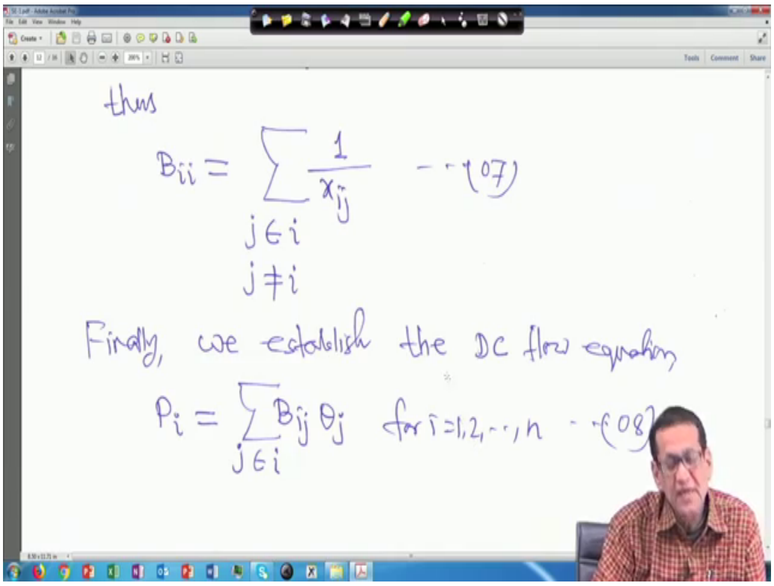

Finally, we established that DC flow your what you call DC flow equation will be P i is equal to j belongs to i, B ij theta ij, for i is equal to 1 to n right.

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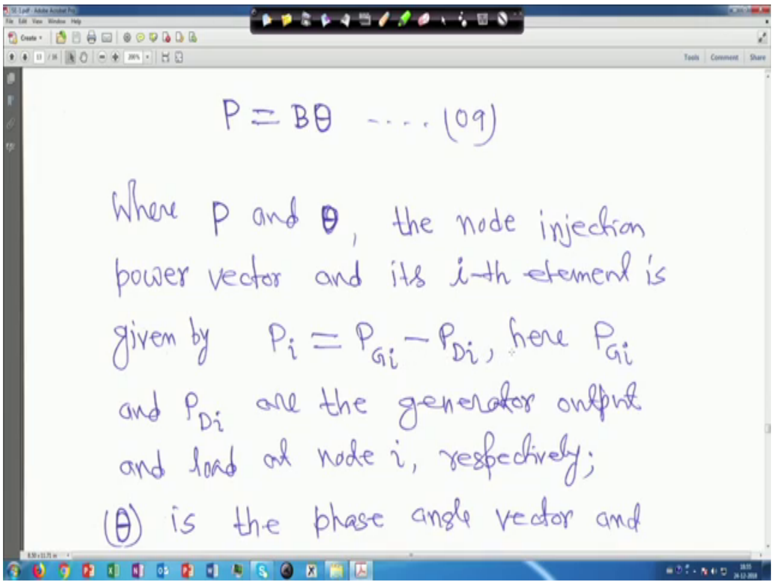

Therefore, your or in the matrix form we will write P is equal to B theta, this way we can write, where P and theta, first we will see that P, then node injection power P is the node injection power and its ith element is your given by P i is equal to P Gi minus P Di you know that the P Gi is the generation at node i, and d i is the P Di is the load, then power injection P i will be P Gi minus P Di.

Here P Gi and P Di are the generated output and load at node i, respectively that you know from the load flow study. And the theta is the phase angle vector, and B is the matrix whose elements are defined by equation 6 and 7 right. So, this is actually when you go back to question 6 and 7, so we this thing has been defined right.

And other thing is that that this equation that your this is actually this equation that we have droped first term is zero right, so this equation I told you above equation, I told you previously and it is 04. So, first term in the right hand of the above equation is zero. So, a question to you that why it is zero right.

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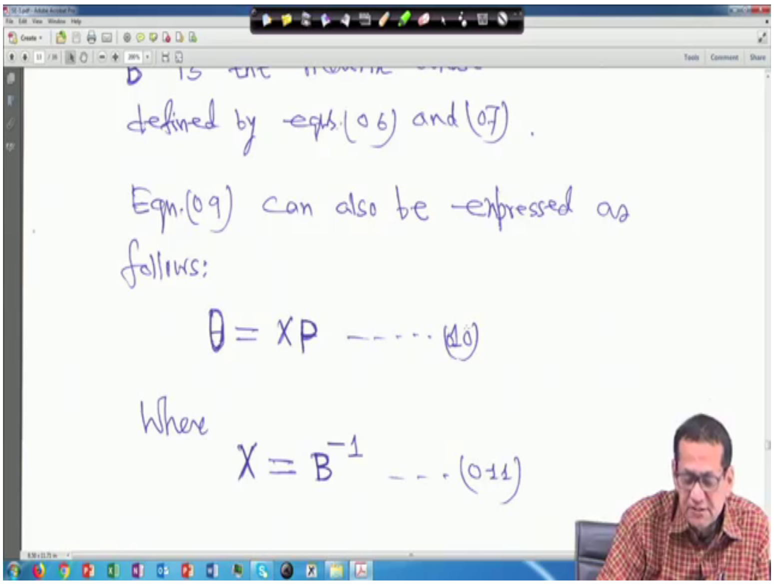

So, this one finally that your then we can write theta is equal to from that above equation, it is your it is your P is equal to B theta. So, theta is equal to right take that your X P theta that is X P is equal to nothing but your B inverse so right sorry. So, this is equation-10 010, and this equation-011.

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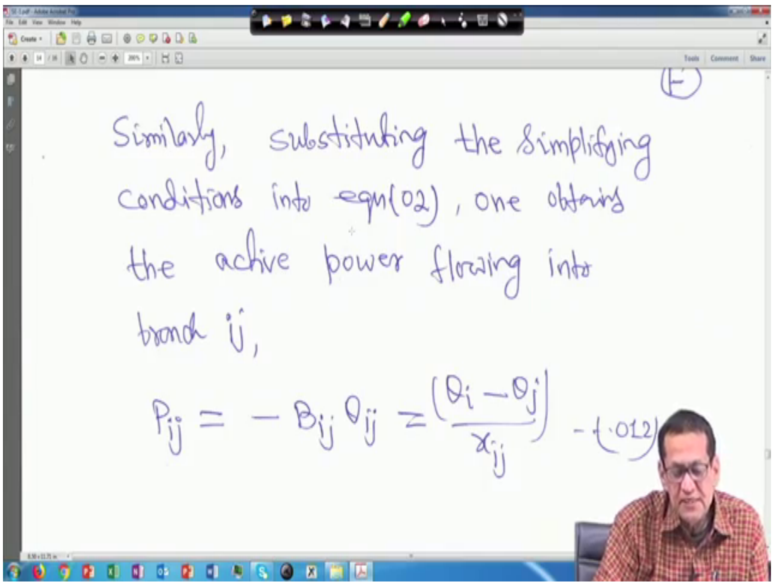

So, if it is so, then similarly substituting the simplifying condition in to equal 02, one obtain the above power flowing above active power flowing into p branch P ij, it is nothing but minus B ij theta ij. So, minus B ij is 1 upon x ij, so it is power flow from branch flow which is theta i minus theta j up on x ij right. So, this is actually your what you call that your computation of DC power flow.

