Power System Generation, Transmission and Distribution

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Lecture No. # 33

Optimal Unit Commitment

We start with the lecture number 33 rd, Optimal Unit Commitment. I have already explained you what is unit commitment? Say for example, there is a load. Now that load varies from hour to hour, day to day, week to week. So, you cannot have a permanent solution which units should be on, which units should to be off, it varies from load to load.

Suppose there is a given load, now we have to find out which units of the power station should be on to tackle that load, to take up that load and which units should are not required should be put off 1, 0 - available, not available; working, not working. This is the binary situation which solution you to find out, and this is called unit commitment problem solution.

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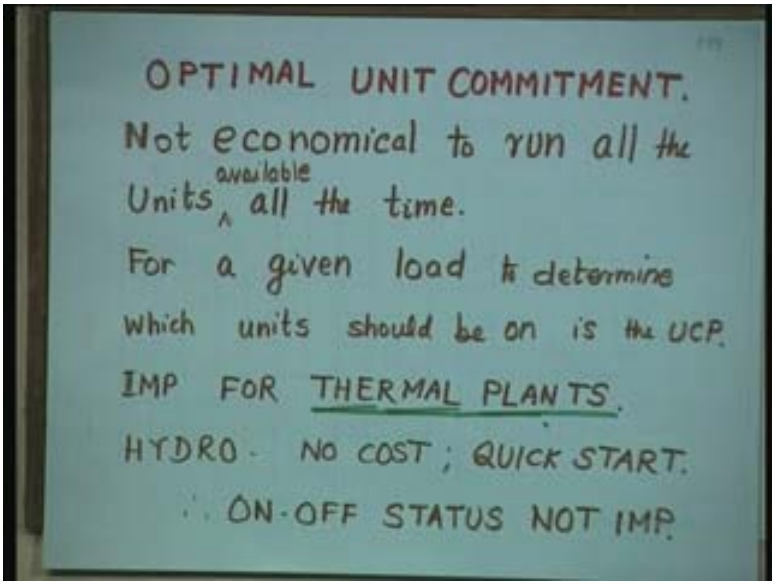

Now the… It is not economical to run all the units available all the time. For a given load to determine which units should be on is the unit commitment problem. Now why this problem is only important for thermal power plants, it is not important for hydro nor it is important for nuclear. Let me first explain you why it is not important for nuclear.

So, nuclear power plants are base load power plants. There is hardly any control, which you can have on nuclear power plant. If you remember recently the prime minister is inaugurated 500 mega watt unit, nuclear unit fast breeder reactor in Kalpakkam near Chennai. So, once it is on, it remains on and it supplies the base load. Base load explains you earlier is a load which is therefore, all the time. So, there is no variation. So, there is no variation in this nuclear power unit a maintenance period.

Similarly hydro, there is no fuel; there is no money, in world in the fuel. Fuel is a water, water is available free of charge. So, there is no optimization involved as and when and then the main reason is it is a quick starting units. Hydro units do not take much time to start. So, where is a question now a priory planning done? This is just available to you. And that is why thermal units on the contrary needs leave time of 2 to 8 hours depending on whether the boiler was coal, whether the coal is just put, there is no stream, you have to start from cold start, hot start, etc, etc. And that is why this problem is important, only for thermal power plants.

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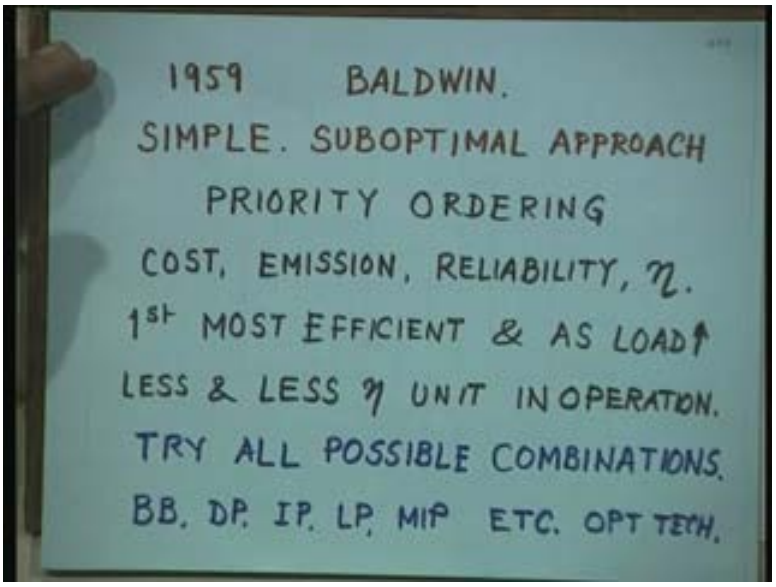

The first paper in this area came in 1959, the author was Baldwin. He just applied simple suboptimal approach. He did a priority ordering like you have priority ordering in a class who is the best student, the next best, the next best and so on. And normally teachers should scattered to the last student in the class. If he understands, it is assumed that everybody is understood. The class is meant for all the students not for few top students.

So, here what they do, they create a list of all the units available in a particular power plant, let say Indraprastha power plant, there are 5 units, let say Badarpur power plant, there are 5 units. You know your units very well. So, you can always which is the best unit, the next best, the next best and then last best one thing can be CGPA, other can be all round performers, sports, extracurricular activities, co-curricular activities, dramatics, whether he is taking part in union is students you know activities, SRA, whatever it is.

