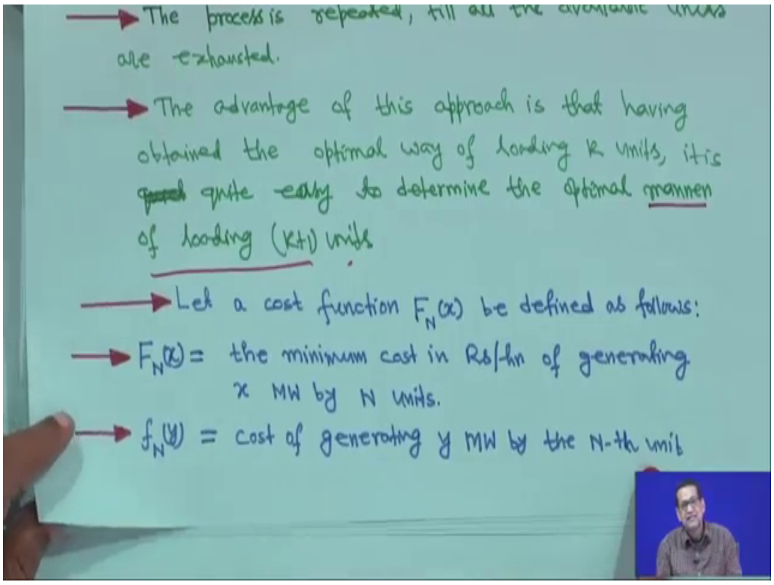
Power System Engineering
Prof. Debapriya Das
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 60
Unit Commitment (Contd.)

Ok, so now, here you have to understand actually, right very, very I mean computation easy, but very high, but I will show you one or two thing.

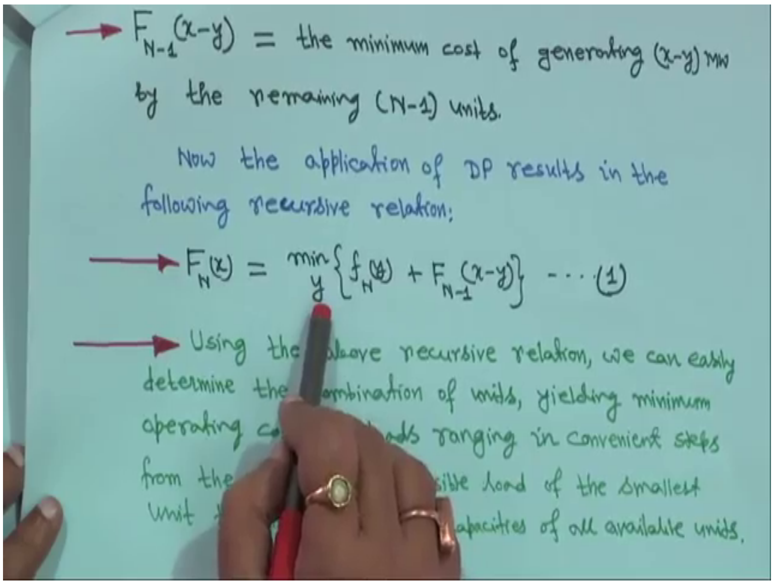
(Refer Slide Time: 00:17)



For example, let a cost function this is capital F suffix capital N x, right? To be defined as follows, right. So, F capital F we are using capital F and small f that is why I am telling, this capital F suffix N x is the minimum cost in rupees per hour say, or may be dollar per hour also no problem or any other currency unit does not matter, right? The minimum cost in rupees per hour of generating x megawatt by N units, right? So, this is the minimum cost right.

So, that is you are making at capital F N x is equal to minimum cost in rupees per hour of generating x megawatt by N units, right? This is one and small f capital N suffix y is equal to cost of generating y y megawatt by the N th unit, right? This is the meaning it is megawatt by N units and this is actually N th unit right. So, therefore, equation is very simple we just we look that therefore, capital F N minus 1 x minus y, that is you're the minimum cost of generating x minus y megawatt, right?

(Refer Slide Time: 01:21)

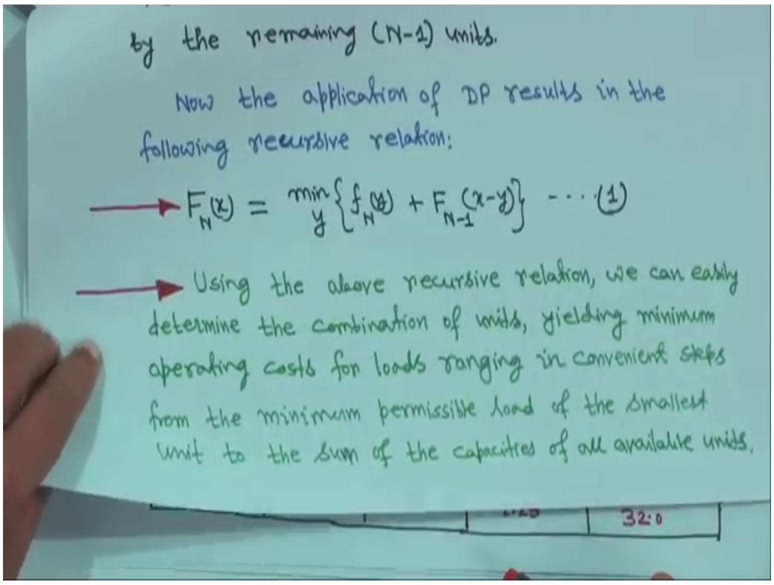


Here, we are where we are taking that nomenclature is like this that capital F suffix N x the minimum cost in rupees per hour of generating x megawatt by N units, right. And here small f capital N y is equal to cost of generating y megawatt by the N th unit.

If it is if your y megawatt generated by this, you are what you call? By the N th unit then remaining N minus 1 unit that is capital F N minus 1 it and remaining megawatt will be x minus y. That is the minimum cost of generating x minus y megawatt this is the meaning by the remaining N minus 1 units, right? So now, the application of dynamic programming result in the following recursive relation that is capital F N x, is equal to minimise y, right? F N y this small f capital N suffix y plus N is the unit number N is the unit number, right?

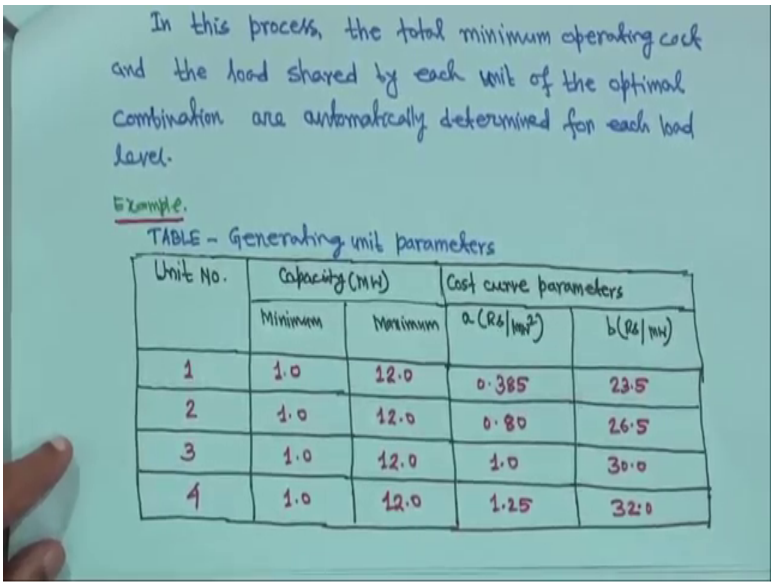
Capital F N minus 1 x minus y this equation is very simple know. You when you look it it is nothing actually no mathematics like this, but very very complicated actually, right? I mean very, very you are what you call very computationally we have to spend lot of time.

(Refer Slide Time: 02:52)



For example, use just I will show you how it things are using the above recursive relation, we can easily determine the combination of units; yielding minimum operating cost for loads ranging in convenient step from the minimum permissible load to the smallest unit to the sum of the capacities of all the available units, right? So, using this equation only we will make it that will be the, you are what you call that optimum combination of the unit and minimum cost.

(Refer Slide Time: 03:15)

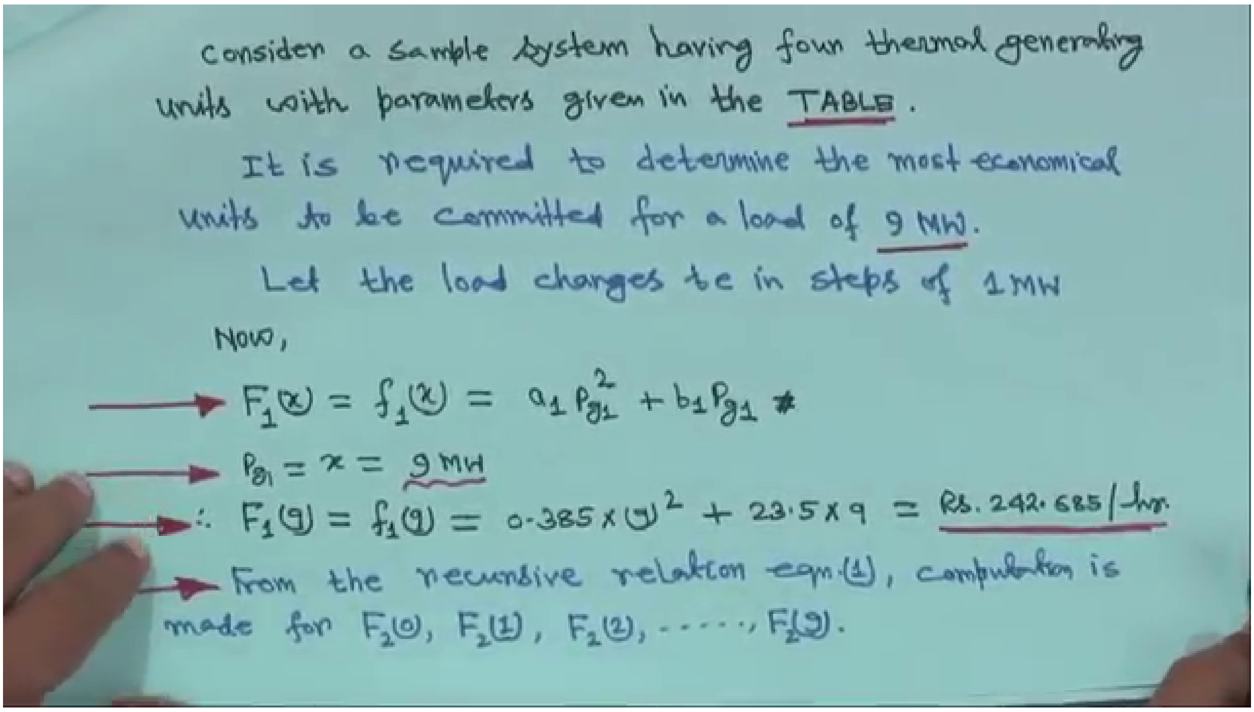


In this process, the total minimum operating cost and the load shared by each unit of the optimal combination are automatically determined for each load level. Question is that here, you know you have to you have to go for in a disk step, had it been soft computing technique things are very easier actually, right? Only thing is several constants are there it may be time consuming, but coding point of view that soft computing technique is very easier right, but in any way, those are beyond the scope, but suppose, this is a table, table number is not given this generating parameters are given.

