Power System Analysis
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Lecture - 39
Optimal system operation (Contd.)

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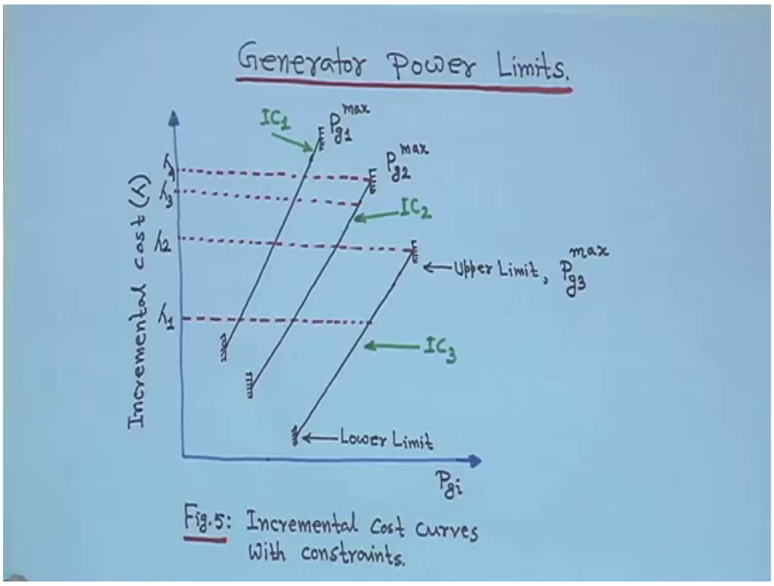

Again come back to the generator power limits. So, in this case a little bit you have to understand because when you solve the problem you will know this, this is ICS know we have taken the straight line one because quantity cost characteristic. So, this is your this is say IC 1 this is your minimum limit lower limit say if it is P g 1 max this one actually P g 1 min I have not written here, but understandable this is P g 1 min. Similarly, if this is another IC, if it is P g 2 max then this is your P g 2 min. And if this is by IC 3 that for general three is that incremental cost three, if it is upper limit here it is P g 3 max then here it will lower limit will be P g 3 min.

Now, the generators actually all have to operate on or what you call that equal lambda basis. Suppose here it is given some value, this is incremental cost lambda suppose some value like lambda 1 here. So, in this case all the generators will what you call will work on this what you call on this basis equal lambda basis. Now, this is your P g i this side is the P g i that you are what you call that power generation for the i th unit.

Now, question is that now you are suppose you are load is increasing that generator power will increase; that means, this lambda line they will be operate on equal lambda you slide it upwards you slide it upwards. So, when it will come at that after some at some value of lambda 2 when it will come here some value of lambda 2 that it will touch the upper limit of the your generator 3 that is your P g 3 max. So, once it start that limit, so at that time you have to said the generation that is you are what you call P g 3 is equal to P g 3 max, there is no further increase you cannot do that this is the maximum limit.

Again if you move upwards suppose lower further as increase for example, lower further as increase, suppose this is lambda 3 and at the time these two generating unit one and two generators will change, but this one will be kept fixed that this value, because it cannot increase. Now, at the time the these two units will operate on equal lambda basis for example, lambda 3 equal lambda basis. So, again load is increasing, again the this line you move upwards finally, it will come here P g 2 max. So, at that time it is lambda 4. So, at this point P g 2 has to be said at P g 2 max. So, if load further is increase then it further is increase only these unit will take it till it reaches to its maximum value. I hope you have understood these that means, that these are the lower limit, they will operate at equal lambda basis, now if load is increasing generator has to increase so lambda, so move upwards.

So, when it is going to touching the limit of the first that is the unit three maximum, so beyond that if the load further increase then what will happen these two unit at the time operate at equal lambda basis, but these one value P g 3 must be kept at P g 3 max. Then three load is increasing and increasing then it will touch here at your lambda 4 that is P g 2 max, there also you have to say P g 2 is equal to P g 2 max. After that if load further increase that that only these unit has to take care of the load till it touches to its P g 1 is equal to P g 1 max value that means, in general if total your what you call that your loss is ignored. Then maximum load it can take I mean P g 1 max plus P g 2 max plus P g 3 max this is the total maximum generation is equal to total load not more than that. Loss is neglected remember loss is neglected. So, this part this is now this is understandable to you, so that is why this is your figure 5.

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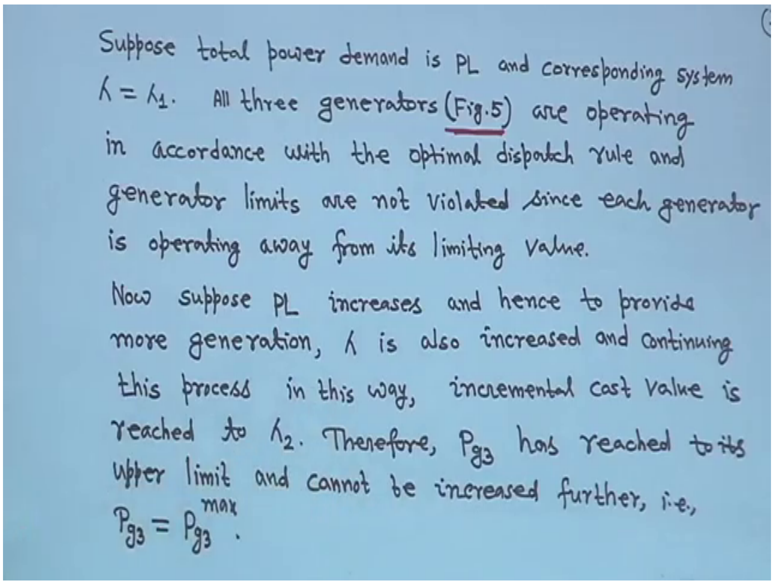

Whatever I have said all these things actually have been explained here. So, I am not repeating this. So, whatever I have said you might have understood. So, if you have this thing, you can read it once again, but this is the thing I have written here, but I have explain everything.