So, similarly, here the various figures of merit are efficiency which is the most efficient unit. No.1. Next can be cost, which is the cheapest unit. It other alternative can be pollution where you use provided you use a different fuel for different units. If you same fuel for all units pollution thing is gone, because it will create similar pollution. But if you have a different fuel for different units, one is oil, one is coal, third is let's say gas and so on. Then you can have one parameter as pollution.

So, these are various reliability, the unit has never faded. So that is your most reliable unit, have it number one. So, first number one will take load, if still load is left, then second, still some load is left then third, no load is left, fourth, fifth, take rest, zero zero. This is the sub optimal approach.

Though it is so obvious, but yet it took the Baldwin to write a paper and present it to explain to the world, look this is how we should work. It's however a sub optimal approach; it's not an optimal approach. That is called priority ordering. So, this is what I have written three things cost, pollution or emission, reliability, efficiency. I have already talked about all the four. First most efficient as load increases, less and less efficient unit is put into operation, right.

For example, how do you do your expenses? Suppose you got your scholarship, first is most important expanses, fees, otherwise you will be out of IIT, then food, otherwise you will not be given food, I do not know what are the rules here, room rent, electricity bill then comes your books, who read the books anywhere or other expanses, restaurant,

cinema etcetera, etcetera. So, this is a priority you have fixed for yourself, nobody else it is you who were to fix your priorities. Try all possible combination is one option which will be the most optimal. Try all possible combination, first unit, second unit, second unit, first unit, you must rate permutation combination in your high school or middle school or wherever. But best is to apply optimization technique.

If try all possible combination is like presented doctors do. Blood tests, urine test, full test, x-ray everything. Because they get commission or they won't take any chance. They can be second school of thought also, they may not get commission yet he want to please say, tomorrow something happens to student his jobs is in danger. right study students paper you must seen wrong injection was given to a student anytime not student, to a boy I wish have you read that news? Times of India, third page, student's photo not student, some boy's photo he must be student somewhere, anyway so optimization techniques. Now I have already told you several times, what is optimization? Optimization field started because of Second World War. Did I tell you this story? So, one yes is there. Others who don't remember can go to human ask.

There was a leader who came for giving lecture, he said how many people know what I am going to speak, some half the hands come up. How many do not do not know what I am going to speak, another half. Those who know should tell to another people those who don't know. So, this gentleman knows what I said I said what Churchill told to his scientist and engineers. He called meeting and he said, war has started, I have limited resources though the united kingdom was rolling the whole world, there was no sunset in British empire those days, Newzealand sun rises goes to right up to West Indies and Canada you know. So, 24 hours there is the sun in the British Empire.

So, he says, you start working towards optimization, I do not want people to die; I do not want people spend more money, yet I want to win the war. So, objective function was winning the war, subjective minimum casualties, minimum expanses. This is an objective function. Here you want to satisfy a load, this is your problem. Objective function is with minimum cost, with minimum pollution, with maximum reliability. These are the optimization problems, subjective the load has to be met and etcetera, etcetera.

So, BB is Branch and Bound technique, DP is Dynamic Programming technique, IP is Integer Programming technique, LP is Linear Programming, MIP is Mixed Integer Programming, etc. If you have done the optimization technique course and electrical there are known course, power system optimization. Have you done that courses electrical view, but that's for power system, not for control. You are in control, but you do optimal control right that is similar to that.

You have then you know some j is there, find calculus of variation turn you must our rate well much; you know, conditions and principles of optimality. Now all those things they have done. Let's do only one method we do not of time only three more lecture left.

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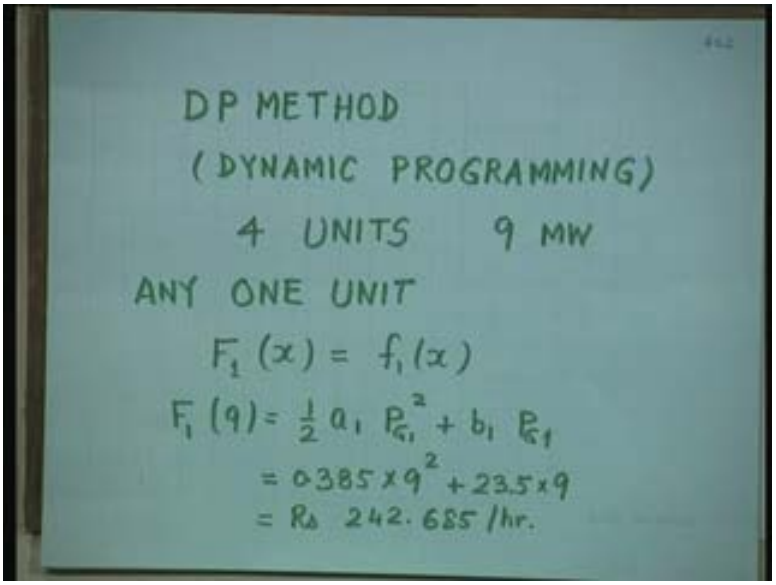

So, dynamic programming we will do. Now dynamic programming is of light as your control friends will know, when he have to take multi stage decision. That means, decision is not to be taken in one go. What are these; practically every problem in life has to be solved in stages. I do not thing like Maharashtra is 10 days are over they still solving the problem who should be the C.M. The aero plane, the pilot does not take the plane; I do not know how many of had travel.