Though this parameter there are 4 unit, right? 1 2 3 4 there are 4 units say and capacity is every generator is minimum minimum capacity generating capacity is 1 megawatt and maximum is 12 megawatt. So, for all this things minimum is 1 maximum is 12, right? And cost curve parameters a is given rupees per megawatt megawatt square and b is rupees per megawatt c term is not here, right. So; that means, the cost curve is actually a P g square plus b P g this is the form because it is rupees per megawatt square.

So, it will be a because you have to your objective functions should be in terms of rupees. So, it will be a into p g square plus b that you have seen for optimal operation in power system of course, there c was there right? But question is that here c was neglected, right. Only a and b we have taken. And these are the these are the a values for unit1 unit 2-unit 3 unit 4 and this is b value for unit1 unit 2 unit 3 and unit 4, right?

(Refer Slide Time: 04:50)



So now, you have to consider a sample system that is there that is a sample system that is the 4-unit system, right? All 4 are thermal generating units that parameters also given I have told you, right? Now, it is required to determine the most economical units to be committed for a load of 9. Suppose, your total load demand is 9 megawatt, suppose total load demand is 9 megawatt then you have to find out of this 4 units which are most economical right? So, and, but there minimum generation is this one, idea is something like this right. So, here there are 4 units, there are 4 units. So, if all the units are operating say then total minimum generation will be 4 megawatt.

If you add all and maximum generator if you all operating, that is a total maximum will be 48 megawatt, because 12 into 4 48 megawatt right? But anyway, it is supplying just 9 megawatt, right? So, we have to see sometimes 1 unit is possible because maximum is 12 1 unit, can whether it is economical or not or 2 units also possible 3 units also possible 4 unit also possible right, but we have to see the, which combination right?

So, in this case first1 is that your F1 x suppose let the load changes this steps in 1 megawatt we are changing that load step change in 1 megawatt only right; that means, iF1 unit generating 9 megawatt another unit generating 0 megawatt. If 2 0 9 then 1 8 then

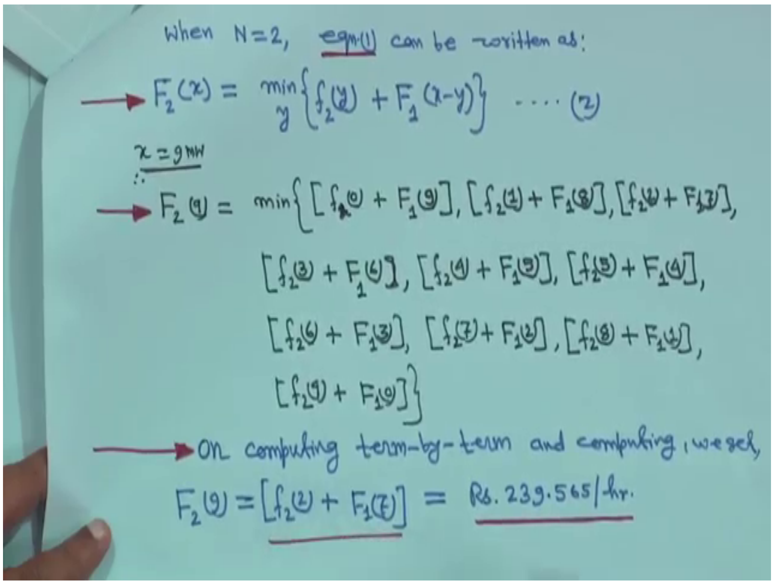
2 7 then 3 6 like this way combination you have to take. If you take less than that your accuracy will increase, but computational effort will be much much, more right?

So now, capital F1 x that is a first unit right; that means, suppose this for this number in arbitrary you can take any number it does not matter right? So, first unit this first unit say when N is equal to 1 capital F1 x, is equal to small F1 x, is equal to a 1 P g 1 square plus b 1 pg1 now pg1 actually is a 9 megawatt. Suppose, when unit 1 is generating say all the 9 megawatt right. So, in that case your F1 9 capital F1 9 is equal to small f1 9 is equal to your a1 is 0.38 pi 5 from this table 0.385 and. B1 is 220 3.5 because is a1 b1 a2 b2 a3 b3 a4 b4. In general, we have given a and b, right? So, in that case it is 0.385 into 9 square plus 23.5 into 9 and that is coming actually rupees 242.685 per hour it is coming.

Although, I can take this paise thing we can eliminate no need actually you can make it approximately 243, but for the sake of mathematics I have written this, right? From the recursive relation, that equation 1, from the recursive relation this is your equation 1, right. I mean this equation this equation this equation from this equation this recursive relation this equation, right. From this equation you can make it like this you can you can make it like this that computation is made for f 2 0 capital F 2 0 capital F 2 1 capital F 2 2 up to capital F 2 9. So, how one can make it to this capital F 2 0 capital F 2 1 F 2 2 like this?

So, how one can do it when N is equal to 2, I mean 2 units. So, when N is equal to 2. Then equation 1 can be written as, it was actually f N x capital F N x. So, N is equal to 2. So, it is F 2 x is equal to min it is y. then it is small f 2 y because N is equal to 2. And this one your N minus 1 that is 2 minus 1 that is here it is. When N is equal to 2 it will be capital F 2 x is equal to min y small f 2 y plus N is equal to 2 F1 x minus y right. So, this is equation 1.

(Refer Slide Time: 08:43)

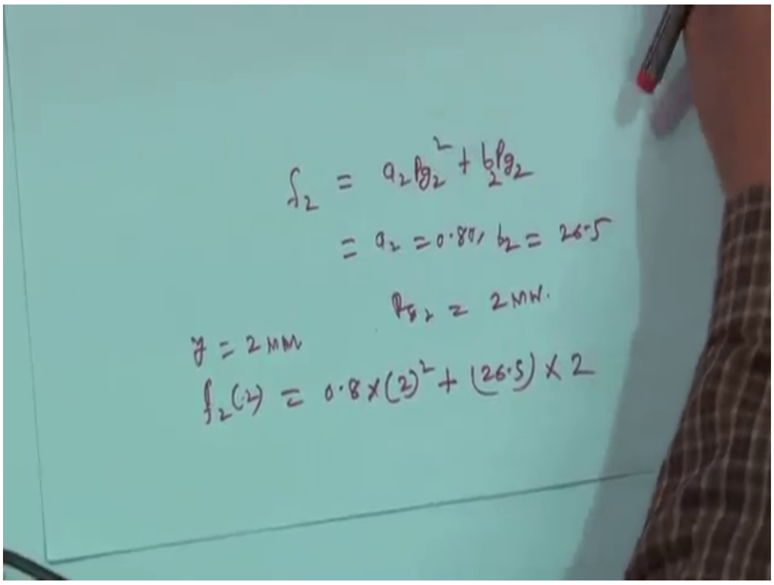


So, same thing we are put in here that equation 1 we are putting N is equal to just 2 that is all, right. Now, this is the minimum; that means, you have to combine all the minimum, but total load is 9-megawatt total load is 9 megawatt now look; that means, how many combinations are coming in a step of 1 megawatt? First is when y is equal to 0 when y is equal to 0 say, then it is f 2 0 plus F1 9 because x is equal to 9, x is equal to 9, right. Then when y is equal to 1, it is f 2 1 plus F 1 is 8 plus 1 will have to 9 then comma then f 2 2 plus F 1 your 7, right. Then f 2 3 plus F 1 6 then f 2 4 plus F 1 5 this is small f capital F, right.

Then small f 2 5 plus capital F1 4 then small f 2 6, 6 plus 3 9 you have to consider all the combination. So, your capital F1 3 small f 2 7 plus capital F1 2 7 plus 2 9 and small f 2 8 plus capital F 1 1 and small f 2 9 and capital F1 0 so, all this combinations you have to make it, right? For this 2 units because total demand is 9 megawatt if you make total demand is say 20 megawatt for example, then how many combination will come? 0, 20 then 1 19, 2 18 this way; that means, so many combinations right.

So, anyway on computing if you know everything you have to compute term by term, right? So, whenever we are calling that f 2; that means, this is the second unit, right. When here N is equal to 2 means small f 2 means the second unit, right. And capital F1 is the first one right. So, if you make all this combination you will find this f 2 2 plus F 1 7 actually this is the minimum.

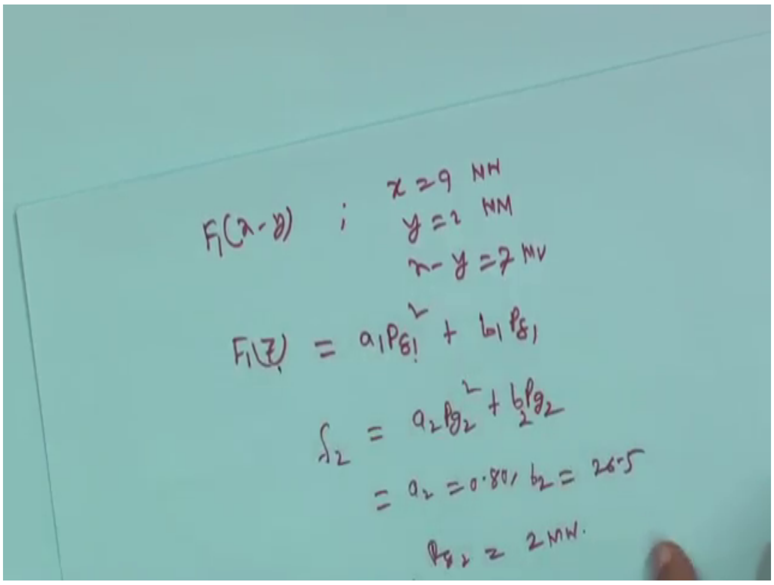
(Refer Slide Time: 10:42)



That means, only this part I will show you that what is f 2 that; f 2 2 actually it is the second unit it is the second unit. So, if we if you write that you are what you call cost curve that is your f 2 is equal to this one, right. It is a 2 P g 2 square plus your b P g 2, right. This is your from this from this data from this one right; that means, your; that means, a 2 is equal to here is 0.80, say unit I am not putting and your this one b 2 this is b 2 b 2 is equal to your 26.5 and then your this P g 2 here f 2 2 is the combination that is 2 megawatt; that means, P g 2 is equal to 2 megawatt right; that means, you compute ; that means, your f 2 2; that means, f 2 2 that is x is equal to actually y is equal to your 2 megawatt that is y is equal to 2 megawatt this one this one y is equal to 2 megawatt right.