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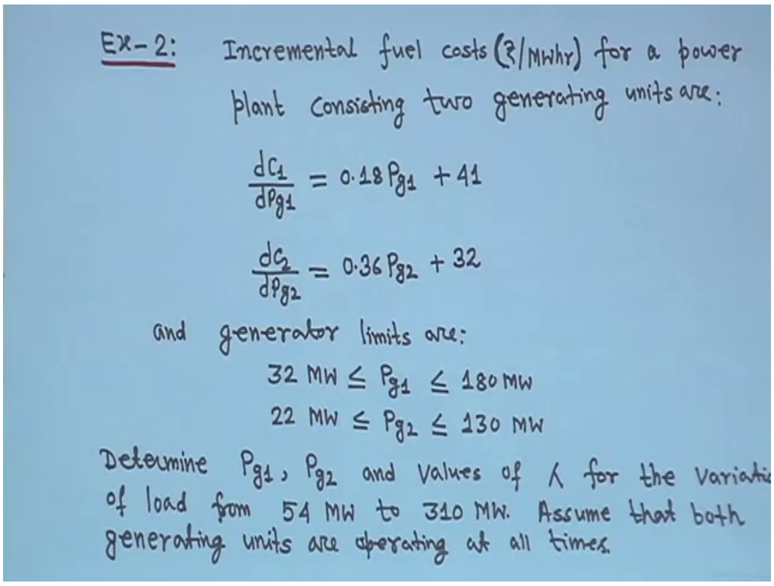

So, next is we will take another example, example 2, and just try to understand. So, suppose incremental fuel cost rupees per megawatt hour for a power plant considering two generating units are given bellow dC 1 upon d P g 1 is equal to 0.18 P g 1 plus 41 and dc 2 upon d P g 2 is given 0.36 P g 2 plus 32. So, generator limits are given for these two units that is P g 1 minimum generation is 32 megawatt, maximum 180 megawatt; and P g 2 minimum is 22 megawatt maximum 132 megawatt that means, minimum load will be 32 plus 22. If you take that you are what you call that is your P g 1 plus P g 2 total minimum generation 32 plus 22, if both operates together, so that we will see later and this is maximum 180 and 130. So, maximum is 180, 130 means 310 megawatt, so that means this generator can supply 310 megawatt load and this one we will see minimum side how it can operate.

Now, you have determine P g 1 P g 2 and values of lambda for the variation of load from 54 megawatt to 310 mega watt. Assume that both generating units are operating at all the times. So, you have to find out P g 1 and P g 2 and lambda variation for different load bearing 54 to 310 megawatt, 32 plus 22 - 54. So, minimum load is taken I had given the data given 54 megawatt.

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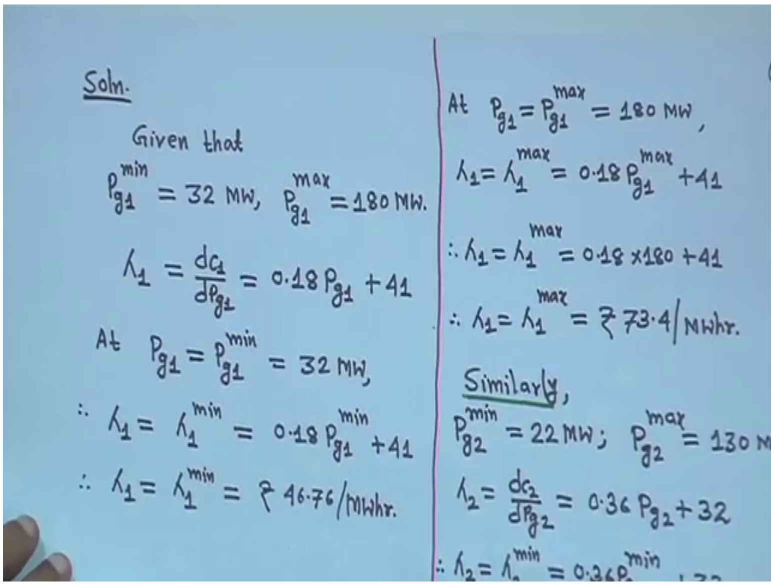

Now, how to do this you given that P g 1 min is equal to 32 megawatt, this is given. P g 1 max is given 180 megawatt. So, lambda 1 is equal to dC 1 for unit 1, dC 1 d P g 1 that is 0.18 P g 1 plus 41, this lambda 1 lambda 2 is given actually. This is lambda 1 this is lambda 2, these two data are given. Therefore, this lambda 1 is equal to d C 1 upon d P g 1 that is 0.18 P g 1 plus 41. At P g 1 is equal to P g 1 min when generating at it say your lower limit that is 32 megawatt that means, your lambda 1 is equal to lambda 1 min that you substitute P g 1 is equal to P g 1 min here, therefore, it is 0.18 P g 1 min plus 41. And P g 1 min is equal to 32 megawatt you substitute here 32.