Anybody?

Have anybody travel in airplane now. As on when you travel first time you will see, pilot does not take the plane to the height of 33000 feet or 11000 meters in one go. It is not

that the moment he takes of goes of 3000. No, he goes in stages, goes and then the clouds gone and further go of then stages. So, is a multi stage he controls in a way that eventually goes in to 33000 heights which is the most optimum height where we play, can go at the very fast speed.

Marriage, you do not just see and married, you first uncle will go then father will go and then some aunty will go and in olden days, the you know it is it is to be done in stages you should see what sort of house they live in, what is the qualification and so on, both sides, is not in one side. So, it takes time. Your studies, you don't study write from July 1 or August 1 to November 24th and whatever date till you exams last, the same tempo.

You till exam break then you start then you every rent you or whatever then Diwali whatever. So, you go in a zigzag fashion, you plan your way which subject to study more, whose teacher is lenient, which teacher is duff, what are it is fast call, what is that of gracing use to give you find out everything you know fast history and then you tuned accordingly your studies right.

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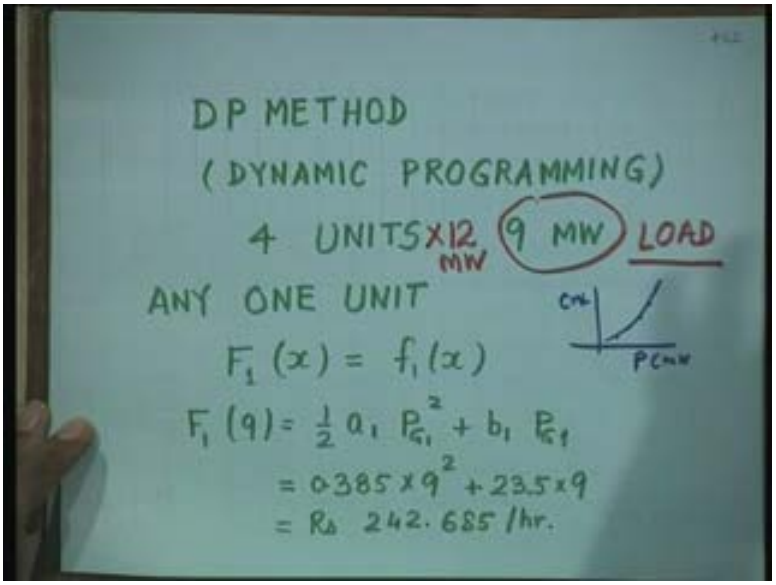

So, similarly, here I take an example of 4 units each unit is of 12 mega watt capacity, each unit is of 12 mega watt capacity and I have a load of 9 mega watt. My job is to satisfy load of 9 mega watt. This is the small township village, may be of 100 people and load is in 9 mega watt and 4 units of small. Now we are going was smaller units as I told you, dispatch system you know, distributed system.

I have already explained you, if not you can read the chapter one and that is very good thing for interviews. Normally interviews nobody will ask you, because nobody knows in unit commitments. Hardly anybody studied in commitment, so they will only ask you general things which are given in chapter one, new edition, third edition.

Let check any unit, random unit. F1 x is equal to f1 x this is only one unit. So, cost of that unit is a overall cost, there is no difference between the overall cost and unit cost, unit difference is one. So, F1 9 the formula is quadratic formula. Half a 1 P G square plus b P G, a and b are cost coefficients. We already see in last time how do you fit in cost curve there is they, just to recapsulate. This is the curve, this is your cost this is your P in mega watt and this curve, curve fitting we can have a quadratic curve and this is the quadratic curve, a and b are coefficients.

Curve fitting technique all of you know, numeric analysis the values of a's and b's are given on substituting that, so it is 0. 385 into 9 square, plus 23.5 which is the value of b 1 into 9, the answer is 242.685 rupees per hour for 9 mega watt, if you use just for in it, if you use, we can use because each unit has 12 mega watt each unit can satisfy 9 mega watt no problem. Here in this slide I am giving you the data. The 4 units the, if unit is on this question I asked in magnitude there is a minimum load which must come on if unit is on.

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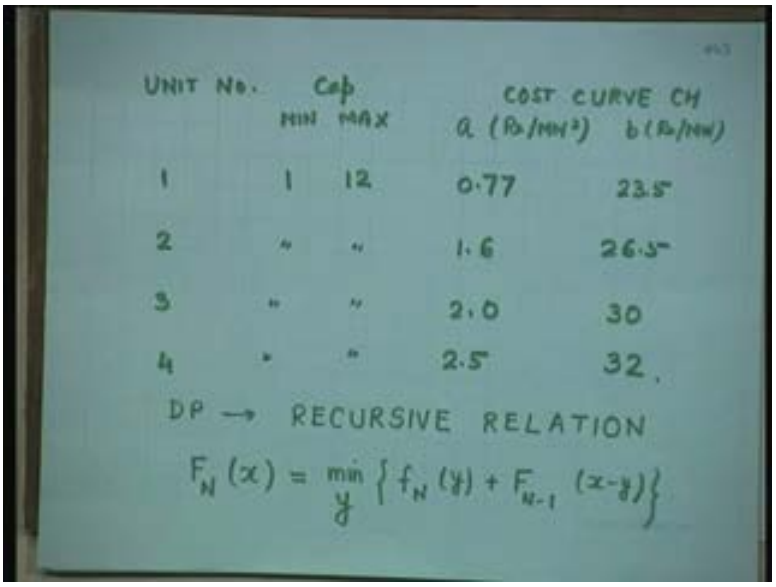

