Power System Generation, Transmission and Distribution

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Lecture No. # 32

Optimal System Operation (Economic Operation)

Let us start the next topic, that is, optimal system operation, which is also called economic operation.

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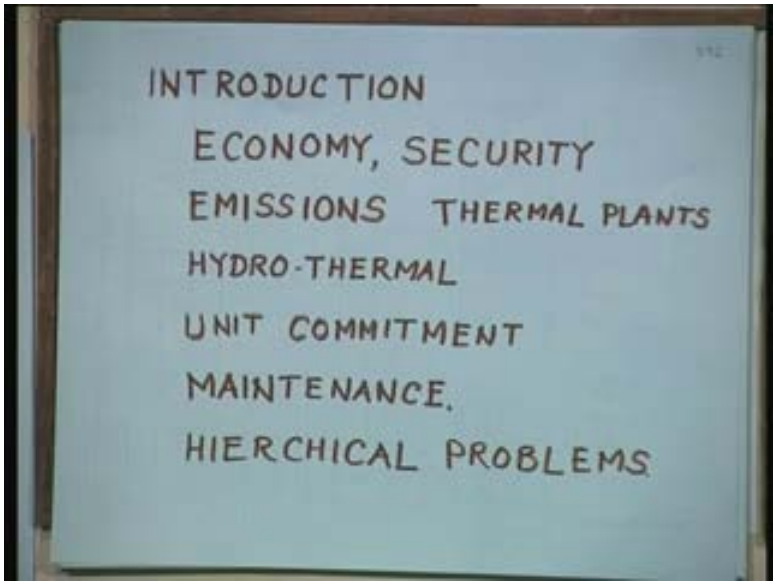

As I have told you in last lecture, while introducing this topic, that there are 100s, 1000s of load flow and we are not interested in all of them because in real life, in practical life, we want the best load flow; now, best is what? It is a subjective thing, as I have been telling you always, is it from economy point of view?; security that is, reliability; is it pollution? that is, emission. Now, are there only thermal plants or is it a combination of hydro and thermal or is it a combination of thermal, hydro, nuclear.

Let me tell you, as far as modeling is concerned, nuclear is same as thermal, in fact, that is also called thermal plant. Thermal means what? Anywhere steam is produced, now whether you burn coal, whether you burn natural gas, whether you burn petrol or LPG or

waste or you know, nuclear fuel, that is uranium, lithonium, thorium, whole idea is to convert water into steam and once steam is created, that steam can be passed to turbine and then through generator power is produced. So, hydro, thermal, nuclear is same as hydro-thermal.

What is unit commitment? That is a very important problem, normally not done even in Post-graduate studies. I will explain you what is unit commitment as we go ahead in this chapter. What is maintenance? As I have been telling you in India, we do not have maintenance culture; we hardly maintain anything including ourselves. As I told you, you do not walk, you want to take a lift, even youngsters like you are waiting on the road for 10 minutes to get a car and to get in, in that 10 minutes you can as well reach the classes, but that is a human tendency, hierarchical problems, these all problems are hierarchical or multilevel. You control people should know better what is the multilevel control, what is hierarchical control; you have to follow certain steps. As doctor comes to see you, he first checks your pulse, then blood pressure, then if necessary, the other, I know, other tests. Similarly, here the 1st problem, which a power system control engineer, let me put it, addresses is load forecasting.

Load forecasting is a very important problem even in control system or even in energy system. Unless and until you know the requirement, even in daily life, the housewife has to be told how many people are going to come for dinner, unless and until you tell how she would prepare the food for how many persons. So, requirement is nothing, but load. So, load has to be first ascertained, forecasted well in advance. Load forecasting is a separate chapter in fact, if you want you can read the chapter, I do not think you will be able to cover it in this class, let us see how much time is available.