Then lambda 1 is equal to lambda 1 min, you will get rupees 46.76 per megawatt hour. This is lambda 1 min is per unit 1 rupees 46.76 per megawatt hour this is for unit one then now maximum value now when P g 1 is equal to P g 1 max it is 180 megawatt. Now, therefore, lambda 1 is equal to lambda 1 max is equal to 0.18 P g 1 max here, you substitute P g 1 is equal to P g 1 max. So, plus 41 therefore, lambda 1 and your P g 1 max is 180 megawatt. So, substitute here 180 you will get lambda 1 is equal to lambda 1 max is equal to rupees 73.4 per megawatt hour that means, lambda 1 min we got 46.76 and lambda 1 max 73.4 within these this lambda vary.

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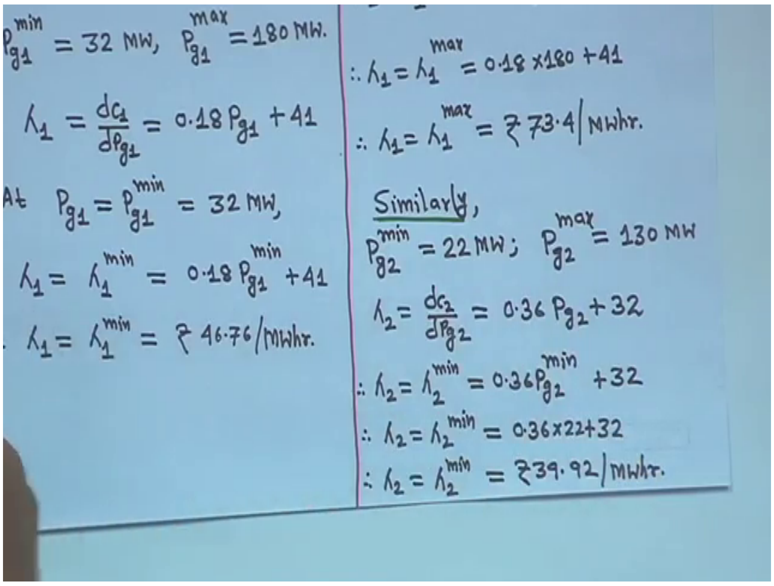

Similarly, for the unit-2 P g 2 min is equal to 22 megawatt and P g 2 max 132 130 megawatt therefore, lambda 2 is equal to this one dC 2 d P g 2 is equal to 0.36 P g 2 plus 32. Now, first you put if your lambda 2 your P g 2 is equal to P g 2 min in this equation, so lambda 2 is equal to lambda 2 min is equal to 0.36 P g 2 min plus 32, and P g 2 min is 22 megawatt. So, if you substitute here 22, you will get lambda 2 is equal to lambda 2 min, it is rupees 39.92 per megawatt hour, this is lambda 2 min. Similarly, in this expression, you put what you call lambda 2 your this thing sorry P g 2 is equal to P g 2 max here.

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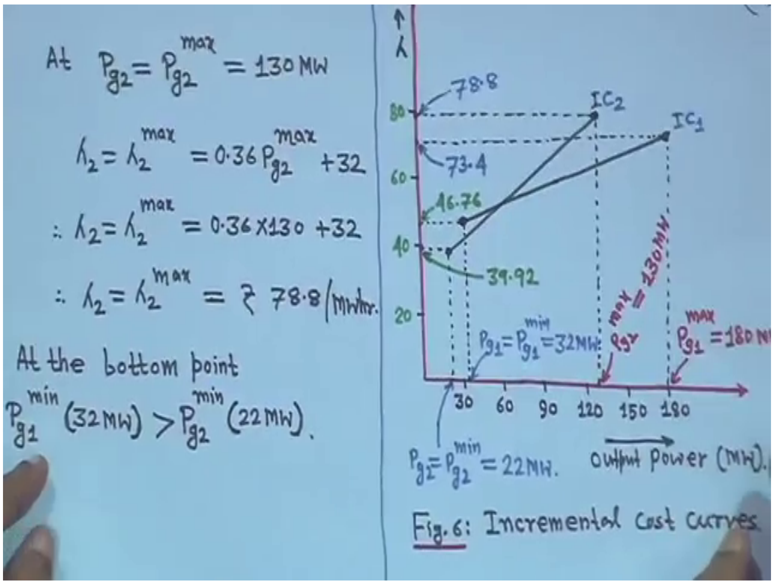

So, if you do so then lambda 2 is equal to lambda 2 max will be 0.36 P g 2 max plus 32. Therefore, lambda 2 is equal to lambda 2 max is equal to 0.36 into 130 plus 32, you will get lambda 2 is equal to lambda 2 max that is rupees 78.8 per megawatt hour. So, that means, at the bottom point; that means, look. Now, we have drawn IC 1, IC 2 curves, this is for IC 1 and this is for IC 2. So, IC 2 actually your this is P g 2 your what you call min that is your 22 megawatt at this point 22 megawatt I have written here. And here it is 39.92 almost 40, so it is starting from here and its max value that is your what you call IC 2s max value this is your 130 megawatt, and its max value here is IC 2, it is 78.8 almost nearly 80, 78.8 lambda value this side is lambda. And similarly for your P g 1 min, it is 32 megawatt. So, it is near thirty that is 32 megawatt and its minimum lambda value is 46.76. So, here it is starting from here and its maximum is P g 1 max 180 megawatt it is going up to this and according to its graph it is 73.4 this lambda value is this point is says 73.4.