So, minimum load is one, below one should not be operated. Once it operate minimum has to be one which cannot be 0. I've already explained you the reason un earlier lectures maximum is 12 that is the highest capacity. Cost curve CH is given a and b 0.77, and 23.5 if you can see this and you are all intelligent, being IT students, you can say it is order of increasing cost. I have already prioritize the 4 units in order of increasing cost. So, it makes sense to use first unit to satisfy 9 mega watts. Now what is dynamic programming as a said, it uses it gives you recursive relation, ask your control friends and principle of optimality has to be applied right.

So, this is that recursive relation, which we have to write for anytime we use dynamic programming. F N x, what is the meaning of this? If you want to satisfy x mega watt by N units, this is the cost, is equal to minimize y, f N y start from N H unit, the last unit. Let last unit taken y mega watt load then remaining x minus y will be taken by remaining N minus 1 units. Submit regard to minimize it, optimization variable is y what should be the value, we should come on the N H unit, this is the equation. If you can solve it you will get optimization. I am not going to do here bellmen's principle principle optimality you can read dynamic programming whether in optimization books or in control books. These three guys are sitting here. They should able to explain you what is dynamic programming.

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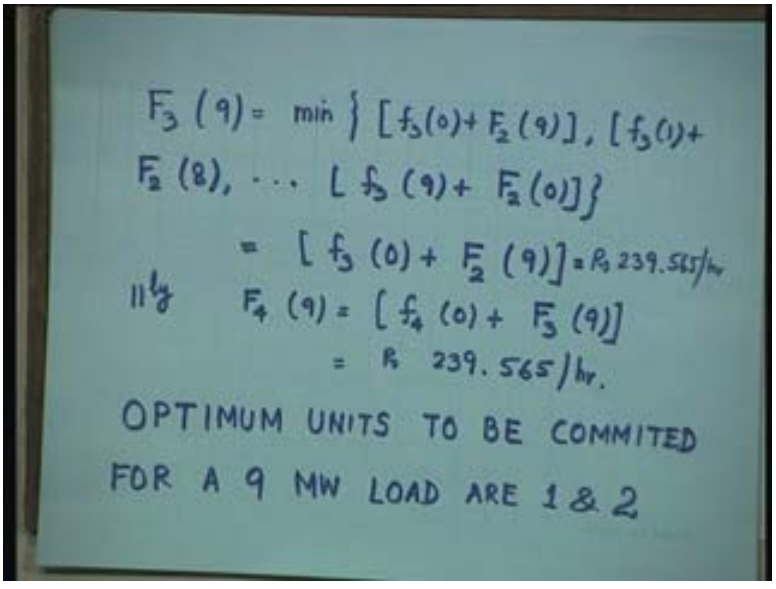

Now we are got a value of cost for one unit. Suppose we take two units and yet you want to satisfy 9 mega watt, now we use the step sizes 1 mega watt. It is up to you what step sizes you want to use, I want to use 1 mega watt for, which is sufficiently accurate and easy to calculate, you can calculate even by hand. So, what are the various possible combinations, second unit 0, first unit all the 9, second unit 1 first unit 8, second unit 2 first unit 7 and so on, last is second unit full 9, so first unit 0. These are the only possible combinations, once you say my step size is 1 mega watt. If you said 2 mega watt this will change, if you say 0.5 mega watt this will change, but as long as step size is 1 mega watt this is the equation you will get. Now you evaluate it.

On comparing term by term and computing we get the ideal combination optimal combination is 2 mega watt should come from second unit and 7 mega watt should come from first unit. And the answer is less than the first one 239, it was 242 if you recall 0.565 rupees per hour; that means, it is better to satisfy 9 mega watt by combination of 2 units rather than 1 unit alone. This is the clear message I get form this so for calculations. Similarly, we can compute F 2 8, F 2 0 all these we can find out for other loads.

Find out F 3 9, I had third unit for 9 mega watt. Same combination third unit 0 2 units combinations 9, please see the beauty here. Now you do not need to consider second and one units separately again because you already have the combination. This is where it differs from all possible combinations. Now, I am not going to separate first and two because I have already done that. The result is now available to me. So, I am not going to further segregate second and one no. I have already seen that. I have already got the answers. So, now, I say only third and block of first two.

So, f 3 1, F 2 8, f 3 9, F 2 0, luckily or whatever I find the result is third unit should not participate, as the common sense will also tell you, for 9 mega watt, what you need 36 mega watt on 12, 12, 12. So this one is enough, which is residently also takes reliability into account. What are the two units fail, still the consumer will never come to know about it. right your single unit is capable of giving 9 mega watt, because it is a 12 mega watt unit. So, the consumer should never come to know something has gone wrong in the plant. So, this also takes there is a built in inherent reliable operation guaranteed.

So, the answer continues to be 239.565; similarly, fourth unit nit less to say the fourth unit has no business to operate on it continues to the answers continues to be optimum units to be committed for a 9 mega watt load are 1 and 2.