If you know the above voltage angle, if you know theta i, and theta j right, this angle if it is known to you, then you can find you can compute that your what you call that power flow from bus i to bus j right. So, while making all this equations, again and again I am telling. By chance if you find any typographical any of writing error from my side, you just send put a question to the forum or you send an email right. So, this is actually DC power flow equation.

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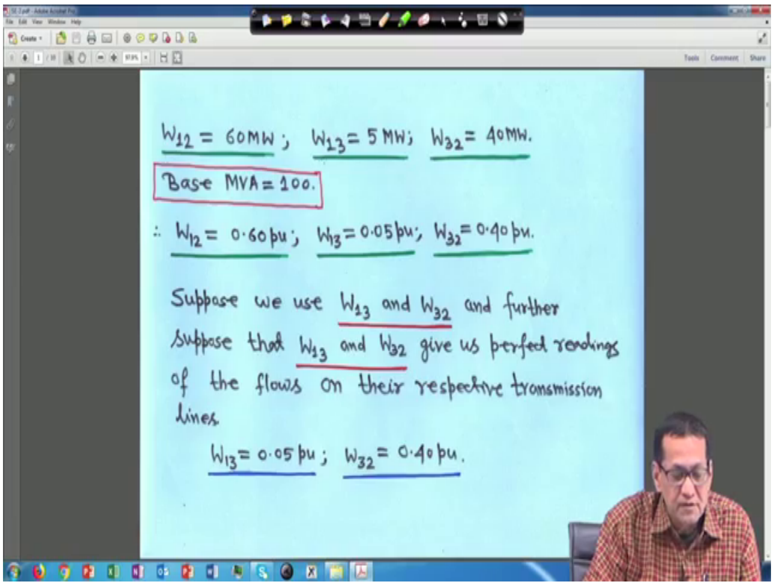

So, next is just hold on so just hold on.

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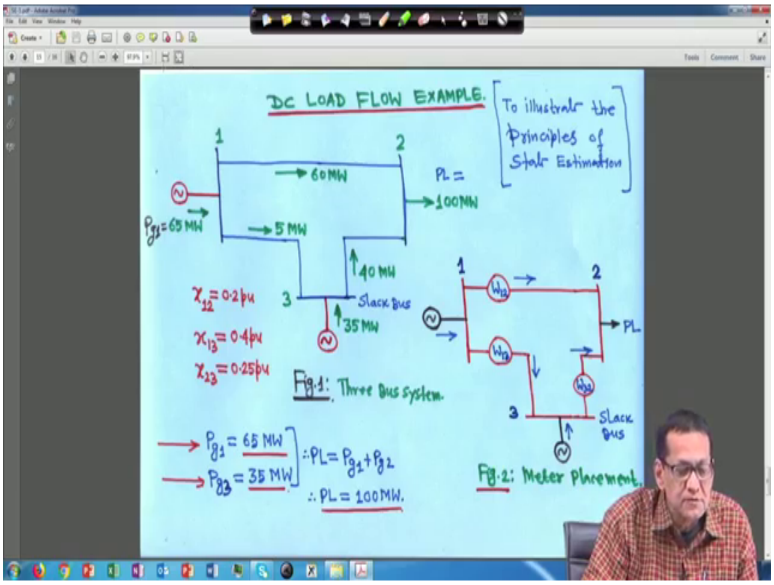

So, next is that your DC load flow example. Now, for example, try to let us try to understand this one right. Suppose, we have a here actually you will find very simple as far as this load flow is concerned. Suppose, you have a DC load that is why, I told you what is DC load flow little bit, but here whatever we need actually it is very simple thing.

Suppose, you have a three-bus problem right and this is your slag bus this is your slag bus, so this bus is node mark as number-3. So, last bus we have taken as a slag bus instead of marking bus 1. And the other two buses two buses right. Now, this is the flow is given, this is generator, so suppose its power is injecting a 65 megawatt. So, this 5 megawatt is you wanted 60 megawatt is going to this side, and 5 megawatt this direction 60, so totally 65 right.

And here this generator is giving 35 megawatt right, and this 5 megawatt also, this is 35 megawatt injection, and this side another 5 megawatt injection, so totally 40 megawatt injection. So, this 40 Watt leaving this 40 megawatt leaving this bus 3 and going here, so that means, this 60 is coming here, and this 40 is coming here. So, totally load is 100 megawatt. So, no loss nothing is considered, so it is a perfect balance perfect balance right.

So, now its reactance is given x 12 is 0.2 per unit, x 13 is given 0.4 per unit, and x 23 actually 0.2 per unit right. So, this is actually we will illustrate in a principles of state estimation. And then what you do that you suppose now, we have connected 3 metres in 3 lines right that just hold on just hold on, let me move little bit up just hold on.

So, this is actually suppose we have connected 1 metre here that your W 12 we are telling right, another metre in line 1 3, so W 13, another metre in W 32, so it is in line 3 to 2 right. And bus 3, it has cut actually, it is a slag bus right.

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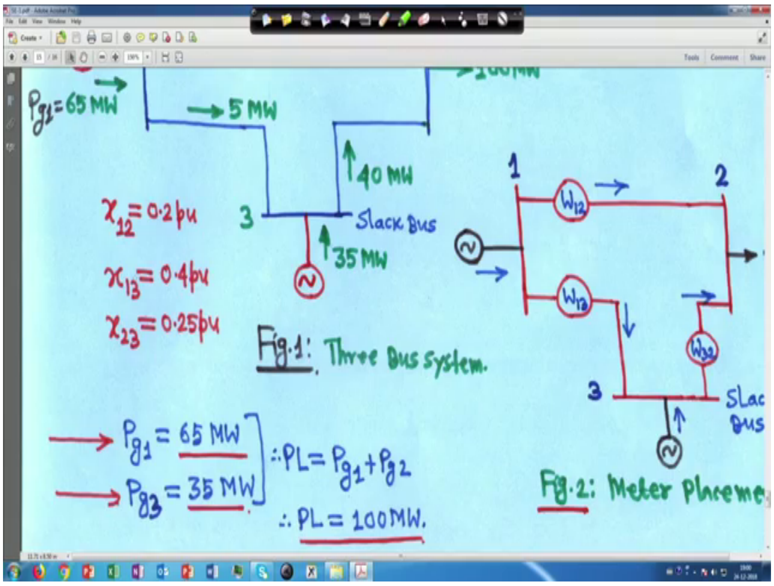

So, now the three-bus system now what is happening, initially I told you that for all these things all the data is given, and it is given and it is P g1 your 65 megawatt, P g3 35 megawatt, PL is equal to P g1 plus P g2 100 megawatt. Now, we are measuring this is actually say this is actually correct one say. Now, we are measuring the power flows through the line 1 2 to the line 1 to 3, and in the line 3 to 2 by 1 by 3 metres W 12, W 13, and W 32 right, so that is your metre placement right.