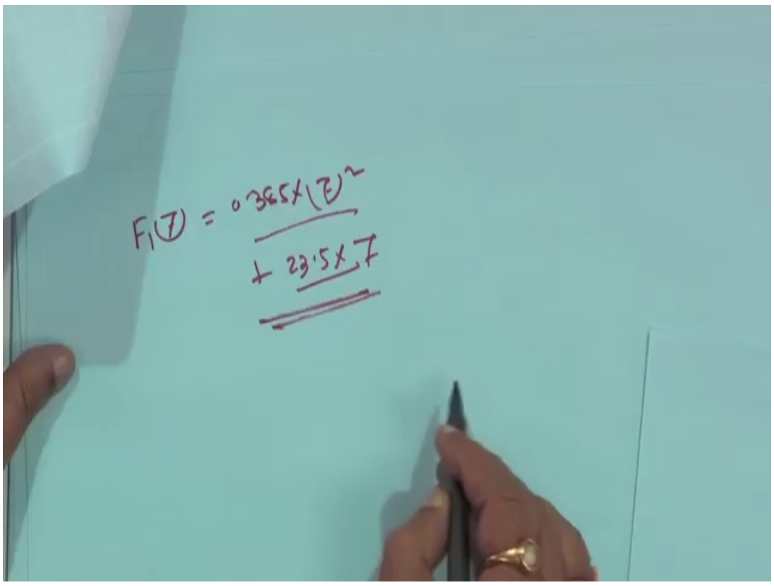
Therefore, your f 2 2 that is y is equal to your 2 megawatt, right. Therefore, f 2 2 will be your a2 0.8 into your 2 square plus b 2 b 2 is your 26.5 into your p g 2 into 2 this is your f 2 2 and whatever we are telling here, that this next is F1 7 F1 7 for the unit1, right. F1 7 is for the unit1; that means, for capital F 1 making it here capital F 1.

(Refer Slide Time: 12:10)



For the unit1 that is your x minus y right, but total demand is given x is equal to 9 megawatt and y is equal to 2 megawatt; that means, x minus y is equal to 7 megawatt right; that means, your F 17, is equal to that cost characteristic is first one, right. I first I write a 1 P g 1 square plus you are what you call your b1 P g1, but P g1 actually 7 P g. So, P g 1 actually 7; that means, your here I am making it; that means, your F1 7 that is your F1 7 actually this is your a 1.

(Refer Slide Time: 12:49)



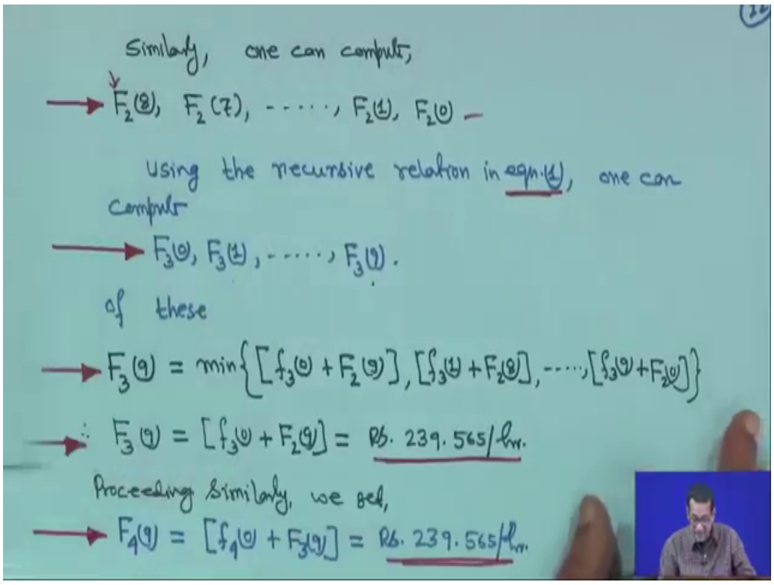
So, we have this a 1 is 0.385 we have already computed, right. 0.385 into your 7 square into 7 square plus this b 1 is 23.5 it is 23.5 into you are what you call 7. So, whatever it coming; that means, your combination is I mean whatever you have got the optimal combination is F 2 9 is equal to f 2 2 plus F1 7.

That means whatever f 2 value get from here, right. And whatever you get from here you please add this 2 like that, right? And this is coming rupees 239.565 hour for the sake of completeness. I am making it this is minimum, but you have to calculate all these only all this all the combinations you have to compute. The way I showed one, you have to compute all this things and out of which it is coming minimum I just I am not just putting arbitrarily that this is minimum right?

I have computed all this things, after computing I saw all this computation this morning also I thought I should not show you here, right? So, it will it will kill lot of time, right. So, but this is the minimum one, right? Suppose, if suppose if it is given suppose some assignment or something we will not give you one megawatt. Suppose, 9 megawatt we can give you only 3-megawatt step change step change. So, in that case it will be 09, then it will be your 36 then it will be 63 and 90 so, only 4 calculation 4 combination and you need 8 calculation because here 1 1 2 each one so, 8 only 8 calculations.

So, that will be result will be erroneous, but you have some feeling you have some feeling, right? So, that is that way classroom exercise you can make it. At least you will know how to compute right. So, this is for first one end; that means, this unit and this unit if second unit generate 2 megawatt and first unit generate 7-megawatt total is 9, then this is the minimum for first two units, right. Then what will what are objective will be that second thing is when we are adding the third unit know you have to compute, you have to you are what you call compute F 2 8, F 2 7 etcetera, right?

(Refer Slide Time: 15:04)



So, when you compute F 2 8 F 2 7 this is required actually when you compute similarly you compute F 2 8. F 2 8 means; that just F 2 8 you cannot compute you have to take again the combination of 1 7, then 2 6, then you are what you call 3 5 like this all this combination you have to take the minimum of this right.

It is just not like I can compute your F 2 8, right. You have to take your combination of 1 7 then you are what you call 2 6. Similarly, here also when it is F 2 7 means this all are actually minimum value. So, every time you have to compute you have to take the minimum values the way I showed you that like this one, all this combinations you have to consider.

For a F 2 8 also you have to take all combination because, this minimum F 2 is require. For example, why it is F 2 8, F 2 7, F 2 1 when we are taking this minimum for example, idea is using the recursive relation of one can compute F 3 0, F 3 1, F 3 9, right. Now suppose unit 3 is added. So, F 3 9 minimum is F 3 0; that means, we will take the cost characteristic of the third unit, cost characteristic of the third unit; that means, these unit we are considering this third unit will take, right. And once you take this third unit, right. Then you have to make f 3 0, F 2 9, F 2 9 minimum we have got it just we have got it know this is the minimum.

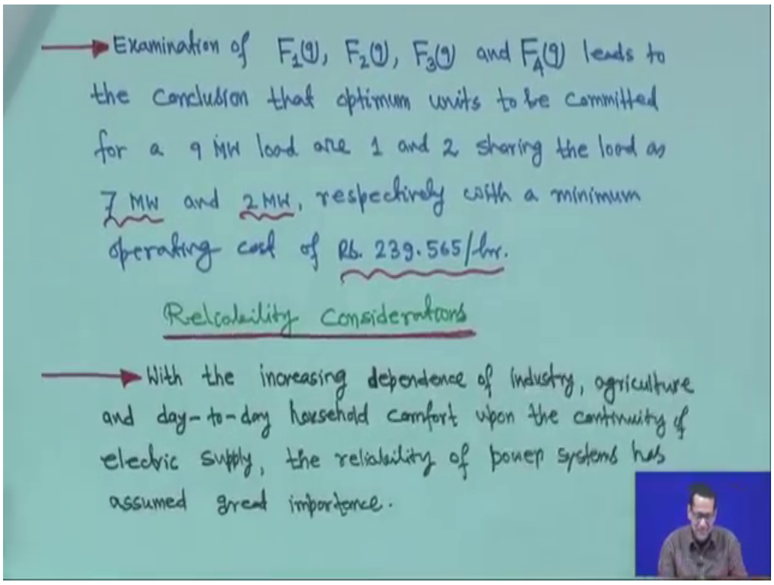
F 2 9 minimum we have got it this one, this one this one is the F 2 9 we have got it. This F 2 9 we have got it and f 3 0, f 3 0, actually it is 0 because unit is not operating; that means, in this case it is only 1 or 2 for f 3 9, but when it is F 3 1 you have to compute this your what you call this, this, this one when it is F 3 1 that come to the come to this, this table F 3 1 you have to take this one that a 3 P g 3 square plus b P g 3 this way this this, this compute for f 3.

So, once you make f 3, but look here F 2 8 is coming this F 2 8 you have to take the minimum of all combination; that means, here whatever I am telling F 2 8 F 2 7 these are the minimum value right; that means, again you have to go for your what you call that F 2 1 plus F 2 7 like this we have to go right? Small f 2 1 plus your capital F 2 your 7 like this the I mean the way we have taken and then that was 9 megawatt, that was do for 8 megawatt then 7 megawatt and up to come up to this and then every time you have the minimum. Just cannot you take that I mean just you imagine that what is the how much is the effort or your what you call that computational effort.

It is actually your sky high the computation and, your what you call in dynamic programming, but I am telling you that this is the philosophy this is the philosophy; that means, these are all actually minimum everything you have to see which combination will give you minimum cost for unit1 and unit 2 for which it is generating 8 megawatt. Similarly, 7 megawatt these are all minimum and those minimum thing F 2 8 then, next one will come f 3 2 plus F 2 7. This F 2 7 again minimum you have to take out of all combination 1 6 2 5 like this out of which one is minimum. That one you have to put it here then only you will get the good result otherwise never, right? So, similarly this way up to f 3 9 plus F 2 0 this way if you compute again you will find all this combinations have higher value than this one. So, F 3 9 actually giving f 3 0 plus F 2 9 that is rupees 239.56 this; that means, unit1 and 2 still it is operating, right? Unit 2 is generating 2 megawatt unit1 is 7 megawatt, right?

This is whatever we have got from here whatever we have got from here. This is unit 2 is 2 megawatt unit1 is generating 7 megawatt, right. So, that is similarly if you proceed for similar way if you proceed for F 4 9. Similarly, again minimum f 4 0 plus F 3 9 like this if you move like this again if you make all sort of combinations you will get again this is the minimum; that means, every time you can see that this is 0 f 4 0 0 P g 0 means that f 4 will be 0 and F 3 9 actually becoming actually f 2 9 right. Because this is 0 this unit is not generating any power these generating is not generating any power every time this is coming minimum; that means, to supply 9 megawatt that unit1 and 2 combination is the best one right.