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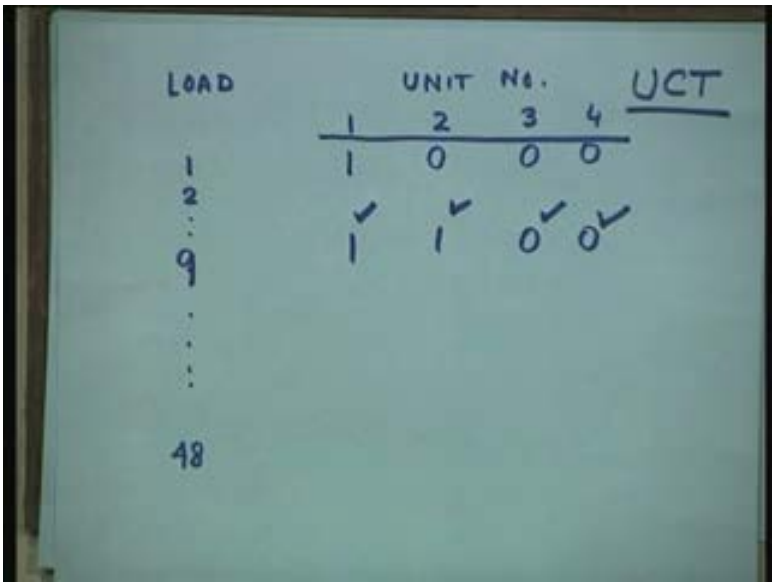

So, what are the total solution total solution I will get is load, unit number, 1 2 3 4 load is 1 mega watt, 2 mega watt and goes up to 48 mega watt. Because there are 4 units, 12 mega watt each, 12 into 4, you did in your first class or nursery I don't know which class 48. Such a huge table you are to hang in front of you. You are the control engineer; you are the energy engineer in load dispatch center. I have been telling you requesting you to go to the across the road the load dispatch center in fact control people should be more interested in going there because it is all control going on there. AGC and TG like that.

So, you can have a trip organized by your coordinator I am take coordinator whatever are you yourself and go there and just have a look at that. That will give you practical aspects how they are controlling frequency, how they are controlling economic operation, how they are doing unit commitment. All these whole power system course is going on there in practice. May be you may feel enthused interested in joining power grid and tpc, it's not necessary to join only IT what is IT? IT is a tool, you will apply IT here also and if you are doing good you will get money.

Now this can be 1 mega watt 1 0 0. I know only 9 mega watt solution it was 1 1 0 0, third unit not participating, fourth unit not participating; only first and second unit are

participating. So, this table is called unit commitment table, but is so big why not telescope it and do what.

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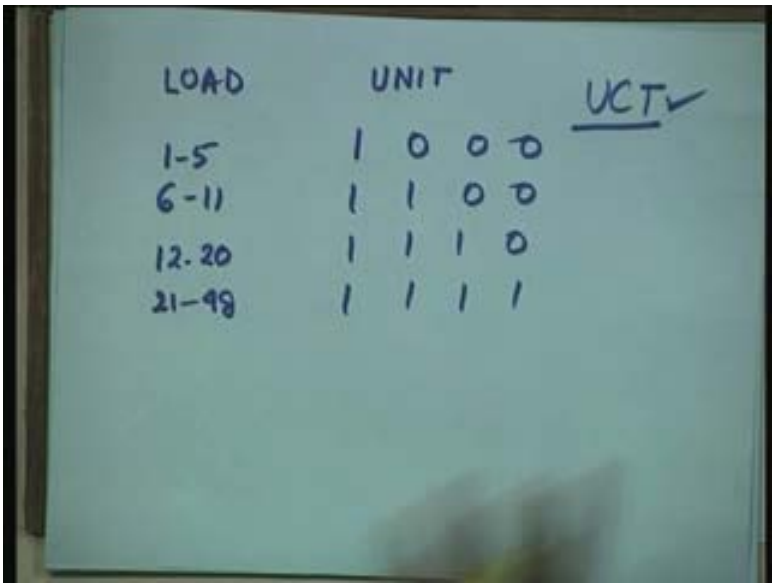

Do this. 1 to 5, 6 to 11, 12 to 20, 21 to 48, create a range; 1 0 0 0, 1 1 0 0, 1 1 1 0, 1 1 1 1, neat, compact, 4 by 4 matrix. After all, there is load at which second unit come in. There is a load at which the third unit comes in. There is a load at which fourth unit come in. So, what is the big idea having 1 2 3 4 5 6 up to 48. Let's combine, now this is the neat, compact, good looking, short, unit commitment table and this is this has to be computed once and for all. You don't have to compute it every day, as long as fuel price unit remains same, as long as no DA increase, as long as no maintenance charges increase, your operating cost units change unless until a's and b's change, then this will change your coefficients cost coefficients. So this is called unit commitment table using dynamic programming.

Sharing the load as 7 mega watt and 2 mega watt respectively with minimum operating cost of rupees 239.565 per hour.