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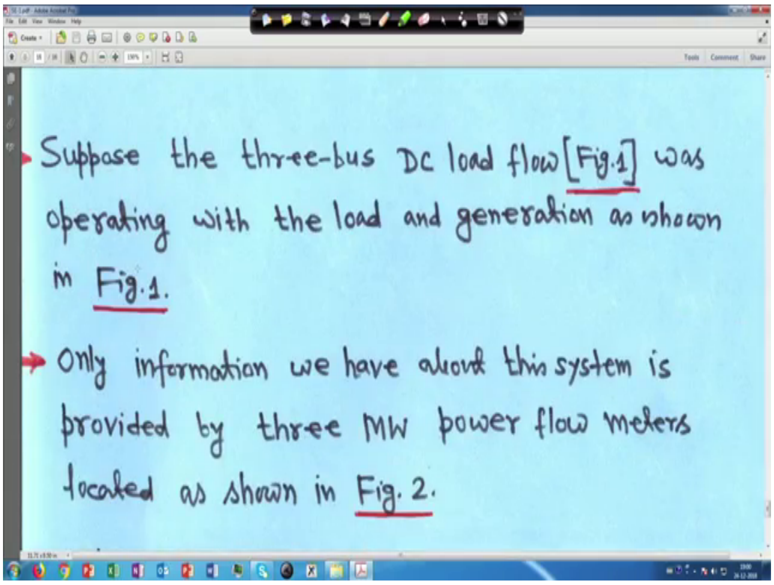

So, suppose that three dc three-bus DC flow was operating with the load and generation as shown in figure-1, I showed you right. Now, only information we have about this system is provided by three megawatt power flow metres located as shown in figure-2. So, this figure I showed you, this is figure-2 right.

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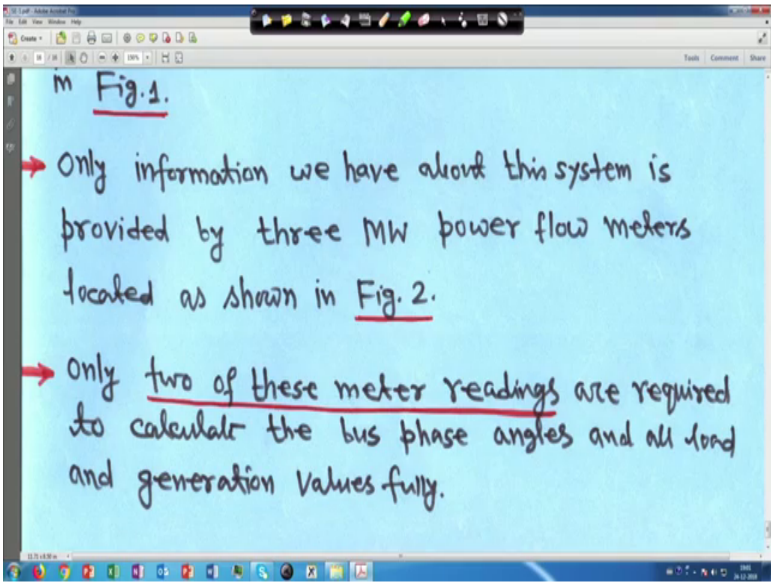

So, only two of these metre readings are required to calculate the bus phase angles and all loads and generated values your load generation values fully. So, only two of these metre readings are required actually to calculate the bus phase angles and all load and generation values fully right. So, in this case, next we will move to the next page, just hold on.

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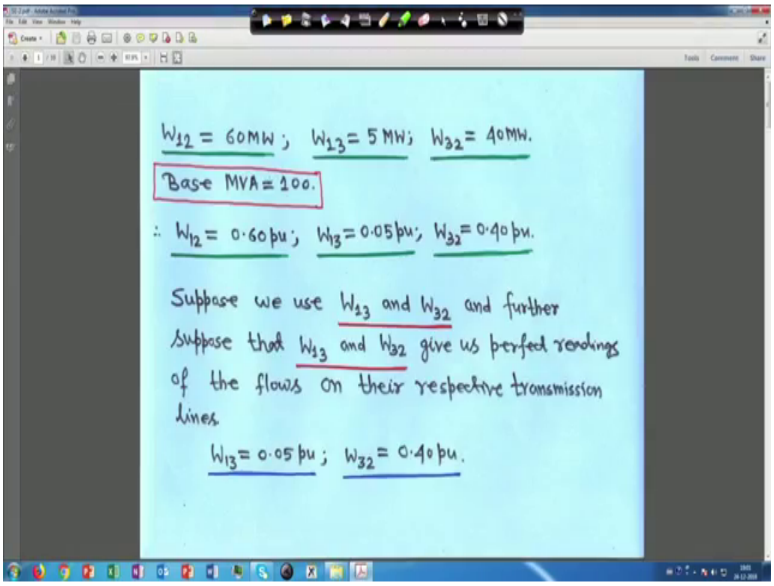

So, just let me increase the size. So, suppose now this watt metre when it is reading W 12, 60 megawatt; W 13, 5 megawatt; W 32 is 40 megawatt. And base MVA is 100. So, W 12 0.60, W 13 0.05 per unit, and W 32 is 0.40 per unit, this is perfect one right.

Now, suppose we use W 13 and W 3 that 2 2 watt metre or 2 metre in line 1 3, and line 3 2 and further suppose that that W 13 and W 3 2 gives the perfect readings of the flows on the on their respective transmission lines, it is a perfect flow, suppose it is given. Then W 13 is equal to 0.05 that is watt metre placed in the line 1 3, and other metre placed in line 3 to 2 0.4 per unit right.

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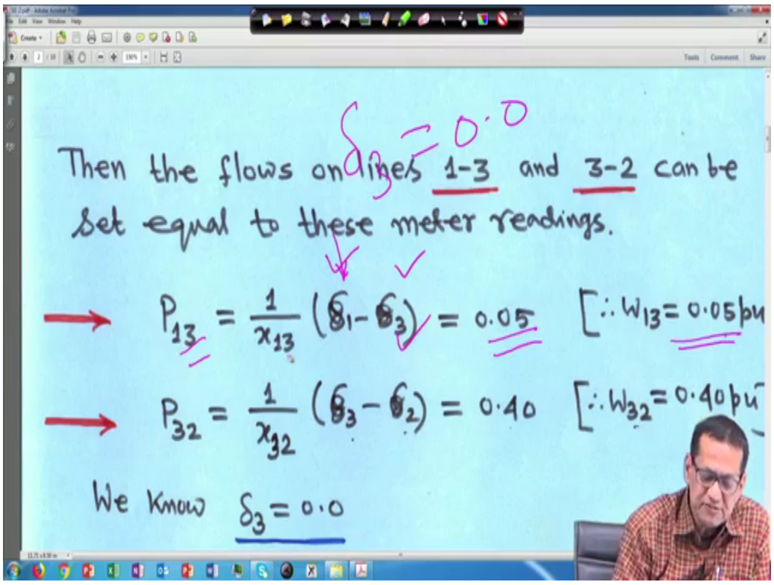

Now, then the flows in line 1-3 and 3-2 can be set equal to this metre readings. For example, P 13 will take 1 upon x 13, we have taken that angle instead of theta now through out we will increase, so it will assume delta 1 and delta 3. So, P 13 is simply 1 upon x 13 delta 1 minus delta 3. So, we have given all x 13, x 32, and x 12 values. So, substitute all, so you will get 0.05. W 13 your that is 0.05 right. So, this is power flows from line 1 to 2.