This way IC 1, IC 2 are plotted. And this is your and P g 1 min is shown P g 1 min is shown, P g 2 min is also shown, P g 1 max is here, P g 2 max is here, a lambda value is minimum and maximum values are computed, accordingly these two your IC curves this is straight line actually this is drawn. So, this side is the total out, this side is the output power megawatt, this side is the output power megawatt and this is lambda and this is incremental cost curves.

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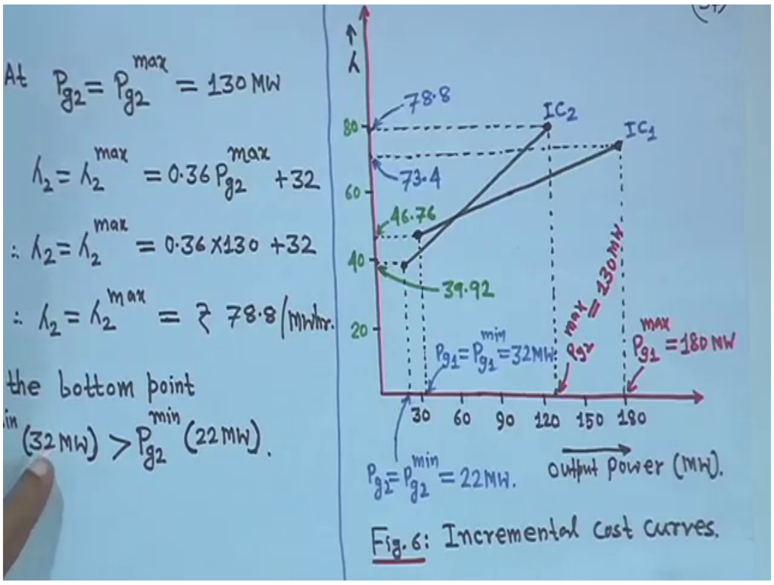

So, I repeat this is your P g 2 is equal to P g 2 min 22 megawatt. This corresponding lambda value is we got 39.92 we got it. And P g 2 and it is P g 2 is equal to you are what you call P g 2 max 130 megawatt 32 you got that value is lambda is seventy eight point you are what you call 8. So, accordingly it is straight line joining. So, automatically you can just joint these two point. So, here when it is P g 2 is equal to 22, lambda is equal to 39.12. When it is 130 that is it is 78.8, it another point, so you can make it similarly for IC 1, when P g 1 is equal to 32 you know lambda is equal to 46.76. And when it is 180 you know it is 73.4, so these two joints, so you get this lines. So, this is that IC 1 and IC 2 characteristic, this is first thing. So, this you have to make it. Once you have done, so now look at that how we will do it.

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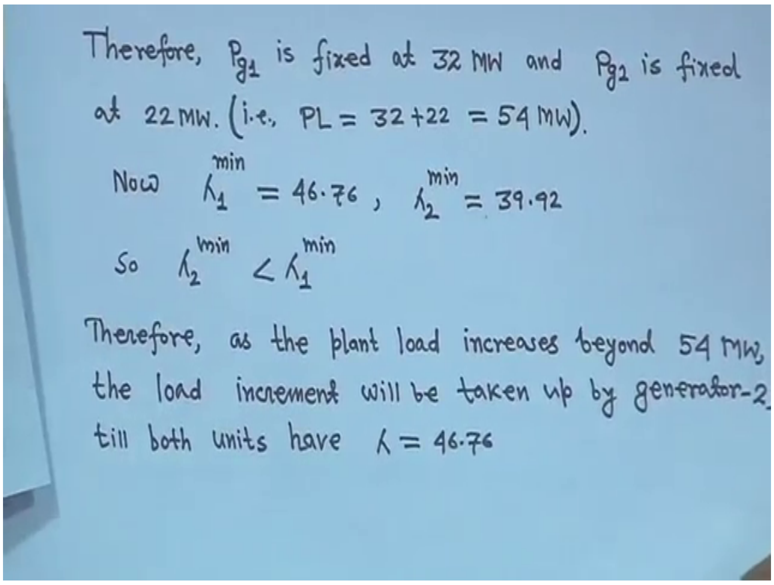

Therefore P g 1 is fixed at 32 megawatt and P g 2 is fixed at 22 megawatt total load is 32 plus 22 that is 54 megawatt load will vary it is given 54 to 310 megawatt. Now, look lambda 1 minimum is equal to 46.76, and lambda 2 minimum is 39.92 that means, lambda 2 minimum actually is less than lambda 1 min. That means therefore, as the plant load increases beyond 54 megawatt, the load increment will taken up by generator two till both units have lambda is equal to 46.76 that means, this one is your what you call this is your IC 2 and this is your IC 1 and lowest value is 39.92.

If you increase the lambda value upwards that in that case what will happen that your this till it comes to 46.76 that means, what you call this as the plant load increases beyond 54 megawatt I mean it totally is 54 megawatt the load increment will be taken up by generator two. That means, this one will be taken up by generator two a till both have lambda is equal to 46.76. So and it will come here. So, this way you are what you call this IC 2, this IC 2 is equal to thirty nine point your this is a lowest one is 39.92 for IC 2. So, at that time, if you increase the lambda unless until it comes here, so your what you call that load increment will taken up by generator two till both are have equal lambda that is 46.76. That means, what will happen that at lambda is equal to your this lambda hold on.