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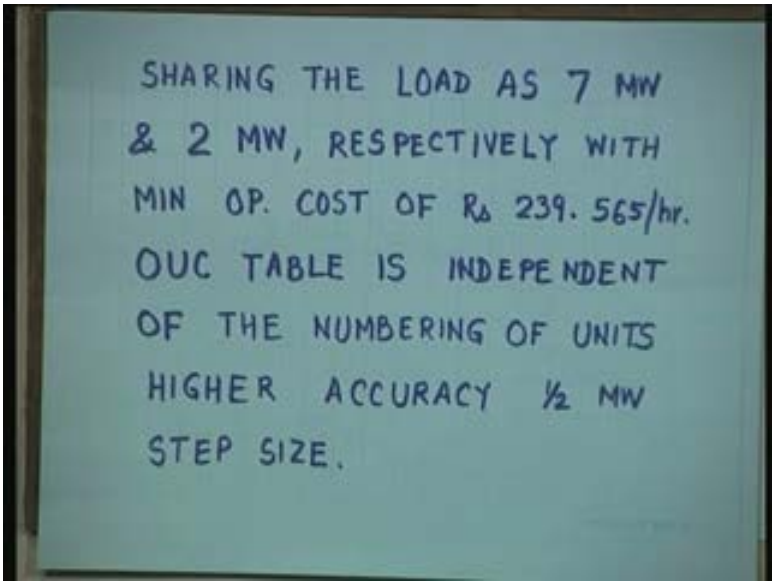

Now unit commitment table is optimal OUC means optimal unit commitment table is independent of the numbering of units. It's not necessary that like a load flow, optimal ordering you can order any bus 1, 2, 3, 4 without loss of generality. Suppose you order the most populous unit number one it will be 0 0 0 1, 0 0 1 1, 0 1 1 1, 1 1 1 1, it is alright that is. So, only changes will be...

So, is not sacrosanct that you have to order, but it gives you logic that you are most best candidate is number 1 and 2 number 3 number 4, when there is no problem at all. Higher accuracy means, well if you want higher accuracy half mega watt step size, 1 by 4 mega watt step size, depends upon you, but load is 1000 mega watt then step size normally chosen is 5 mega watt. There is no pointing in choosing it like it is madness. Though you have a computer is very fast still why do it, it is foolish. So, step size should be as for the problem.

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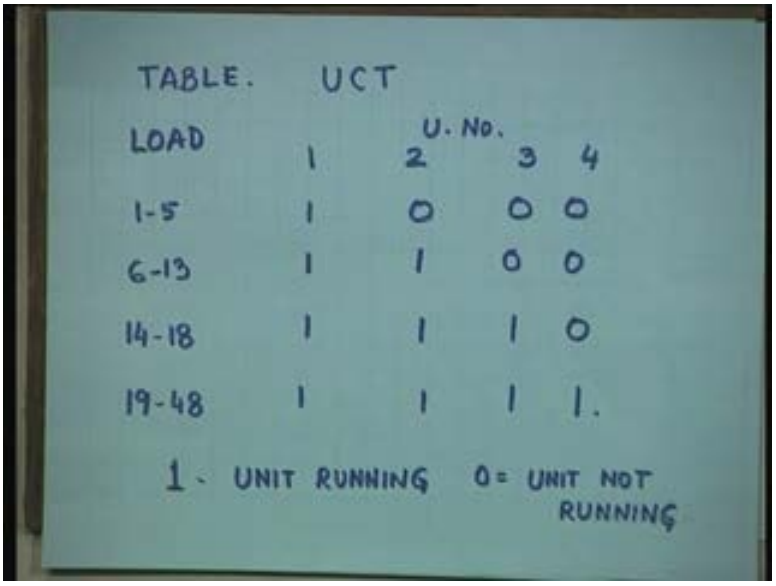

This is the unit commitment table which I have already shown you this are exact figures for that data. So, I will appreciate if one of you, some of you, all of you try to get this table yourself by writing some program c, c plus, c double plus. God know the how many pluses, whichever programming you know try to write a small program in c whether you get this results or not. And that is sort of an assignment, I give you with no mark just motivation is accrued you will feel happy I have what unit commitment result, and if you appear in Baldwin NTPC or NHPC or PHPC you can tell them this is what I have done what this here this the result.

So, this is the exact figures 1 to 5 6, I wrote some figures there. This is the exact which you should get. If you do not get it do point it out to me that that it will be my mistake. 6 13 14 18 19 48. 1 shows unit running, 0 shows unit not running, available, not available, working, not working, binary situation. Can you visualize in non binary situation? Yes anybody? That is called derating of units.

What is derating, anybody?

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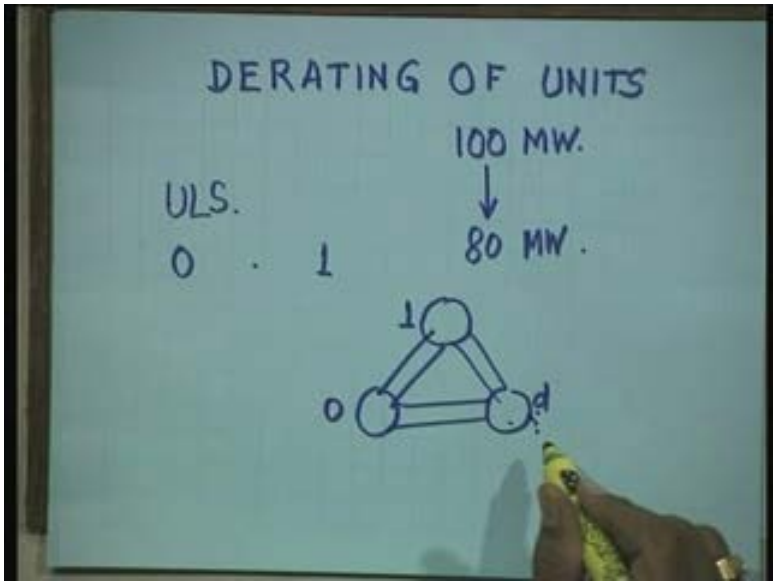

Anybody what is derating? The unit is of 100 mega watt, but it has become old like me, 60 years. I turn 60 on 7th October. Now once you become 60 means you are senior citizens. So, you are not supposed to as efficient as hard working as a 20, 21 whatever your age group. So, once Badarpur unit has already served for 10 years 15 years useful life time span.