Similarly, and bus 3 is a slag bus 3 is a slag bus, so delta 3 is equal to 0.0; so, delta 3 actually taken 0.0 right. So, with this with this x 13 is known, so you can calculate what is the value of your what you call that delta 1, because P 13 that watt metre reading is here. Actually, p 13 is nothing but W 13 reading.

Similarly, that P 32 is 1 upon x 32 delta 3 minus delta 2 is equal to this watt metre reading, this is nothing but P 32 is equal to W 32 that is equal to 0.40 per unit, the and delta 3 is 0, because it is a slag bus. So, from this if you know the delta 3 is 0, from here you can calculate what is delta 1. And similarly, delta 3 is 0, it is slag bus from here you can calculate delta 2, because these two are known right. So, basically this one is equal to 0.05, and this one is equal to 0.4. So, delta 3 is 0, delta 3 is 0; so from here you can calculate delta value, it will be negative. And from here you calculate delta 1 value, it will be positive right.

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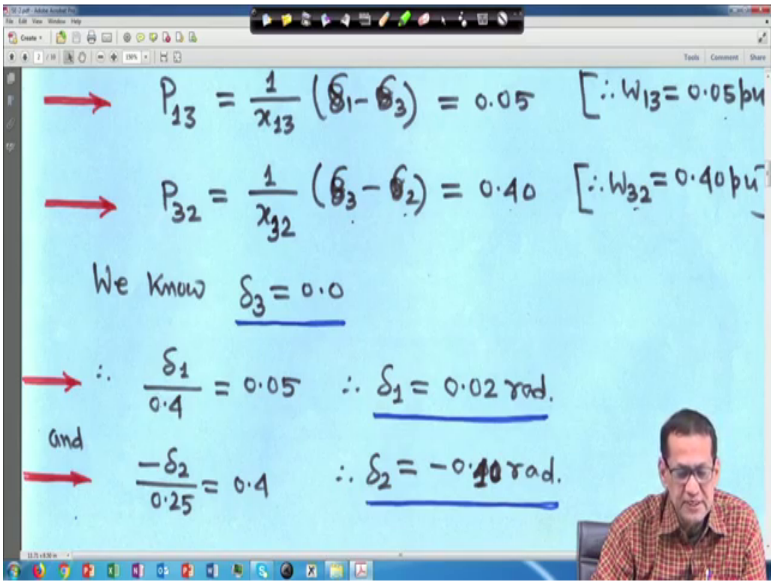

So, whatever value you will get whatever value you will get, so delta 1 then your delta 1 that is your by 0.4 that is x 13 was given 0.4 per unit, so is equal to 0.05. So, delta 1 is equal to 0.02 radian right. Similarly, minus delta 2 because delta 3 is 0 here, so minus delta 2 and x 32 is 0.25. So, minus delta 2 by 0.25 is equal to 0.4. So, delta 2 we will get minus 0.1 radian as long as that reading were perfect. So, this is the value of delta 1, and delta 2, and delta 3 is 0, because it is a slag bus we have taken right.

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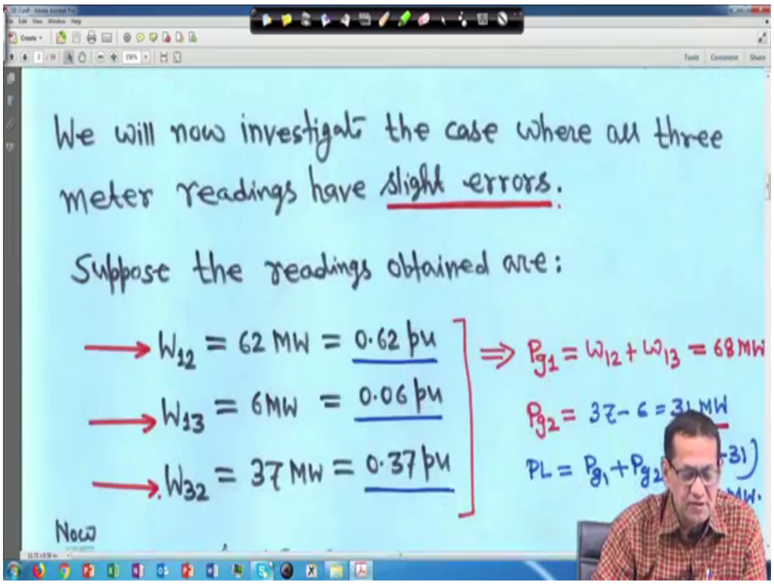

So, now we will now investigate the case where all three meter readings have slight errors. Now, suppose we assume that metre reading have slight errors, suppose that the readings obtained are suppose we have this reading say metre is giving meter placed in line 1 2, it is giving 62 megawatt, so 100 (Refer Time: 15:16) based. So, it is 0.062 per unit right.

Similarly, metre placed on line 1 3, actually it is 6 megawatt say, so it is 0.06 per unit, and meter placed on line 3 2, it is 37 megawatt, so 0.37 per unit right. So, in that case what will happen that P g1 will be W 12 plus W 13, we will go back to the figure-1. And simply your you add these two reading W 12 and W 13 better you go to figure-2, where I marked the meter. So, this is actually 68 megawatt is coming. Then P g2 will be 37 minus 6, so 31 megawatt right. And P L will be P g1 plus P g2, so it will become a be a 99 megawatt. And bus 3 is a slag bus, so here delta 3 is equal to 0.0 right.