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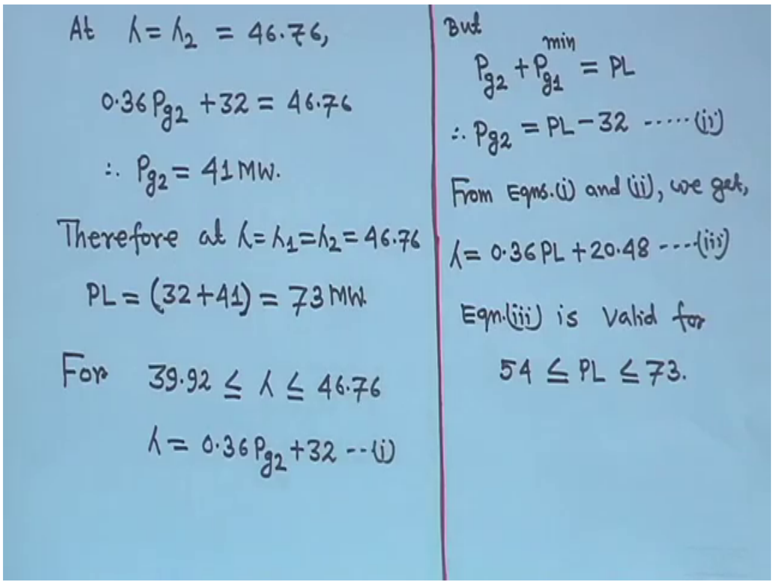

This lambda is equal to lambda 2 is equal to 46.7. While lambda is equal to lambda 2 46.76; that means your 0.36 P g 2 plus 32 is equal to 46.76 that means this your IC 2 this characteristic IC 2, it is 0.36 P g 2 plus 32 this is lambda. So, while lambda is equal to 46.76, so 0.36 P g 2 plus 32 is equal to 46.76, therefore P g 2 will become 41 megawatt. That means, at lambda is equal to lambda 1 lambda 2 46.76 P L will be 73 megawatt that means, when this two lambdas are equal when lambda is equal to lambda 1 is equal to lambda 2 because if you see that that this is P g 2 41. But P g 1 if you look at that P g 1 minimum is 32 because it is coming here that means, it will come up to this one. Therefore this your P g 2 is 41 megawatt; that means and at that time P g 1 at its your minimum value 32 megawatt at that time it is 46.76, therefore, at lambda is equal to lambda 1 lambda 2 46.76 that mean pl is equal to 32 plus 41 that is 73 megawatt. That means, for lambda greater than equal to 39.92 that means, this value 39.92 this value and less than is equal to 46.76 lambda is equal to 0.36 P g 2 plus your 32.

Because that unless and until it comes here this lambda 2 this if you increase this one it is not coming up to these that means, this P g 2 that is your that generator two it has to take this load till it comes 46.7, because it is equal lambda basis. So, if you move it up unless and until lambda comes to 46.76 this IC 2 only has to generate this power because this one is fixed at that time 32 what you call 32 megawatt.

So, in this case what will happen that lambda lying in between 39.92 and 46.76. So, lambda is equal to 0.36 P g 2 plus 32 so that means, that P g 2 plus P g 1 min is total load that means, P g 2 is equal to P L minus 32 that means, your what you call; that means, your this thing your P g 1 min is 32. So, P g 2 is equal to P L minus 32 therefore, this P g 2 you substitute here this P g 2 you substitute here. If you do so you will get lambda is equal to 0.36 pl plus 20.48, this is equation 3.

So, this equation 3 is valid for P L greater than is equal to 54 less than is equal to 73; that means, this is valid when this load is lying, this is the minimum load and this is your less than equal to 73 that means, because total load is 73. So, what we are doing is P g 2 plus P g 1 min is to total load P L that means, P g 2 is equal to P L minus 32 that means, your this P g 2 you substitute here your P g 2 substitute here. If you do so you will get that your what you call lambda is equal to this one. So, this equation is valid when P L is lying in between minimum load 54 and then 73 megawatt up to equal lambda basis when it is 46.76.

So, I told you that legating the limit as long as limit is you are what you call is start this example is starting from the lower limit. So, this is your IC 1, this is your IC 2 unless and until it comes to this point is there unless and until it comes to this point, you are what you call this IC 2 has to IC 1 this your IC 2 has to take the care of that your increase of load till they come to the equal lambda. So, up to 46 points because here it is fake that your 32 megawatt minimum for IC what you call for IC 1, so that is why this is for this load. Next, when load is increased beyond 73 then what will happen, just hold on.