(Refer Slide Time: 19:40)

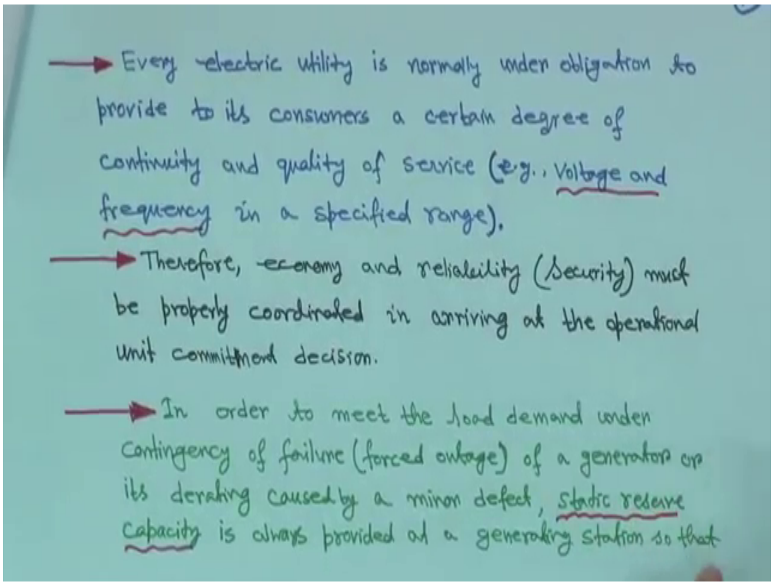


So, that is why Examining F1 9 F 2 9 F 3 9 and Ff 4 9. F 4 9 also you have seen it is only 1 unit now not possibilities 240 point something we have seen, right. For unit1 here it is here it is here this calculation here it is I will show you here F1 we have done it here you have done it and it is 242.68. So, it is higher right? So that means, that means, your only unit after coming all this leads to the conclusion that optimum units to be committed for a 9 megawatt 1 and 2, right?

Sharing load as unit1 your 7 megawatt and unit 2 is 2 megawatt and this is the best one and minimum cost for that load is this much is coming right per hour, right? Although although it is very high in reality, but this is some parameter has been taken per hour; a reality is this cost of generation power is not like that it is very high, but some data has been taken and just to show you that how things are right. So, this is actually dynamic programming little bit, right? Just a how one can proceed, right.

If you have any question when we will go through it you can put the question in forum everything will be everything will be explained right? So, and with the increasing dependence of industry now, the reliability part right, because reliability is another concern very briefly will be explained here. So, with the and how it is related to unit commitment right? With the increasing dependence of industry agriculture and day to day, household comfort upon the continuity of electric supply the reliability of power system has assumed great importance, right. In a power system, suppose it is just giving a simple logic.

(Refer Slide Time: 21:20)



Although if you install a large generating unit say 500 megawatt generating unit. It will be install everything cost I mean it is a single unit it cost will be cheaper.

But reliability will be less suppose, if there is an outage 500-megawatt unit. So, there will be shortage of 500-megawatt power say, but if you install say 100 megawatt 5 units, right. Of course, your install your install cost your what you call install cost and everything will be much higher, because individual 100-megawatt unit it will be not same as your 500 megawatt it will be much higher, but reliability will be more if 1 unit is out, right. 2 unit is out you when 1 unit out you can still supply 400 megawatt if 2 unit is out.

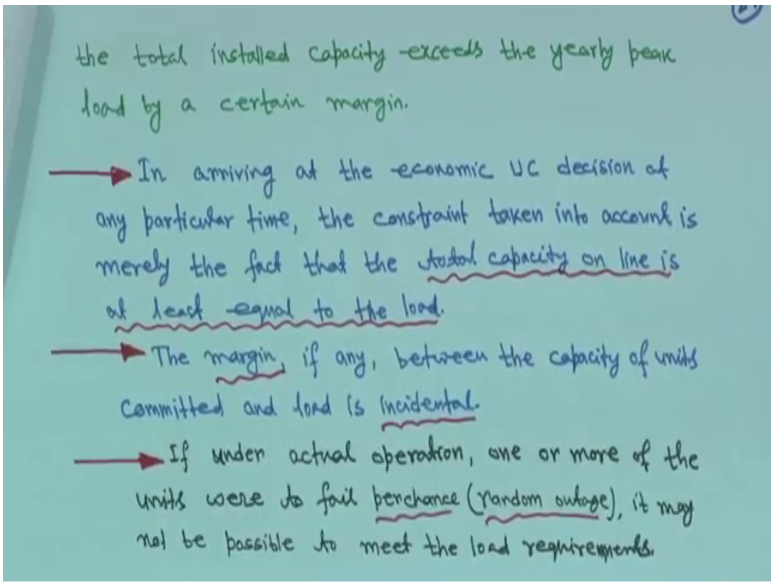
So, at least you can supply 300 megawatt, but if only one 500-megawatt unit is there if it is goes out then 500 megawatt load you cannot supply. So, if you put; that means, if you put larger units you have to see that of course, outage or you know any fault anything happens, right? Then you have to go for this what you call switch of that generating units.

So, 5 loss of 500-megawatt power; that means, that is; that means, reliability is less although your less expensive in terms of you just see 5 500-megawatt unit you install, but if you in install that lower rating unit your reliability will improve, right? That is the that is the your that is the idea right, but anyway always higher rating unit is preferable particularly day by day the cost of everything is going high. So, you have to see that it is supply also 500-megawatt supply that powers continuously, right? Unless and until some abnormalities happen in the power system, right?

So, every electric utility is normally under obligation to provide to it is consumer a certain degree of continuity and quality of service that is voltage and frequency to a specified range, right? This is power quality therefore, economy and reliability, right. That is security must be properly coordinated in arriving at the your what you call operational unit commitment decision.

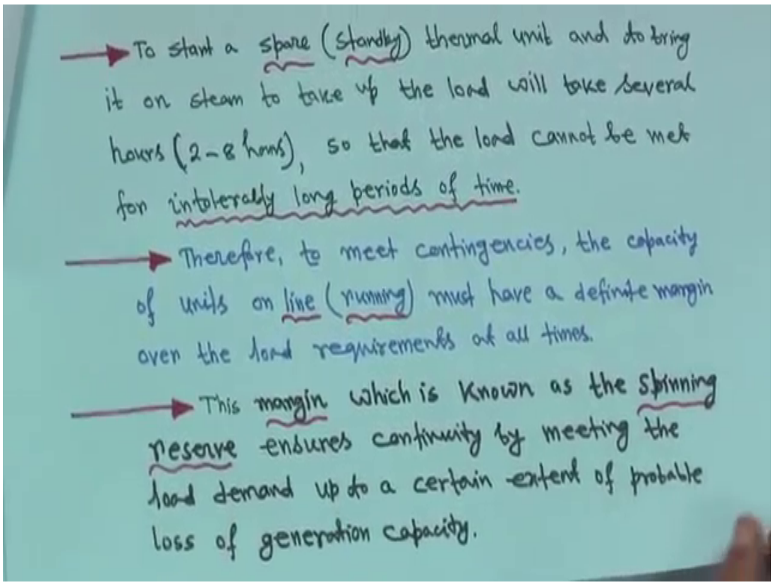
So, in order to meet the load demand under contingency of failure say forced outage, right? Of a generator or it is derating caused by a minor defect say, right. The static your reserve capacity is always provided at a generating station right.

(Refer Slide Time: 23:42)



So, that the total installed capacity exceeds the yearly peak load by a certain margin, right? So, in arriving at the economic unit commitment decision, and at any particular time, the constraint taken into account is merely the fact that the total capacity on line take a total capacity on line is at least equal to the load. Total capacity on line means, that generator many generators are connected, right. It is connected and generating power, right. That those generations at least it has to be equal to the load sometimes we call that total capacity on line, right? Therefore, the margin, but margin if any between the capacity of unit committed and the load is just incidental right. So, generally generation must supply load plus power loss, right. That is the idea load plus power loss that generator will supply. So, if under actual operation, one or more of the units were to fail perchance say random outage it may not be possible to meet the load requirements, right?

(Refer Slide Time: 24:43)



So, to start a spare thermal units if it is a hydro no problem I told you, but if you do not have that facility for hydro, then if you start spare standby thermal unit and to bring it on your, what you call? Steam to take the load will take several hours 2 to 8 hours it takes time, right. Just you cannot start thermal units, right? So, that the load cannot be met intolerably long periods of time; that means, that means you have to there is no other way apart from making load setting, right. Because it takes time so therefore, to meet contingencies that capacity of units on line, on line means I told you the running units must have a definite margin over the load requirements at all time idea is it is idea is something like this.

Suppose, that is what is the meaning suppose 5 units are operating, right? And suppose it is supplying your what you call 500-megawatt load and each unit is generating 100 megawatt each suppose there is certain outage of 1 1 unit; that means, 100 megawatt is loss, right. Then 4 units are operating so load is your 500 megawatt, but generation is 400 megawatt right; that means, there must be some your what you call sometimes is called that you are what you call the margin should be there. So, in the margin means suppose 100-megawatt generator each one getting, but if suppose if every generator is rated those 4 units say 125 megawatt.

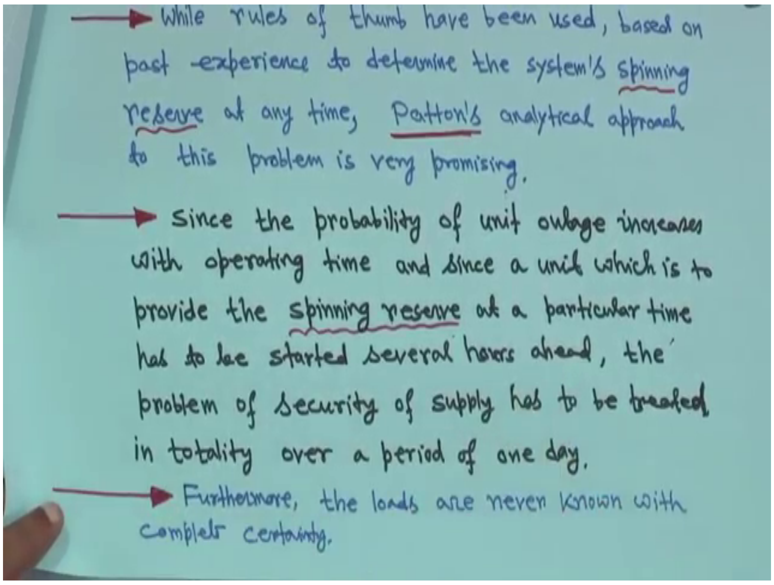
For example, say right then other unit the other 4 units can somehow generate 125 megawatt each such that it can accommodate the load of 500 megawatt, right. That is the meaning that must have a definite margin over the load requirements at all time that is; that means, if 1 unit is out see that other running units can accommodate the load of course, if more units goes out then it is not possible, but; that means, it can generate sometimes your what you call that over generation also 10 15 percent is possible by the generating units, right? So, whatever rated capacity it may be 10 15 percent more, it can generate power also right. So, this is the idea this is the meaning of that. The margin which is known as this is called spinning reserve, right?