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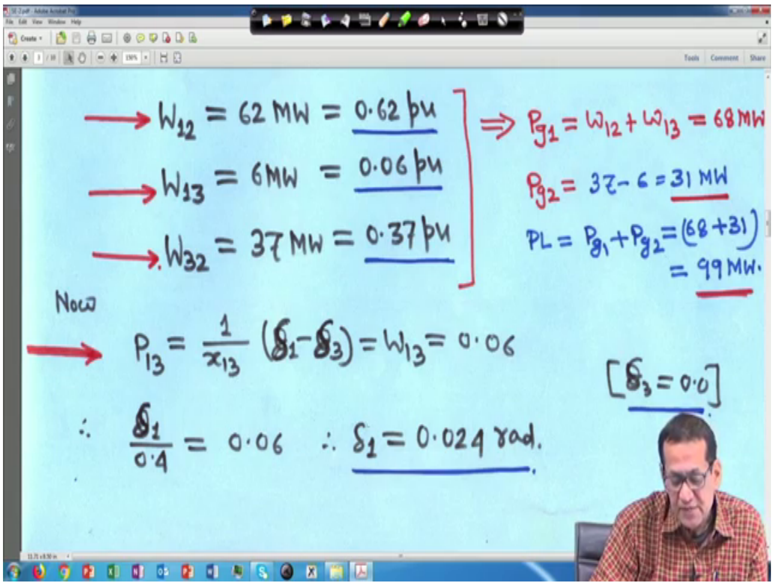

Now, if you calculate that your P 13 that is equal to 1 upon x 3 into delta 1 minus delta 3 that is nothing but W 13, so is equal to 0.06 right, so because metre placed on line 1 3 W 13 reading is 0.06. So, from here you will get delta 1 by 0.4 is equal to 0.6, because x 13 is 0.4, therefore delta 1 will be 0.024 radian right.

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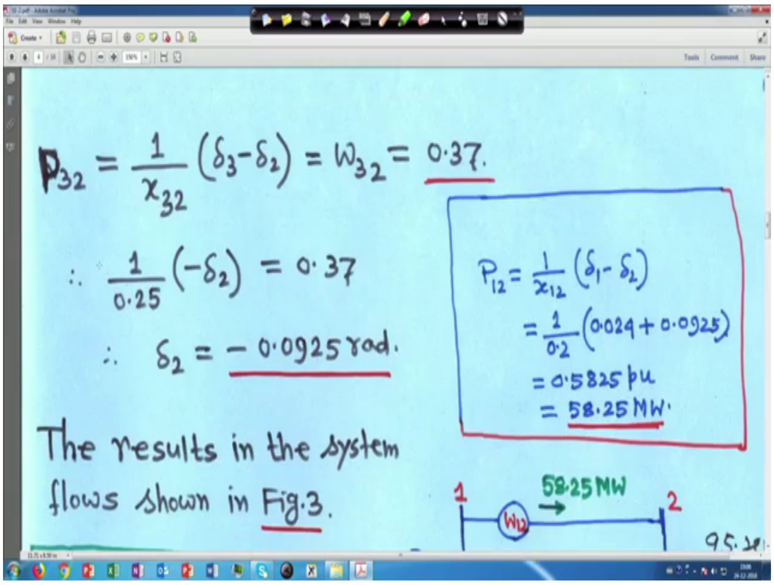

So, similarly P 32 will be 1 upon x 32 that is delta 3 minus delta 2, so delta 3 is 0, therefore 1 upon 0.25 into minus delta 2 is equal to 0.37. Therefore, delta 2 is minus 0.0925 radian; with this calculating delta 1 and delta 2. If you have got this delta 1 and delta 2 values, this is delta 1 is 0.024, and delta 2 is minus 0.0925 radian.

So, now with this if you calculate the line flows that is your power flows in line 1 to 2; so, P 12 to will be 1 upon x 12 delta 1 minus delta 2. If you do so x 12 is 0.2, so 1 upon 0.2, it is 0.024, and delta 2 is minus of this one, so it will be plus 0.0925. If you calculate it is 58.25 megawatt right, so this is the line flows.

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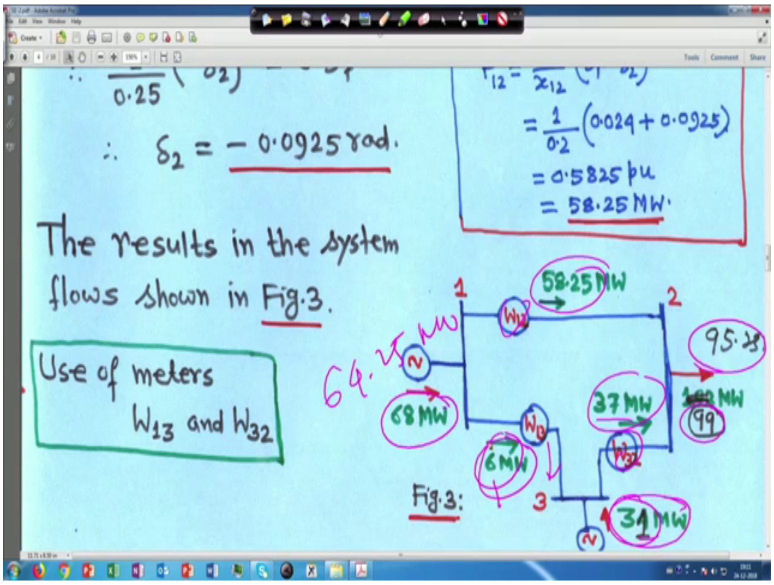

Therefore, that if you look into this diagram, so this is actually, we took this two reading we took this two reading right use of W 13 and W 32. So, these two meter readings, we have taken. And after taking this one that we are getting that these two readings, we can consider right that W 1 to 3 and W 3 to 2, these two readings we consider.

Based on that whatever we calculate, the line flows 58.25 megawatt right. But, if you take if you take that this that reading we actually took 62 megawatt that the this your what you call this watt meter placed in line 1 2, it was 62 megawatt right. But, actually we are not getting that using that two data, we are not getting that. What we are getting actually, we are getting 58.25 megawatt right.

Similarly, before moving further similarly if you take similarly if you take these two readings say these two reading, and try to find out the just hold on let me move little bit up. Now, now if you take these two readings right, then find out what is delta 1 and delta 2, and based on that you find out the power flows from line 3 to 2 you will find, it is not 37 megawatt, it is something else right.

Say similarly, if you take this reading and this reading these two wattmeter reading, and find out delta 1 and delta 2, then you will see that this reading is not 6 megawatt, it will be different it will be different that means, you have basically you have your what you call (Refer Time: 19:13) readings, you need actually two readings, but actually what you have measure three values right. But, in state estimation, we will see all this redundant values that all this measurement we will take, and we will try to go for best estimate later we will see that.

So, in this case you see that is 58.25 megawatt. Now, this is my 68 megawatt, this is 6 megawatt right, so here also it was 68 megawatt, but whatever your what you call earlier you have we have taken like this one, just hold on that this one.

If you go back to this diagram, whatever data we have taken actually P L understandable, but P g 1 is was 68 megawatt, because W 12 plus W 13 is 60 megawatt 68 megawatt. But, here if you look into that here if you look into that, it is not 68 megawatt it will not be 68 megawatt, it will be actually 58.2 plus 6 right.

So, here also it will it will give you that is your 64.25 megawatt, so it is not 60 megawatt. Similarly, here it was 99 earlier megawatt, but now 37 plus 58.2; so it will be load also is not correct, it is giving 95.25 megawatt right.

And similarly, your this your what you call this generation that your this was a this 6 megawatt is your coming here and 37, so this total is 37, because 6 megawatt, and this is giving you a 31, but earlier it was 34 now it is 31. So, ultimately 37 is going here, so 37 plus 58.25, so 95.25 megawatt.