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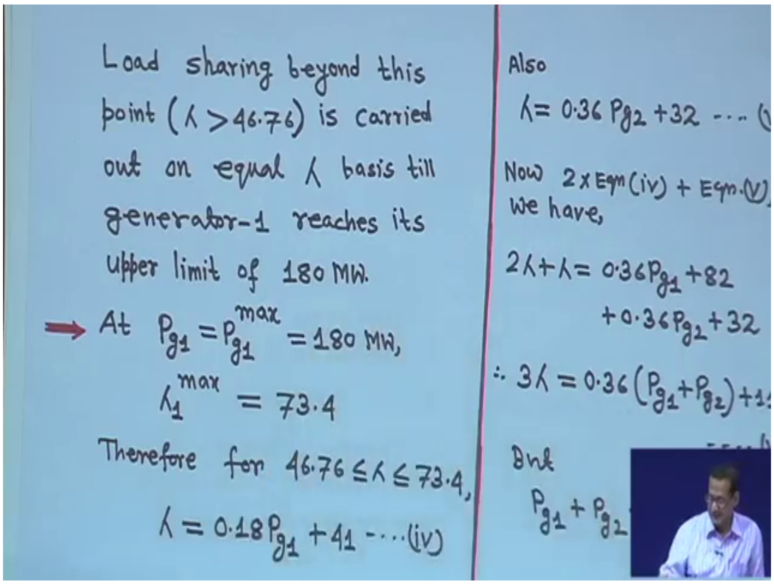

Now, therefore, P g 1 is fixed at 32 megawatt and P g 2 is fixed your just hold on this is your just one minute. Next is load sharing beyond this load sharing beyond this point lambda when lambda greater than 46.76 when it is beyond this is carried out and equal lambda basis till generator one reaches its upper limit of 180 megawatt. That means when now up to this it has come on equal lambda basis that is 46 till you can increase the lambda when it is coming up to this IC 1 is 180 megawatt. And at that time this lambda value that is your lambda 1 for this one max value lambda 1 is 73.4, because you this line this lambda line you are moving up moving up till because if you increase it will moves up then when it will be 73.4 for this one, this we this at this maximum that is 180 megawatt.

So; that means, that is you have to carry out on equal lambda basis we have seen it. So, generator one reaches its maximum of 180 megawatt. There may be P g 1 is equal to P g 1 max that is 180 megawatt at that time lambda 1 max we computed 73.4. Therefore, in between 46.76 and 73 point; so in between 46.76 and 73.4 the lambda, so lambda is equal to 0.18 P g 1 plus 41. This is that cost characteristic is given the dc sorry incremental cost characteristic is given that lambda is equal to 0.18 P g 1 plus 41.

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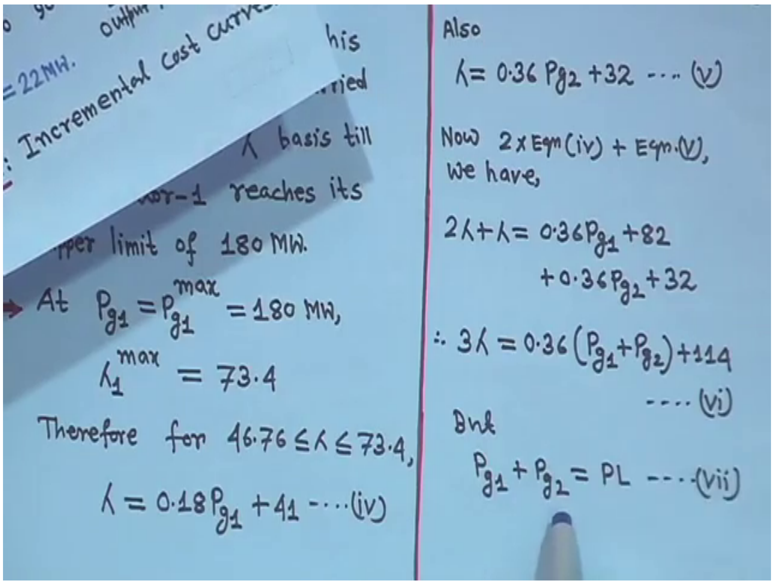

Also second one is for lambda is equal to 0.36 P g 2 plus 32 because between this limit between this your 46.76 and 73.4, they will work on equal lambda basis that is why here also lambda is equal to this one, here also lambda equal to this one. This is I am (Refer Time: 21:15) equation 4, equation 5. Now, what you do, this equation you multiply by two this equation is that is 2 into equation 4 this one plus that equation 5. So, then what you will get two lambda plus lambda 3 lambda 0.36 P g 1 plus 82 plus 0.36 P g 2 plus 32 you will get 3 lambda is equal to this one that is equation 6 we are making. But P g 1 plus P g 2 if there are total load P L loss is ignored here later we will see the loss. So, P g 1 plus P g 2 is equal to P L, therefore, here you put substitute P g 1 plus P g 2 is equal to P L.

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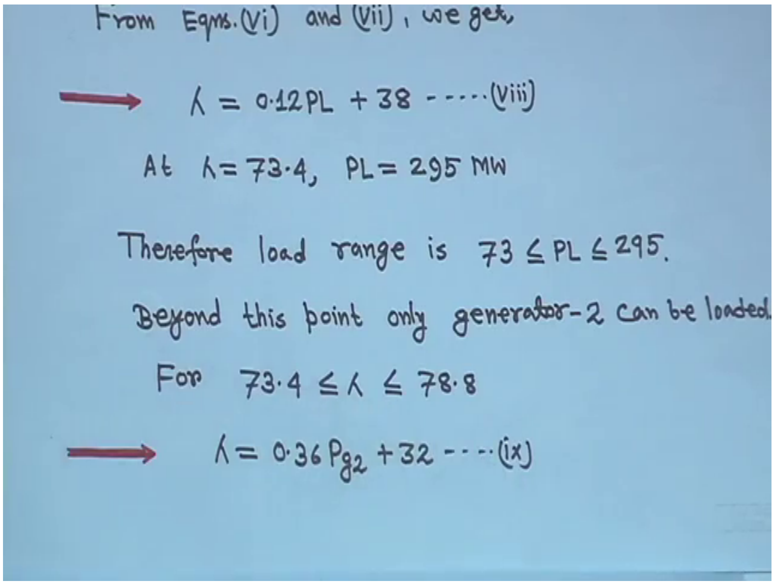