Suppose, expiring this why I think, I have told you in the power system analysis class spinning reserve suppose a generator, can generate suppose is maximum power generating capacity 200 megawatt, right? And suppose it was generating 160 megawatt so, but if 440-megawatt load comes it can take off; that means, that x axis 40 megawatt sometimes we call that this is a spinning reserve, right. That is the meaning of spinning reserve.

Spinning means the message is generating power actually and your, what you call? Turbine generator is actually rotating, right? Spinning so this is called spinning reserve that message in on line that is running right. So, that ensures say your continuity meeting the load demand up to a certain extent of probable loss of generation capacity, but everything I have written for you whatever I am telling from mouth same thing is written here. So, when you go through it will be easier for you right?

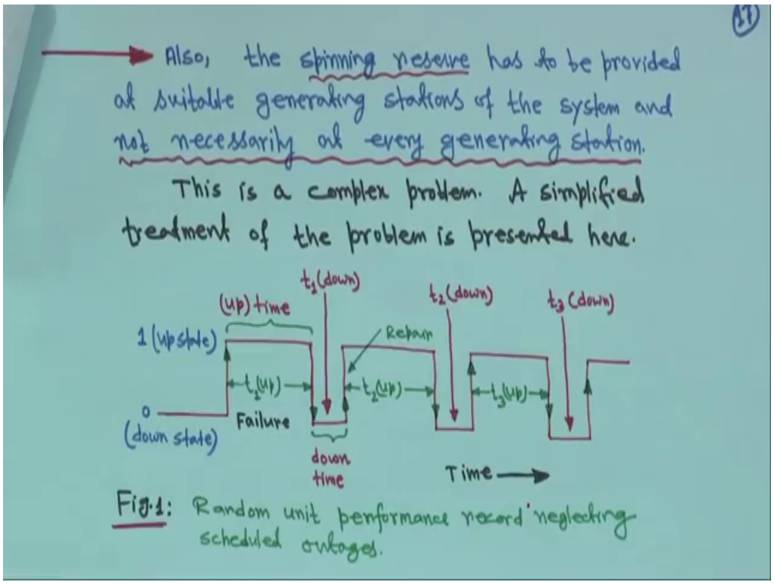
So, while rules of thumb have been used based on first experience to determine the system spinning (Refer Slide Time: 27:52) of course, of course, when you are you working somewhere and you know that your, what you call? That operators are there at the, your power station. So, they are more experienced, right? You will find their knowledge is really too good actually because over the years they are handling that and they know, what time I mean what kind of action can be taken and what time they are they know it when over right. So, Patton's analytical approach of this problem is very promising little bit we will see.

(Refer Slide Time: 28:24)



So, since the probability of Unit outage increases with operating time; that means, if operating for long time then probably of outage also will increase and since, unit which is to provide the spinning reserve at a particular time has to be started several hours ahead, right? That because thermal unit I told you 2 to hours say it takes so; that means, if you want additional unit you have to start this thing unit much bit much much before that, right? The problem of security of supply has to be treated in totality over a period of 1 day we will take the one-day load curve, right? Furthermore, the loads are never known with complete certainty a load is always uncertain loop.

(Refer Slide Time: 29:06)

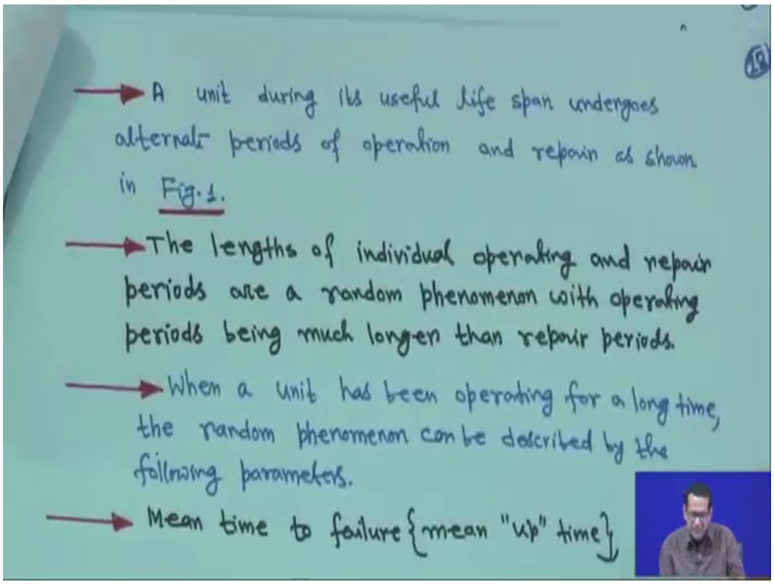


In generally these are not the your topic for the teaching of this course load is actually it is uncertain, right. Generation is also uncertain generation uncertainty, load uncertainties are there, but whatever little bit you are studying it is completely deterministic; that means, everything is certain, right. Also, the spinning reserve has to be provided at suitable generating stations of the system. And not necessarily at every generating station there is that, suppose you have a several power plant no need that every power plant will have a spinning reserve, but some your what you call sum of the generating stating that a spinning reserve should be there.

Now, suppose this is very complex problem, but we take simplified problem look a simplified treatment of the problem is presented here. Suppose up state down state, right. These are up time t1 up time t 2 up time t 3 up time like this at this is t1 down time down time that is repair this is failure.

This is down time; down time this is time this is up state and this is down state because you do not know some missing are on or so off also see if it goes for your repair or when some outage is there routine maintenance right? So, these are up time this t1 t2 to 3 may be different, they are not same that is up time and down time t1 t2 t3 also different not same right. So, random unit performance record neglecting schedule outage, right it is something we have taken one for up state and 0 for down state, right. I mean 1 or 0.

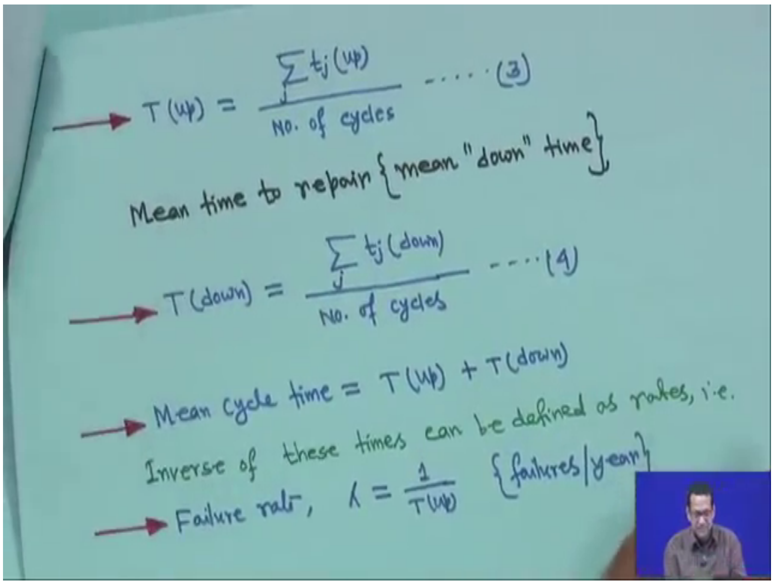
(Refer Slide Time: 30:30)



So, so unit during it is useful life span undergoes alternate periods of operation and repair as shown in figure 1, right. This is your figure 1 alternate thing right, but these are not uniform my diagram looks like it is uniform, but this time it is different, right. Different time that is why make t1 up t2 up t3 up t1 down t2 down t3 down they are not same they may be different, right?

So, the lengths of individual operating and repair periods are a random phenomena with operating periods being much larger than the repair period. This is very natural, if most of the time in repair period then how it generating generate power. So, repair time is much less than the your what you call that operating time up time up time is much higher than the down time. When unit has been operating for a long time, the random phenomena can be described by the following parameters say one thing is mean time to failure we call mean up time, right?

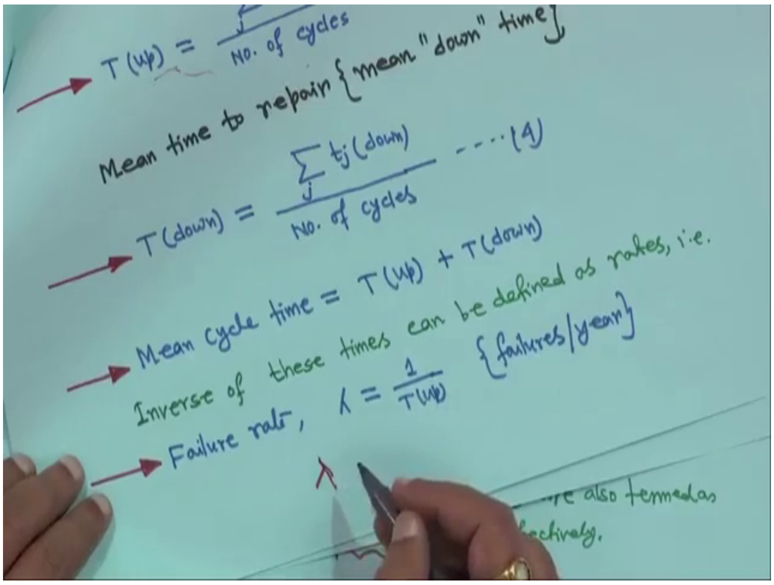
(Refer Slide Time: 31:20)



This is mean time to failure; that means, T up time it is can be given as that sigma t j up sum up all the up time that is this thing, right. And divided by the number of cycles because if you look at the graph it should goes actually your up and down up and down, right? Up and down it goes up and down up state down state up state down state. So, how many cycles are there, right say that is one that is your T up is equal to sum of all the up time, divided by the number of cycles so this is equation 3. Similarly, mean time to repair that is mean down time, right. It is basically T down capital T down is equal to sum all the down time, right. Then number of cycles this is equation 4, right?

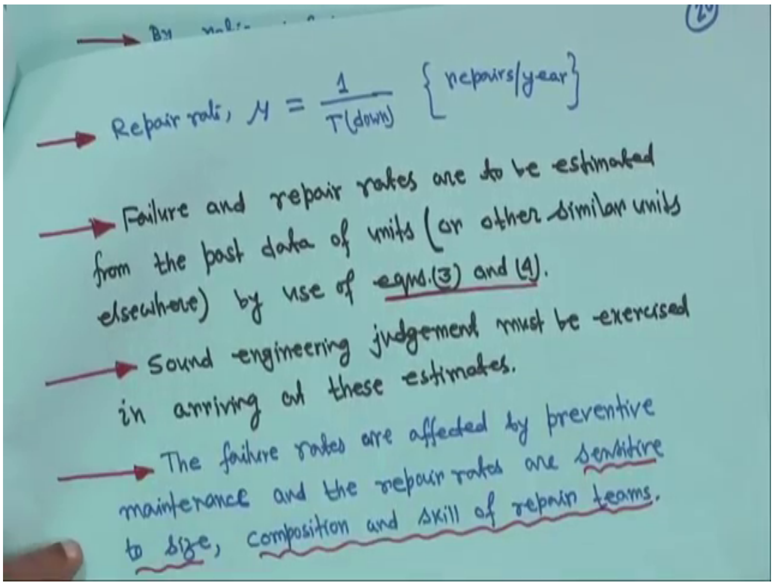
Now, mean cycle time will be total will be T up plus T down that is very simple know here also from this diagram also T this all up and all down you add that will be total cycle time right. So, mean cycle time will be T up plus T down very easy thing it is right? So, inverse of this time can be defined as rates that is failure rate lambda, right? This is actually my habit has become write lambda; actually lambda is like this right? But this has become my habit.