Similarly, if you consider reading meter reading of 1 2 and 1 3, and you will find this will change. And similarly, if you consider this one, this one you will find this one as change right that means, three readings are there, so which one will be the so you are getting three differences sets of delta 1, and delta 2, so but our object will use all this reading use all this readings, and find out the best estimate of delta and delta 2 that we will see later right.

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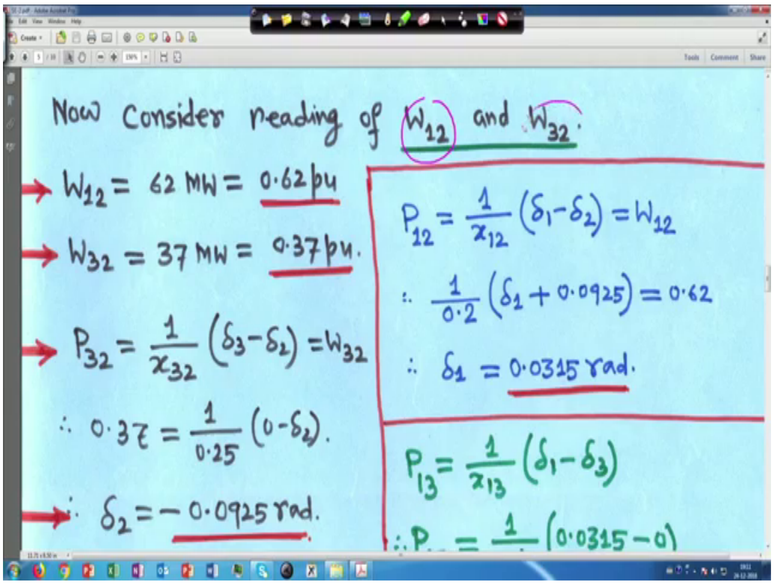

So, now you consider W 12 and W 32, now we have consider these two readings W 12 and W 32 only right. So, in that case your if you if look into you that the W 1 this thing, then you will see that your W 12 is 62 megawatt, and W 32 it is now 0.37 megawatt right. So, this time we have not considered this one.

Now, P 12 that is 1 upon x 1, it will be delta 1 minus delta 2. So, if you calculate delta 1 and delta 2 right, so you will find delta 2 is minus 0.0925 radian. Similarly, hold on; so here delta 1 has been computed here, so P 12 is 1 upon x 2 into delta 1 minus delta 2, so that is actually W is equal to W 12 reading. So, X 12 is 0.2, so delta 1 put delta 2 value here delta 1 plus 0.095, because it is minus so delta 1 is 0.0315 radian right. With this if you calculate the power flows in the line, why what you call 13, because we have considered that two reading right.

So, if you consider the your what you call the powerful filled lines 1 upon x 3 delta 1 minus delta 3, so P 1 3 is coming actually 7.875 megawatt right. Although we have taken this reading that let me go back to that data that it was 6 megawatt, but it is not like that it is more than 7 right, so it is 7.875 megawatt.

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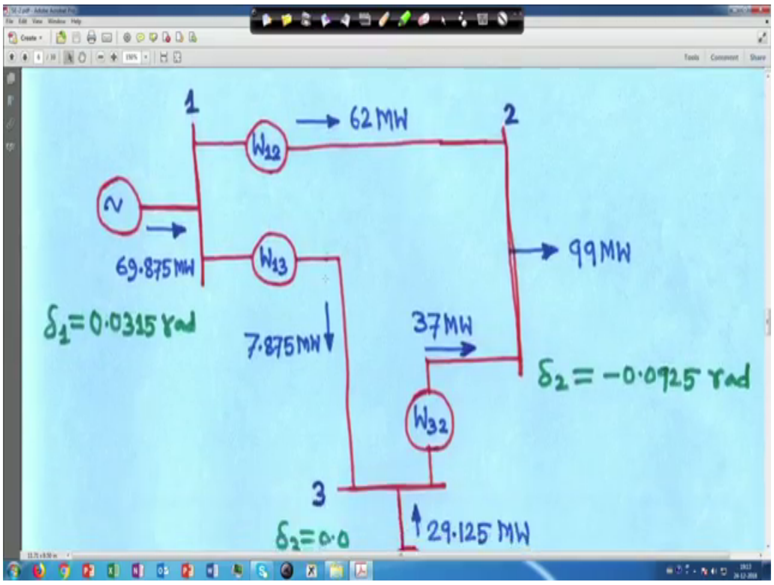

That means, that if we if you plot now if you see the diagram, so this two readings, we took right to compute this one. So, instead of your what you call that 6 it is coming 7.875 megawatt this P g1 plus 62 megawatt plus 7.875, so it is 69.875 megawatt right.

And in this case, it is 62 plus 37 plus, so it is 99 megawatt. And here let me move little bit up here if you see this that your this is 7.875, and this is 37; so 37 minus 7.875. So, generation is actually 29.125 megawatt right. Similarly, if you take the other two readings, you will find a different different flow then here line 3 to 2, if you just take this W 12 and your W 13 reading right.

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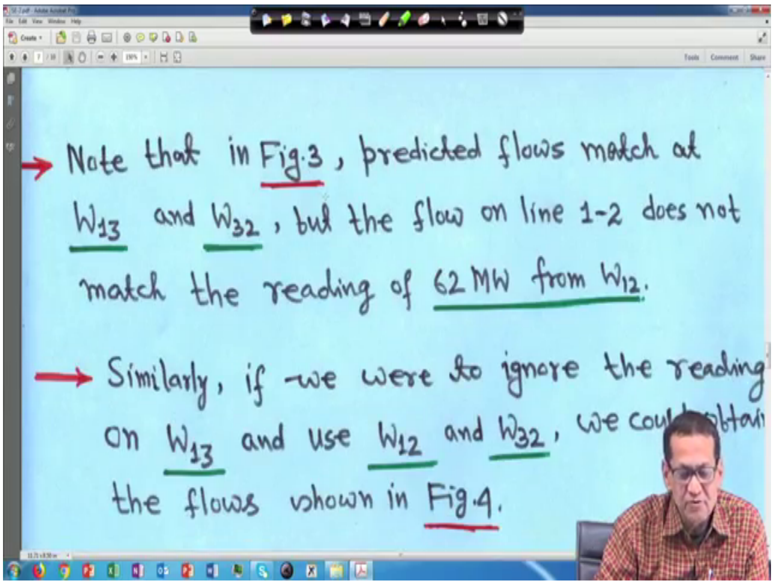

So, from that note that in figure-3, predicted flows match at W 13 and W 32, but the flow on line 1-2 does not match the reading of 62 megawatts from metre 1 1 2 right. Similarly, if you had to ignore the reading on W 13 and use W 12 and W 32, we could obtain the flows shown in figure-4, so that also we have seen right.