If you substitute here then what you will get if you substitute and then just hold on and then you divide this substitute and divided by 3 because this side is 3 lambda. So, substitute by and divide by 3. So, you will get lambda is equal to 0.12 P L plus 38 this is equation 8. Now, while lambda is equal to 73.4 because this is that last value 73.4, this is the last one for this because the maximum value for IC unit one. So, in that case you will get P L is equal to 295 megawatt. So, if P L is equal to 295 megawatt therefore, load range will be between 73 and 295, because previously we have seen that whatever this thing previously we have seen that for between 54 and 73 now beyond that it will be your load range will be in between 73 and 295.

But let me tell you here it is maximum 180 megawatt for your P g 1 that means, what will be P g 2 P g 2 will be 115 megawatt because up to this up to this it is it has gone let 73.4. So, it is maximum is 180 and P L is maximum had gone in this range in between this you are what you call this lambda values in between 46.76 and 73.4 that is your load is 195, but it is touch the limit 180 megawatt. So, the generation of P g 2 will be your 295 minus 180, so 115 megawatt later I had put it in tabular form.

Now, beyond this point only generator two after this further lambda is increase this is a (Refer Time: 23:45) limit. So, it will be kept fixed at 180 megawatt, it will be kept fixed at 180 megawatt. And after that lambda has increased. So, now, this rest of the load will be taken by this unit two generator two therefore, and that will go from your lambda is equal to 73.4 to 78.8. So, in this case the this is the lambda for unit two 0.36 P g 2 plus 32 that is say equation 9 , but when it touches the limit P g 2 that is your maximum P g 2 that is your 130 megawatt this P g 2 130 megawatt.

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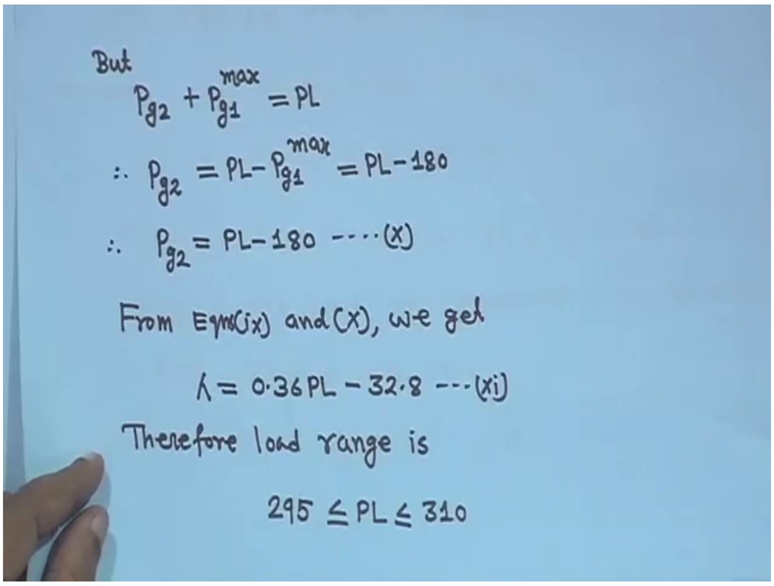

So, in this case, what will happen P g 2 plus P g 1 max will be total P L because at that time your this has reached 180 megawatt therefore, P g 2 plus P g 1 max will be PL. So, P g 2 will be P L minus P g 1 max that is equal to P L minus 180. This P g 2 is equal to P L minus 180 you substitute in that equation your just hold on here. Here you substitute P g 2 is equal to your this thing P L minus 180 you will substitute here because 180 is fix now for unit one. Therefore you will get lambda is equal to 0.36 pl minus 32.8 therefore, the load range will be in between 295 and 310 because maximum is load is 10. So, if you add 180 plus your 130 this will become 31. But it will be and that means, in between load 295 and 310 that mean this last 15 megawatt that this your what you call this generator two has to supply so that means, that means if you I mean this is the lambda this is the relationship between lambda and the load.

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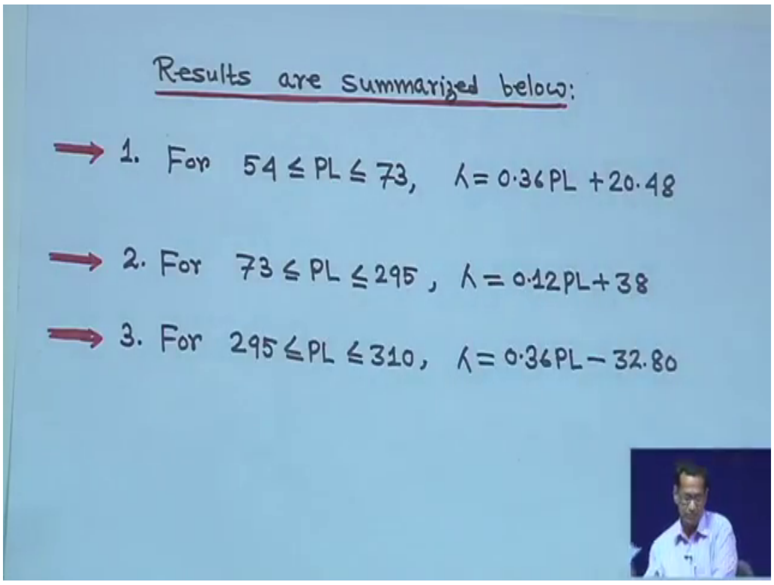