(Refer Slide Time: 32:27)



So, power system analysis course also I told you when I started inductance right. So, this is actually lambda is like this ah, but my habit has become like this, right. So, anyway so if you ask me again and again and write sometimes again I will write this. So, this is lambda is equal to 1 upon T up right that is failures per year. The reciprocal of the up time actually failures per year, right this is your failure rate.

(Refer Slide Time: 32:58)

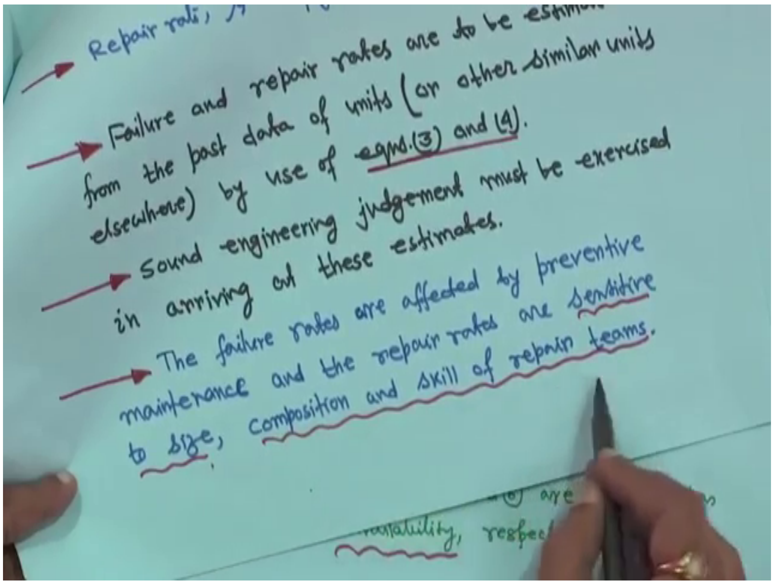


Similarly, that repair rate that is we define as a mu, mu is equal to 1 upon T down reciprocal of the time and we call repairs per year, right? This is your repair rate so and then failure and repair rates are to be estimated from the past data of units. You have the past data, from that you have to you have to see that, right? Or I mean data are stored I mean in the past all data are stored or other similar units elsewhere by use of equation 3 and 4 actually in a power plant suppose some fault has occurred some generators are out right?

So nowadays we have a huge computed database all the solutions are available then we will find that if some some fault has occurred to generated in any power station. They work they do actually, they record actually what type of fault it is and your how it has happened, right? I mean cases how it has happened? And how it has been it was quickly your what you call? Restored that generator to the your what you call? Generator or transformer what so ever to that your system, right on line, right?

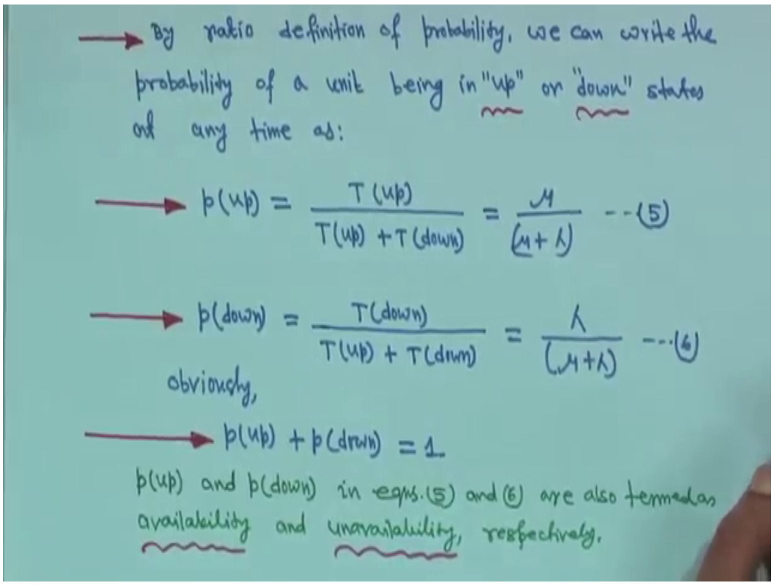
All this things they have the storage I mean what type of fault anything they have the huge database right? So, anywhere if any such thing happens immediately they go and verify what type of fault? And immediately they will see their database and immediately they know that what is there? Your what is the remedy for that right? So, this is very common it is for all the power companies they have the huge database for all site of type of fault and immediately they go to that quick solution. So, this is your because of nowadays computers available everywhere. So, we have all this facilities, nowadays right?

(Refer Slide Time: 34:42)



So sound engineering judgement must be exercised in arriving at these estimates of course, you have to see the data carefully the failure rates are affected by preventive maintenance and the repair rates are sensitive to a size composition and skill of repair teams, right? It is it is to repair rates at sensitive to size composition and skill of repair team that persons actually who are involved in this job right?

(Refer Slide Time: 35:04)



Actually, how quickly they can restore it, but you will find in those job most people are most efficient, right? Many years back, I saw one person in some power plant he was expert in turbine. I here, he is an engineer right, he is an engineer, but I maybe he is retired today ah, but I saw him that he knows turbine like anything, right? And likes like labour he actually works on turbine, right he himself actually the master piece of turbine.

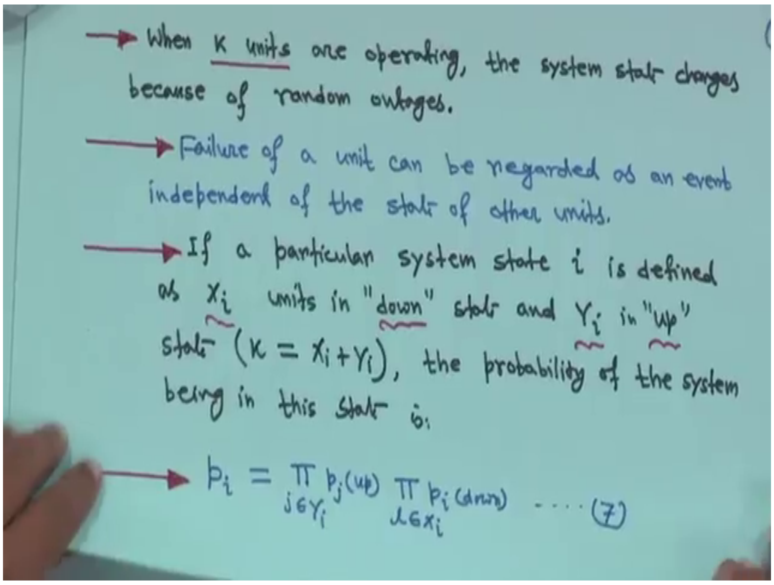
I have seen him working and he knows every nut bolt everything of turbine. I mean unbelievable talent he had, but remember he is not a this your what you call mechanic or anything he is an engineer and. As an engineer, he knows each and everything of the turbine he is expert of turbine I have seen him working also some unit was damaged and whole turbine has been opened his mechanics and others also their supporting staff are there, but himself he is working like anything right?

So, you will find many such people in the industry, right. They are very dedicated for those works, right if you go to the industry then you will see how dedicated are they right? So, anyway come back to this by the ratio definition of probability, we can write the probability of a unit being in up or down state at any time. So, p up is equal to probability T up by T up plus T down that is a total time, right? And we have defined know 1 upon T up is equal to mu and were sorry lambda are 1 upon T down is equal to mu.

So, you just substitute those, right. T up T up is equal to substitute your 1 upon lambda and your T up and T down here also down 1 upon mu we substitute. Whatever we will get you will get mu upon mu plus lambda this is equation 5 that is probability p up and p down is simply T down by the total your cycle time T up plus T down it will be lambda upon mu plus lambda. This is equation 6 this a very simple thing and then p up plus p down is equal to one, right total should be 1.

Now, p up and p down this equation 5 and 6 are also termed as availability and unavailability respectively. This is the probability of the availability, right? And this is the probability of the unavailability, right this is the thing way your simple thing I have made it simple thing for you.

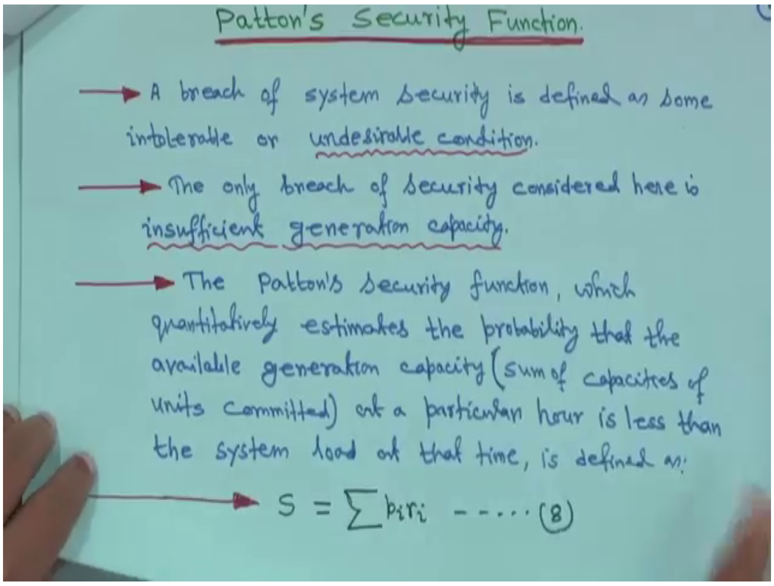
(Refer Slide Time: 37:22)



While K units are, operating the system state your changes because of random outages, right? So, failure of a unit can be regarded as an event independent of the state of other units. I mean each failure is independent to other such that it will be easier for you to analysis it is not depending on other, right? It is every, everyone is an independent state because we are little bit we are talking about probability. So, we are assuming that it is independent of the other units right. So, if a particular system state I say at I state is defined as say capital X suffix i, right. Units in down state and capital Y i suffix i in up state where, k is equal to X i plus Y i it is fine, right?

Then the probability of the system being in this state is it is product j belong to Y i; that means, units which are belong to up state, right. That is Y i in the up-state units, right. That is, you have to make the product you have 3 units probability of all this thing you have to multiply. Then into again product of your units l belong to X i which are in down state, right l belongs to X i into p i this is down, right. This is equation 7 this is a product, it looks like is probability and product is a very simple thing actually very simple thing right.