I told you one word in reliability theory, Reliability Engineering there are M tech courses can be grant in IITs Kadakpur is one of them where the full placed reliability engineer center and there are M tech course here, there is a half center in reliability IT Mech, there and courses on Reliability, Maintenance engineering.

The useful life span of human being is 100 years bulb is 8000 hours, power plant is 25 years. So, ageing, now you can certainly stop ageing by certain cosmetics nowadays available even for gents. There was the time there were no cosmetics for gents I was at your age, but now even gents have lot of cosmetics, beauty parlors, almost equal space, ladies and gents and equal crowd. So, here also there are some cosmetics and that is called retrofitics, and you do certain things where as they get some fatality back. Of course, the part of maintenance you know.

Still that 100 mega watt made it to use 80 mega watt over a time period. So, it may not be 0, it need not be 1, it can be in-between and this is called derated state. So, it it any unit can work in three state, 1, 0 and derated. It will like cough and cold not fever, you

are coming like this gentlemen is not well, he is using handkerchief and you know he is half heartedly here sitting not does not want to miss the class also. But he is not fully fit, but I like can see, but unit is working not 100 mega watt working at 80 mega watt such a unit is called derated units.

I do not think any book gives this concept, but this is a practical concept in practical, otherwise you counted it 100 mega watt is available, but no it is only 80 mega watt available. There can be several derated states 60 sometimes you would not like to be working at 100 mega watt, that is different issue, that is a economic operation problem, how much power you want from that. Do not confuse that with derating. Derating is it is finished it is only 80 mega watt 12 hour 800 mega watt. So, there is a difference between two.

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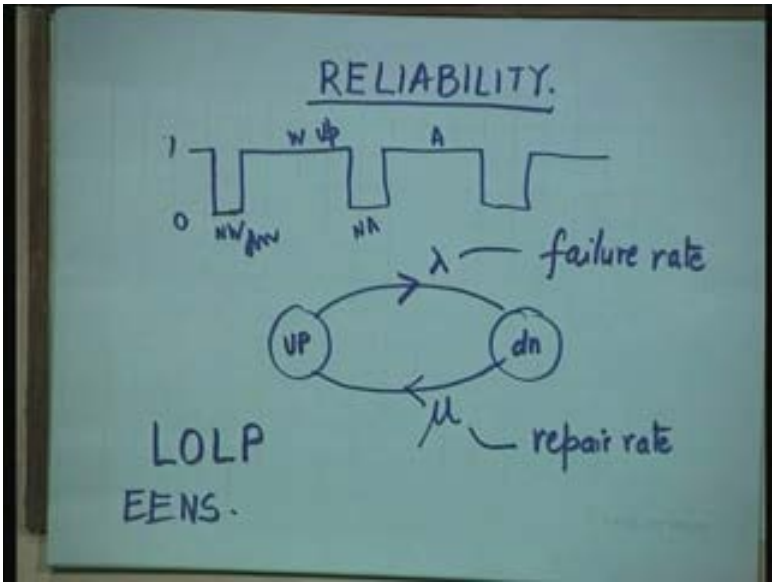

Then we come to reliability. Whatever optimal solution we have to found out is economic unit commitment. But I want secure or reliable unit commitment. Why reliability is suddenly become important. A customer is willing to pay more, if you guarantee in the power, because so much use to electricity. We cannot food, spoil is food which lying in the fridge, he wants to work in corporate sector which all your cooling heating depending on are in are in Europe are in America or Canada were temperature is very low. So, you need that compare your need your laptop to be on, all the time. That is why ups is there and so many things are there.

Now reliability, how do you compute reliability, how do you say that taxi stand is more reliable, because you have to catch of flight at 4 o'clock. At that point you are not worried about 5 rupee extra. You want a taxi driver to get up for yourself, come to your room or your house, ring the call button, sir time over on a flight. This is called reliability.

Another thing you are getting you are putting tell alarm in telephone cell phone, you are asking a neighbor in (( )), somebody goes for morning walk or somebody goes for early studies, which is very rare nowadays. Now only students' getup beyond 8 in nowadays students get up at 4 o'clock 3 o'clock is studying.

So, past history, what is this, how do you know for particular taxi stand is reliability, because in many reliable, I also get cap from there. So, you collect the data I am saying it is reliable and that is called the data has to be its performance chat. So, you have the, this chat for a unit. This is 1, this is 0, this is working, not working, available, not available whichever word you what to use. Please notice one thing in this figure the working period is got to be much much more than not working. Otherwise there is something seriously wrong this system.