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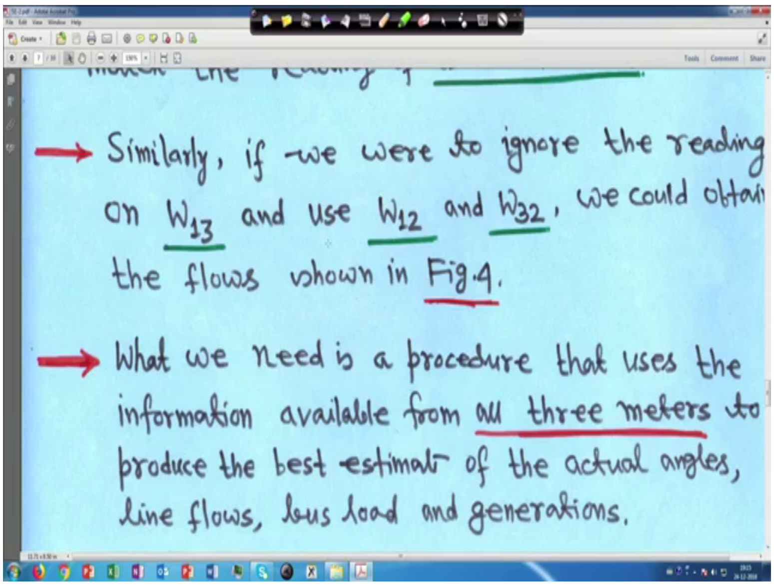

What we need is a what we need is a procedure that actually uses the information available from all the three metres to produce the best estimate of the actual angles, lines flows line flows, bus load and generation. So, what we need is a procedure that we will use information available from the all three metre that means our objective is to your consider all the metre readings, and try to find out the best estimate of the line flows and the angles right voltage angles.

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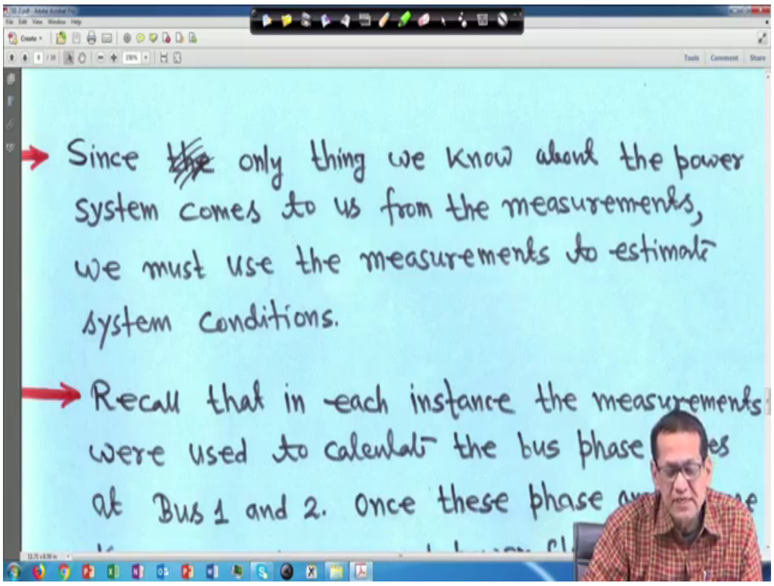

So, since only thing we know about the power system comes to us from the measurements, we must use the measurements to your what you call estimate system condition right.

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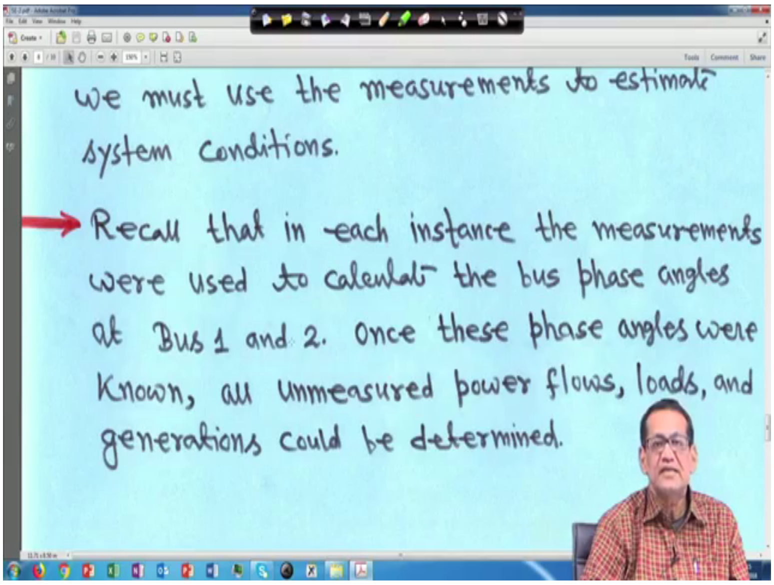

Now, recall that in each instant the measurements were used to calculate the bus phase angles at bus 1 and bus 2. Once these phase angles are known, all unmeasured power flows, loads and generation could be determined right that means, you need the best estimate for this case the best estimate of the voltage angle right.

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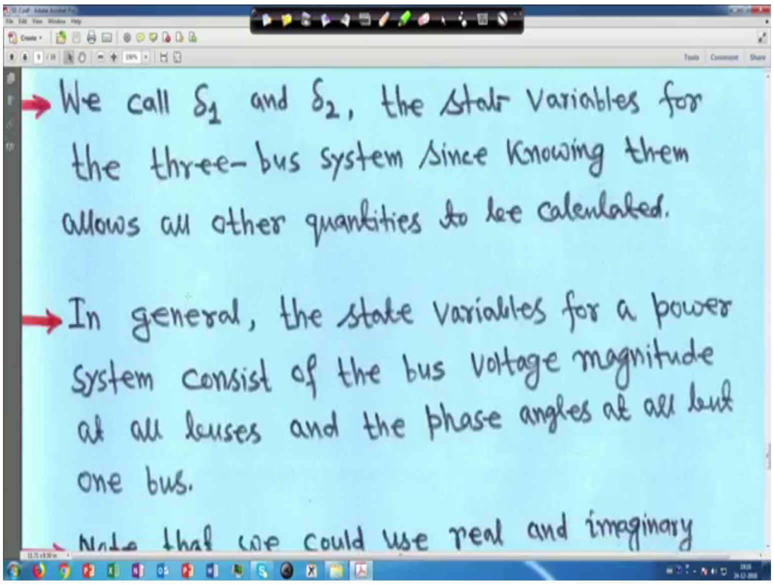

So, we call delta 1 and delta 2 the state variables for the three-bus system since knowing them allows all other quantities to be calculated right, because our objective is we have to find out the best estimate of the delta 1 and delta 2, because slag bus delta 3 is 0 right. So, in general, the state variables for a power system consists of the bus voltage magnitude at all buses and the phase angles at all but one bus right that is slag bus.