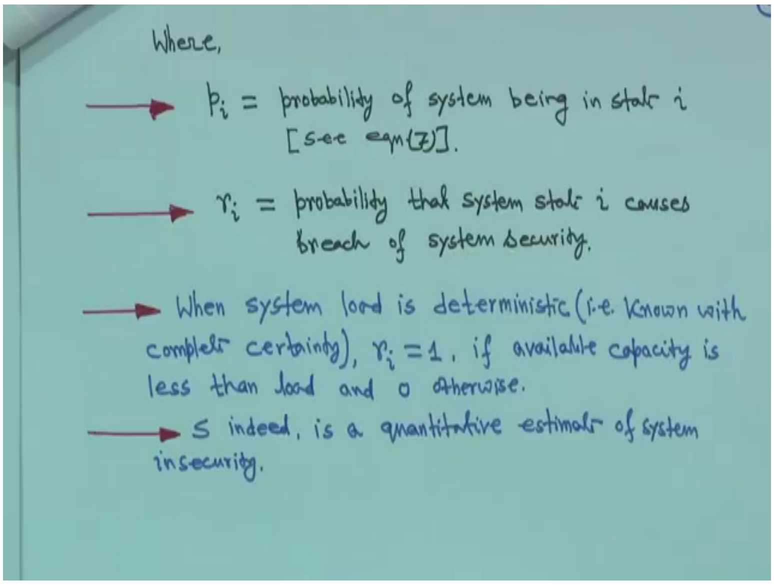
(Refer Slide Time: 38:40)



So now so Patton's security function. So, just we will explain, right many things will assume here and just explain and with completing this, we complete the unit commitment and this course right. So, a breach of system security is defined as some intolerable or undesirable condition. That is breach of system security is known right. So, the only breach of security considered here is insufficient generation capacity.

So, here we will consider the insufficient generation capacity that is your only breach of security. The Patton's security function which qualitatively estimates the probability that the available generation capacity, that is sum of capacities of units committed; that means, which unit which actually around running, right? At a particular hour is less than the system load at that time is defined as s is equal to sigma p i r i right? So, sum of capacity is that is that is the probability that the available generation at a particular hour, is less than the system load at that time is defined as s is equal to your sigma p i r i this is equation 8, right. Now what is p? What is r?

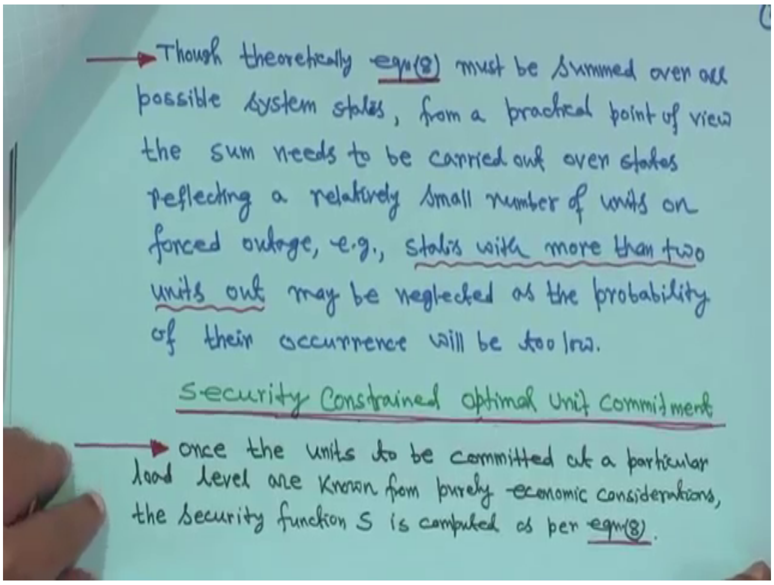
(Refer Slide Time: 39:43)



Now, p i actually probability of system, right being state i, right? This is the probability of system being in state i that is see equation 7. I have written; that means, this equation this equation, this is the equation, you see the equation right. So, it is your from this product of this probability right. So, and r i the probability of system state i causes breach of system security, right? So, this 2 data if is known then we can compute when system load is deterministic.

That means, no uncertainty is there that is known with complete certainty no uncertainty is there. Then in that case r i is equal to one if available capacity is less than the load, right. And it is 0 otherwise either 0 or it is less, right. And second thing is s indeed is a qualitative estimate of system insecurity that is sigma p i r i right?

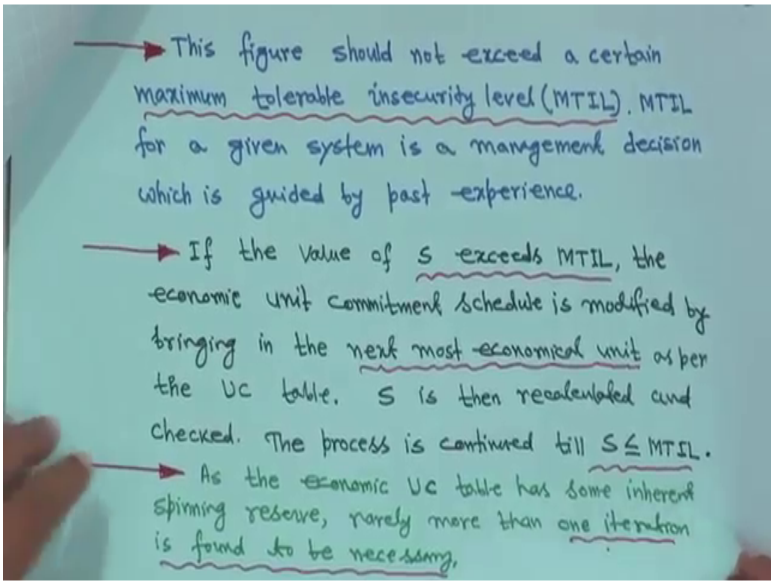
(Refer Slide Time: 40:40)



Now, though theoretically equation 8 must be summed over all possible system state because sigma p i, r i, p 1, r 1 plus p 2, r 2 like this from a practical point of view the sum needs to be carried out over states, reflecting a relatively small number of units on forced outage. Example, that is states with more than 2 units out or maybe I mean states with more than 2 units out it is very rare, right? And second thing is may be neglected as the probability of their occurrence will be too low because, 2 units outage probability is very low. So, you may neglect it right, but if you want detail then perhaps you can do it.

But 2 units 3 unit do you think that that will be totally out together. If it happens then you have to, but probability will be less, right. Now, security constraint optimal unit commitment I will give you a simple example here once the unit to be committed at a particular load level are known from you what purely economic considerations the security function S is computed as per equation 8 means S is equal to sigma p i r i right?

(Refer Slide Time: 41:40)

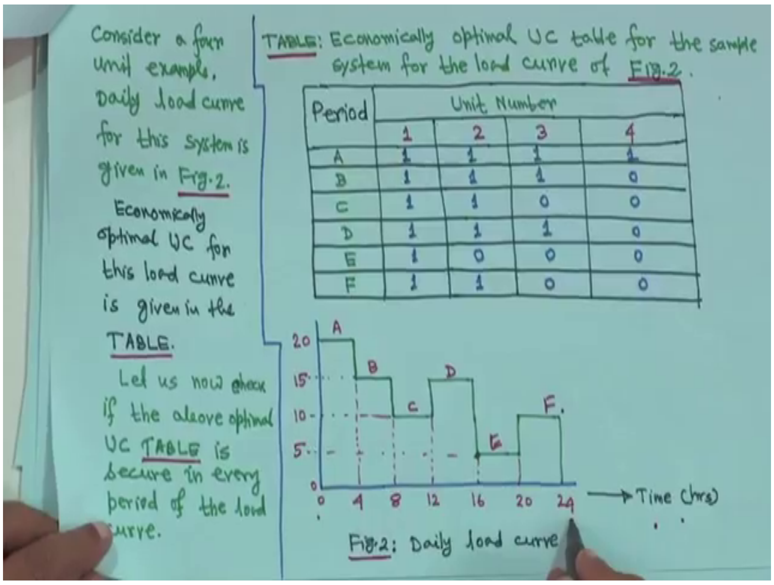


So, this figure should not exceed a certain maximum tolerate your tolerable insecurity level this will be defined by you, right. That MTIL that is maximum tolerable insecurity level will be defined by you that is MTIL, right? For a given system is a management decision which is guided by past from the past experience that you can define this value MTIL that is maximum tolerable you are in securing level right?

So, if the value of s exceeds this one then the economic unit commitment schedule is modified, right. I mean if you are value suppose you have defined this is 0.0005 and your this your the value of s exceeds MTIL, right? And S is becoming say suppose it is for example, it is 0.05 and it is 0.06. So, it is exceeding this one; that means, your whatever condition you said it is not matching. So, you have to you have to go for second iteration something like that.

The economic unit commitment schedule is modified by bringing in the next most economic unit, as per the unit commitment table. So, S is then recalculated and checked the process is continued till S become less than MTIL, right. MTIL you have defined, right? And it has to be less than equal to like this, right. The, but after your unity commitment thing you can check this as the economic unit commitment table has some inherent spinning reserve, you rarely more than one iteration is found to be necessary; that means, when you check this hardly one iteration this can do it.

(Refer Slide Time: 43:13)



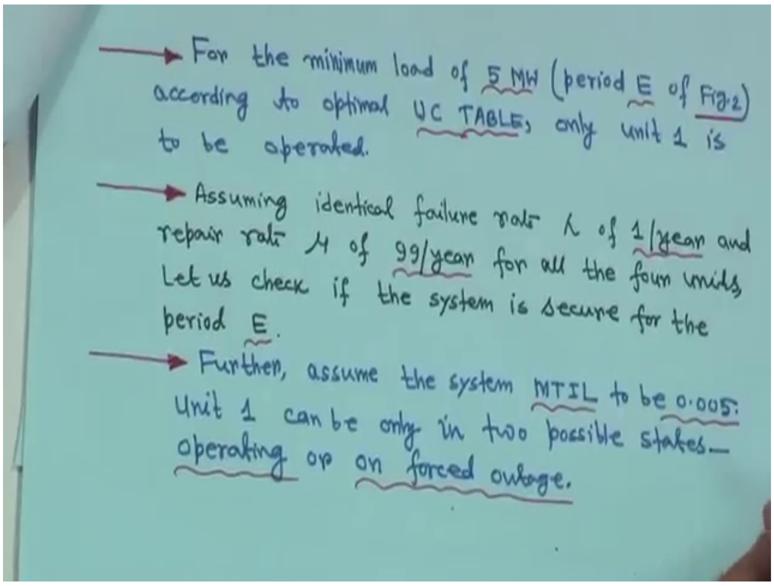
So, how we will do it? For example, suppose this is actually your unit commitment table this is that optimum unit commitment table this has been given. So, after unit commitment suppose, this data is given to you. Suppose, this is that unit commitment table how it operates we have taken a very ideal case this is the load curve ABCDE this is I have forgotten to write this is E and this is F, right. ABCDEF so each each load level we have taken it is a 4 hour each. So, total 24 hours this is time. So, ABCD period is given.