If you see your number of days you attended classes, if it is, it has to be more than number of days you are not attended, unless until your objective function is not to attend the class, because after all you get everything book or everything is given in the best students class notes, they get circulated, they get zero asks and if you explains you something treat you want to. So, many things students do. If that is not the motivation you would like to attend the class then you are for you, you need to attend the class. Sometimes it may so happen, you are late, you are sick not attend the class.

So, this is on, off, available, not available, up and down, as reliability per longs is called upstate and down state. And they plot it like this. Up, down. Why do you go from up to down, failure rate lambda. Lambda is failure rate. Once go to down state, what is the job of system engineer? Get you repair team flinch to action immediately. So, that you come back to up state as early as possible, this is called repair rate. Lambda is called failure rate and mu is called repair rate. This rates will be available for each unit because each unit has the performance chat and from there only you can paradise them if you

reliability is your may name 1, 2, 3, 4 resolve the problem with not cost in mind, but reliability.

How do you compute reliability LOLP. Have you heard of LOLP, loss of load probability. How many days in a year you are not able to supply power. This is an index of a particular utility how good or bad that utility is. How many days didn't you get in milk? That is reliability of that person would gives milk it a do you abstract. You said newspaper you got every day, one day we do not get newspaper you shout. Do not feel comfortable, you are that morning tea is no tea without a newspaper, you are custom you are tune, you are you know, what do you call, to having that one paper in hand and another cup coffee or tea in another hand. So, you feel miserable feel that the fellow fails to deliver the newspaper at your door steps.

Another index, accepted energy not served. This will give you the index of consumers annoys, here not able to serve the energy which is expected, this is your job. So these are the various , they are calculated then you categorize various utilities. And then you can calculate the unit commitment and call it a economic and securing. You just to combine the both I just given in the book you can see and then you will find that you will do it next time and that's the overall optimum, its economical as well as reliable or secure, security.

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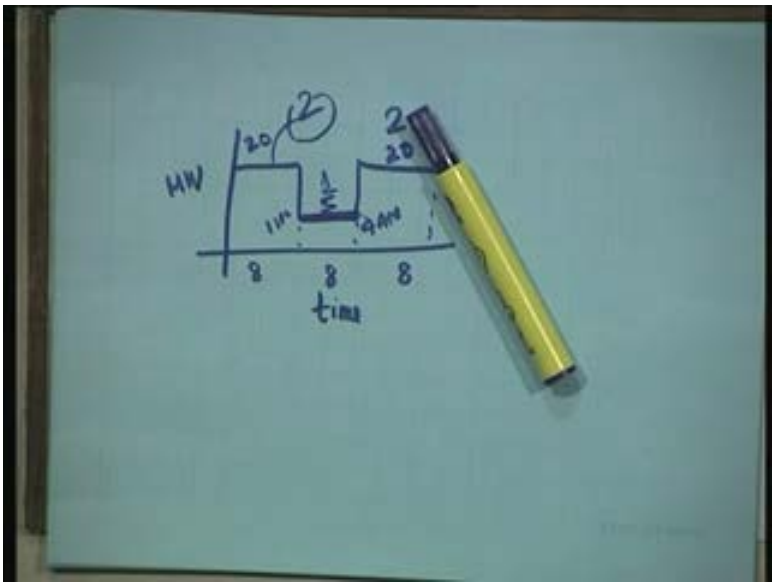

Next is let say these are 24 hours. This is the 8 hours, 8 hours, 8 hours. For simplicity I have drawn this load curve as sleeps of intervals. This is 20 mega watt, this is 5 mega watt again 20 mega watt; obviously, this time is night time, when Bombay they said Bombay never sleeps, let say Delhi, Delhi sleeps. So it is those 5 hours let us say 11 to 4 o'clock, taken 5 hours 11 pm to 4 am, load is minimum, people are sleeping, industries are closed, lights are minimal, only night lamp, even AC is also off, because of time, timer, you know people are normally conscious of extra expanses today. Just they want to sleep and then AC can be off, timer.

Now this is the very important concept, please look into this. I am Badarpur incharge; two units are working here, as for the unit commitment table. One unit is working for 5 mega watt, again 2 units are working here, because 20 mega watt back they are started with 4 am, people starting for morning walk, walking, some people started to 4 am to catch 8 o'clock office coming from Reweti, coming from Sonippet, coming from Mathura and so on. And throughout the world, people live in Pennsylvania and work in Washington DC, people live in New Jersey and come to New York every day, one million people go from New Jersey to New York. Reverse is not that much, like from Delhi to Gurgaon not many people, but comes to Delhi. Of course, now has many offices shifted, city bank many office in Britishers many offices in though may be slowly it will be reversed.

So, what is decision add take as a Badarpur head should I continue to run this 2 units even then this period or I shutdown 1 unit and restart, which is more better option, which is cheaper option, what happens when I run two units here for 5 mega watt it is definitely a costlier option. Because I'm unnecessarily running the second unit, I have to pay money for it. It is not free. But I say what, start up cost.

Otherwise I have to start the second unit again here which is not cheap, which also needs some money and that is called start of cost. So, I have to compare two case, case a, both units running in the middle interval, case b, when one unit is running one unit shutoff and you compare. And then we have overall unit commitment, economic operation, secure operation, overall optimality, considering start of cost is also given in the book, please read it. If you feel not you have not understood to though after this explanation should be clear a numerical problem is solved using the same three sub interval example.

And see for yourself how the unit commitment gets changed and if you do not follow then we will do it next time.