That means if you summarize this then this one for load in between 54 and 73 megawatt I am not written everywhere megawatt understandable lambda equation will be 0.36 pl plus 20.48. For in between load 73 and 295 megawatt, lambda will be 0.12 PL plus 38 and in between true 295 and this one lambda will be 0.36 pl your minus 32 point your this thing what you call 80 that will be this one. That means, first you have to first you have to draw this ICs I told you how to make it.

And accordingly and accordingly you have to see that P g 1 32 and your are what you call P g 2 22 megawatt accordingly. So, you have to see till it 46.76 comes, so P g 2 has to take care of this load and because unless and until it comes after that equal lambda basis. So, these two graph will draw and step by step from for example, 39.92 to 46.76 if then up from here to here to units will work till it comes its maximum value 73.4 and this one after that another unit is there. So, beyond that only this unit two will only work. So, accordingly you will just substitute and put those and get those equations, I mean lambda versus total load. Therefore, I hope you have understood, if you have any problem you can write to me, I will explain, but have a listen to this little bit minutely and try to solve of your own then things will be better look at it, and then see how things are.

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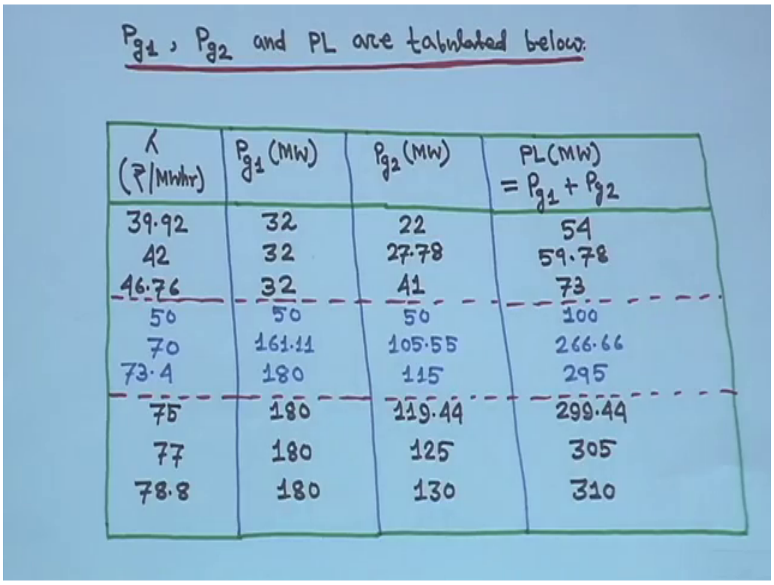

Now, if you just make it a tabular form, so lambda is equal to 39.92 P g 1 is fixed look at this look at this diagram that P g 1 is fixed because it is a 32 megawatt unless because this unit has to take generate your generation up to it comes 46.76. So, it is lambda 39.2 P g 1 is fixed is minimum limit 32 P g 2 22 so 54 that is ok. Now, when it comes to lambda is equal to 42 P g 1 will limit fix, but P g 2 has to generate power because lambda from here you are increasing unless and until it comes 46.76 are that P g 2 that you are what you call P this generator one it cannot generate a take that one. So, that is why that while lambda is equal to 42 it is P g 1 will remain at 32, but P g 2 at that time calculate 27.78 all these equation have been given total will be 59.778. When it will come 46.76, P g 1 will remain at 32, at the time P g 2 is 41 that may at the time P g 2 is 41 for lambda is equal to 46.76 and total is 73.

Similarly, when lambda 50, 70, 73.4 up to that limit I have come that is 73.4 that P g 1 50, P g 2 50 it is 100. And when it is 70, 161.1, 105.55, 266.66 total PL, PL is equal to P g 1 plus P g 2. When it comes up to 73.4; P g 1 fixed, and then 115 P g 2 total 295. Now, when it beyond that that unit two only will take the care of this load further increase still it reaches its maximum limit. So, that is why p 75, 77, 78.8 three values have taken. So, P g 1 is fixed because it has touched it limit. So, P g 1 is 180, 180, 180 an then only P g 2 you have to calculate 199.44, 125 and 78.8 is 130 totally 310. So, 299.44 at 75 lambda when lambda 77, 305 and when it is your what you call 310 total. So, P g 2 reaches its maximum 130 it is 310.

So, this way table I have made it for you such that things will be understanding. So, this only two units have been taken. If you take few units like this it is difficult to solve you know as far as a calculator this thing constant, so at that time we will go for some iterative technique, but this graph whatever you if you have understood then things are all. So, based is a this is IC 2 repeating IC 2 is taking the load whatever increase it is, but P g 1 will eliminate fix still it comes to 46.76. After that IC 1 will take up along with IC 2 it equal lambda basis still it is a 73.4 that is its maximum after that you further increase IC 2 will take.

Thank you we will (Refer Time: 31:09).