So, at your at when peak load when a is equal to 4 peak load, right. Sorry a this 4 hours when this is a peak load A period it is 0 to 4 say first 4 hours. It is may be for mid noon to your what you call next a mid noon it is not like a 0 hours it is some time, right. Something is taken right? So, so question is that, a that during this period that all the units are operating all the 4 units are operating, but during B period it is 15 megawatt all 3 units are operating and one it is off and for your when 10 megawatt, right.

With C period, only 2 units are operating and when D period again it is 3 units are operating it is not operating and E period only one it is operating with 5 megawatt and A period only 2 megawatt is 2 units are operating because it is 10 megawatt is a ideal case I have taken, right? And this is unit after unit commitment say dynamic programming and whatever method this is your unit commitment table and every load level this is load level a load ABCDEF, right and this 24 hours load level is taken.

So now, everything is written here consider a 4-unit example daily load curve for this system given in figure 2, this figure 2 and this is a table. Economically optimal unit commitment table for this load curve is given in this table this is also given corresponding to this load curve and let us now check, if the above optimal unit commitment table is secure in every period of the load curve, right?

(Refer Slide Time: 45:17)



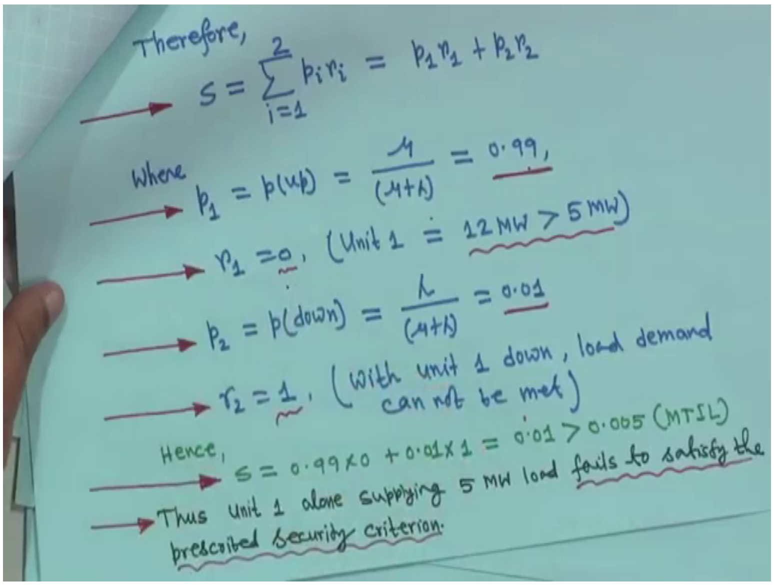
Whether it is not so, what you will do is; for the minimum load of 5 megawatt first I will check minimum mode load. For period E of figure 2 this is the minimum load 5 megawatt this is 5 megawatt and that is period E, right? According to the optimal unit commitment table only unit1 is to be operated after the unit commitment table that only this is the period, only this unit is operating only 1 unit, right. That is unit1 if this is unit number unit1 is operating other units are off right.

So, therefore, assuming identical failure rate for the all the units we are assuming their failure rte is identical. This is lambda, lambda of 1 upon per year, right. And repair rate mu will be 99 per year, right. This is your failure rate and this is your repair rate. Some arbitrary data has been taken right?

So, for all the 4 units let utility structure check if the system is secure for the period E; that means, what does it mean that for unit commitment that only when load is 5 megawatt this only 1 unit is on and this table actually prepare from the same data earlier shown minimum generation is 1 megawatt maximum is 12 megawatts, it is 5 megawatt.

So, 1 unit is operating now. So, further assume that this data has been given to you 0.005 MTIL is given, right. I told you earlier, right. That is your this, this is a decision from the management that maximum tolerable insecurity level MTIL right. So, this data is given to you and you have to check S is equal to pi ri. So, unit1 can be only in 2 possible states either operating or on forced outage; that means, it can operate or forced outage means 5-megawatt load cannot be supplied because all the units are off.

(Refer Slide Time: 47:03)

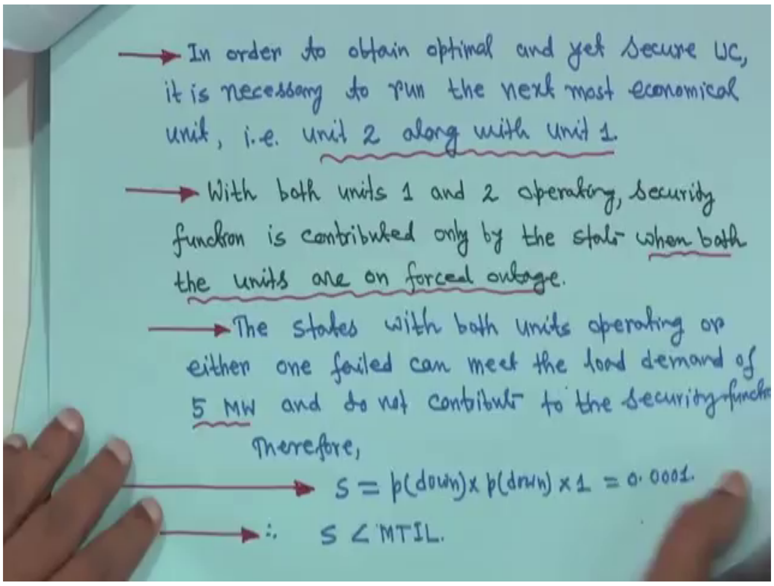


So, in this case, this s is equal to 2 units are there we have to check 2 for 2 units it is a 2 states I is equal to one to 2 p i r i is equal to p 1 r 1 plus p 2 r 2, right? So, in that case what will happen that p 1 is equal to p up, right. 2 states will do. So, it is mu upon mu plus lambda mu plus lambda is equal to your 100 is coming and this is 0.99 because data is given here mu is 99 per year and this is 1 per year. So, p 1 r 1 is 0 because unit1 is 12 megawatt which is greater than 5.

So, generation is what you call much more than the load right. So, r 1is equal to 0 and similarly p 2 that down time is lambda upon mu plus lambda, that is 0.01 because lambda is actually one per year. So, 1 upon 100 so 0.01 So, r 2 is equal to with unit 1 down. So, r 2 is equal to 1 and load demand cannot be met. So now, compute S S is equal to then p1 r1 that is 0.99 into 0 whatever we have got here p 1 r 1 then p 2 r 2 plus p 2 r 2 0.01 into point this thing.

That means, 0.01 greater than 0.005 that is your this MTIL value therefore, thus unit1 above your alone supplying 5-megawatt load fails to satisfy the prescribed security is criteria because we have to bring this one below 0.005; that means, although you have got unit commitment, but you have to check the security also right. So, fail to satisfy the specified prescribed security criterion because a s actually whatever value of S it should be less than equal to MTIL then, what we will do? We will choose the next unit.

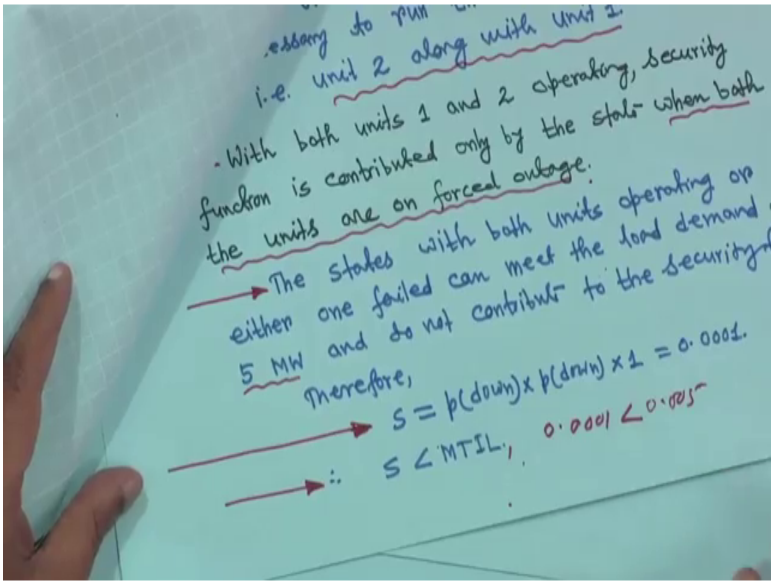
(Refer Slide Time: 48:45)



So, in order to obtain the optimal and yet secure unit commitment is necessary to run the next most economical unit that is unit 2 along with unit1, right? Now with both units one and 2 are operating security function is contributed only by the state when both the units are on force outage. So, in this case, the state with both units operating or either one failed can meet the load demand of 5 megawatt and do not contribute to the security function therefore, that S is equal to can be taken as p down into p down into 1, right?

That means, it is it will be actually; that means, this one you are what you call? That r is equal to your, what you call that 1 right. And you have to consider your what you call? This is another unit we are putting. So, it is power is 0.01. So, 0.01 into p down into p down So, 0.01 into 0.01 so, it is point triple naught1 and therefore, this this is actually this says actually your less than your what you call 0 0 0 1 less than your, what you call?

(Refer Slide Time: 49:45)



What you have defined that is 0.005; that means, 005; that means, your criteria is satisfied.

So, just nothing but put at unit and follow the same procedure and this is for classroom purpose only I have made it. In reality, many issues are there many constants are there, right. So many issues are there. So, so with this with this this power system engineering course just 1 or 2 minutes briefing then it will be this thing. So, I will suggest, that you please go through all the notes and everything those will listen to the last lecture, I will tell that particularly that distribution load flow everything has been given in detail, right?

So, please, right down everything and solution methodology is also you know very easy, right. And for that a lot of report has been given to generate that write those thing and everything was made all hand calculation everything all the numerical everything all by your this, personally right? So, if you have any if you find any calculation error or anything you please send the mail or put the question in the forum. We will give all the answers to you, right. I mean all the answers and whatever has been made starting from your insulator, then your cable, then everything.

Only one thing I forgot to show you that particular in the coronal loss that is insulator thing I showed you that for b's your b type your connection for insulator, I will show you the how corona happens some good photograph and I completely forward to show you that photograph. If possible, some corona photograph in the forum or somewhere I will ask my t a's they will upload it, right. They will scan it and upload it you can have a look that how corona happens, I forgot it I later I recall I forgot it right?

So, rest of the thing hope things will be quite easier to you and please just go through it. And if you have any doubt or anything you please send the mail I will reply or I will ask my t a's also to reply on behalf of me and this is this is very 30-hour course means actually in the classroom. You know that it will be nearly doubled, right? Because here nobody is sitting in front of me and, but I am imagination I always think that students are sitting in front of me and that way that way I try and if you have any clarification or anything of this course, please send it to send mail to me, right?

So, thank you very much and I do hope you will you know you will listen all this video lectures. So, thank you very much.

Thank you.