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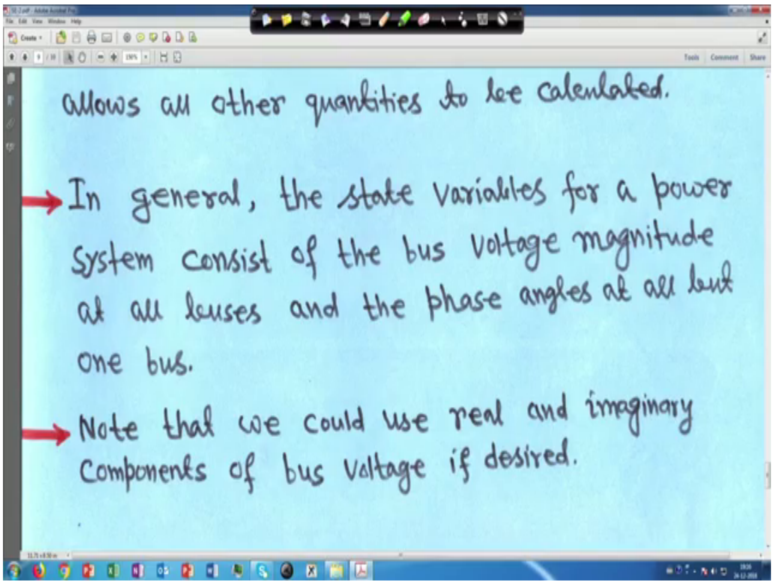

So, note that we could use real and imaginary components of bus voltage if desired that also possible that also possible.

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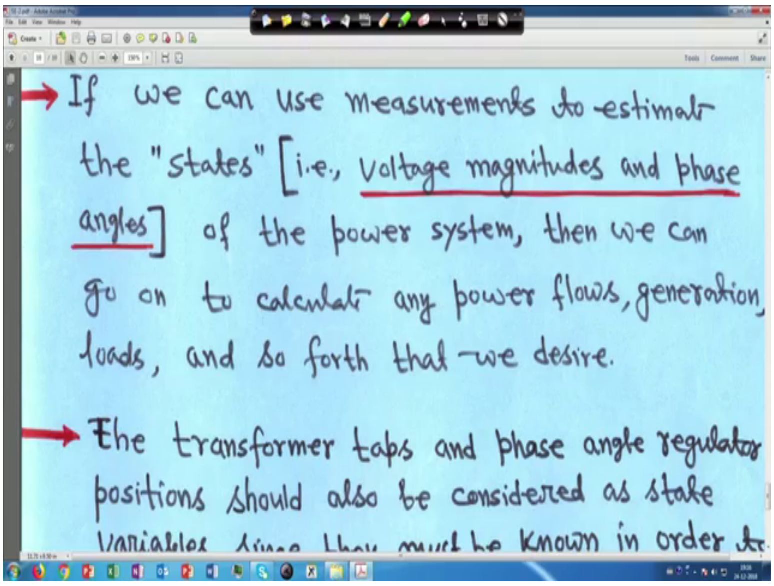

Now, if you use the measurement to estimate the states right that is the voltage magnitudes and phase angles state means, say voltage magnitude and phase angle of the power system, then we can go to calculate any power flows, generation, loads and so forth that we desire right sorry.

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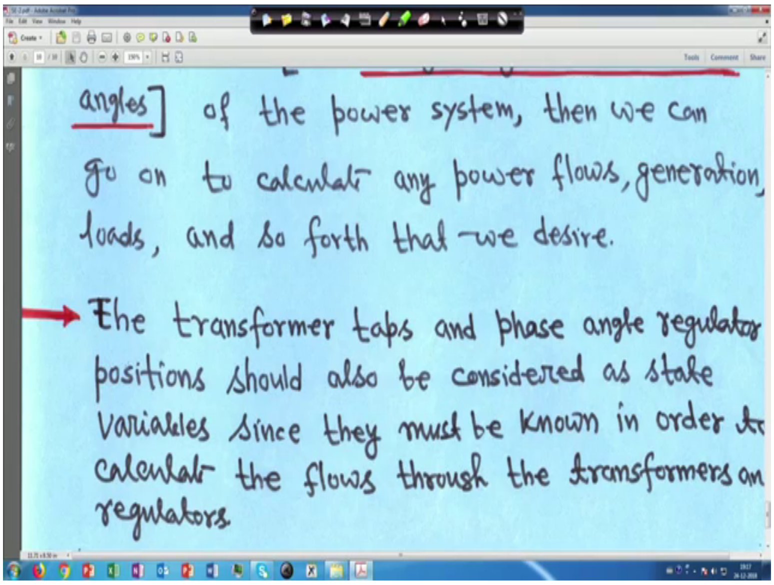

The transformer taps and phase angle regulator positions should also be considered as state variables right. Since, they must be known in order to calculate the flows through the transformer on transformers and regulators right. So, all these things can we considered right. So, now next we will go to the your; what you call that your this thing.

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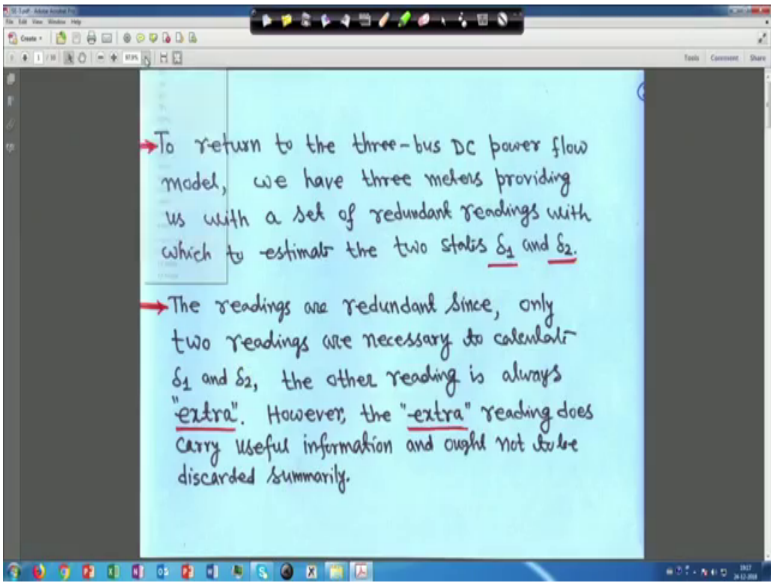

Now, if we return to the three-bus problem if we return to the three-bus DC power flow model, we have three meters providing us with a set of redundant readings with which with which to estimate the two states that is delta 1 and delta 2.

The readings are redundant right, since only two readings are necessary you have three readings plus one reading every case, we found that one reading is actually not necessary, but we have to find out some methodology such that we can consider all the readings or we can get the best estimate of delta 1 and delta 2 right. So, to the other reading is always extra, because one reading is always extra we have seen.

However, the extra readings does carry useful information and what not to be discarded summarily. So, we cannot you are just discard, this what you call this reading right. So, we have to find out some technique such that we will consider your what you call in mean in this case what is happening, number of state variables are two, but number of measurement is three, because we have three readings.

So, number of state variables is greater than your number of measurement right number of measurement right. So, if you so similarly it is possible that number of measurement, and number of sate variables are same, this will be another condition. Another condition another condition may be that number of state variables are more, but number of measurements are less that we will see later right.

So, thank you very much, we will be back again.