You can have a short, very short term load forecasting, next 10 minutes how the load is going to change. Nowadays, on TV, all the time live temperatures come, gone are the era when only 1 news used to be there, 9 o'clock news, only 4 mega cities' temperatures used to come not so long ago on Doordarshan, now this tell you the temperatures of many cities all the time. So, very short term load forecasting, short-term load forecasting, tomorrow, that is 29th of September, what will be the load after a week, month, year, after 5 years, 10 years. You may ask me question, why do you need to know what will be load in 2012? The range is 2004-08 years, hence why I am saying 2012? That finishes the, 5th, 5 year plan to 12th 5 years plan. So, that is why, that year 2012 because in case

you need power plant in 2012, you have to start planning right now because the gestation period for hydro power plant is 7 to 8 years, that is the time we have. And even in thermal power plant you have some 5 to 6 years of gestation period. Gestation period is the time required before a megawatt is produced from power plant, from the time it is conceived, it is planned, it is decided the government orders are obtained, o.k. you can go ahead with a power plant, and that is why it is needed long term planning, very long term planning to decide the initiation of the, installation of new power plants, because you have to decide which place, which site, which fuel, from where you are going to get resources: is it world bank, is it non-resident Indians, foreign direct investment, or it is a private party. Nowadays, Reliance is busy in opening power plants in U.P., Ambanis. So, you have to decide. Even we are going to have a power plant in IIT, 12 megawatt, may be by the time you finish your PhD it will start, in case you join PhD or when you come here after 2, 3 years. 12 megawatt, that is guest fired, the USSR, former USSR is giving us some jet engines, mirage engines, which are useless to them, but then, we can produce power out of those, and Indraprastha Gas Company is willing to give us gas at a reasonable rate. I do not want to use subsidized because subsidy is a dirty word in reforms, you, you cannot, that is why they are reducing subsidy every year, gas price is already 350, yet there is a subsidy. So, how long government is supposed to give you. For example, your, your studies here are subsidized by MHRD, the actual expenses come per student is much more than your fees that you pay, so your education is subsidized by tax payer's money anyway.

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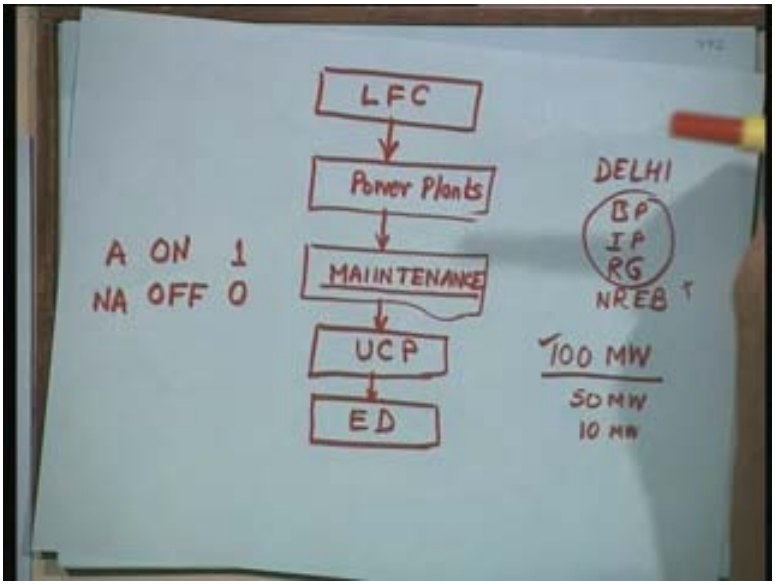

So, that is why, we need to do load forecasting and that is our 1st multilevel, is load forecasting problem. Once load forecasting is known, then you should know, what are the power plants that you have, which are going to supply this particular load? And out of these power plants, each power plant has certain number of units, like Badarpur has 5 units, 200 megawatts 3 unit and 100 megawatt 2 units. So, out of these units, let us say for Delhi you have Badarpur, you have Indraprastha, you have Rajghat and then, you get power from NREB. Now, which of these units, which are in your boundary you can worry about that. NREB is not Delhi sort of a state business, it is whole of north India. Now, which units will be on maintenance, you have to decide. Now, maintenance is very important, in fact necessary by law, that boiler should be maintained once in 3 years; otherwise, your license is not renewed, so it is mandatory, it is a legal requirement. So, those units, which are on maintenance, obviously they are not available to participate in power generation. If you are on leave you cannot attend this class, if you are busy elsewhere you cannot attend this class, that is, the people who are not outside will be inside. So, those units, which are on maintenance, cannot participate in producing power. So, this decision will be taken in this level, after that you have to solve unit commitment problem.

What is unit commitment problem? Out of available units, which units will be on and which units will be off, 1, 0 – available, not available. Why you want to put then, on and off status, we may not need all units? See, if you have your money in the bank, say 5000, that does not mean you should go to the ATM and get all 5000 out, you do not now need it. Why should now you get 5000 out, it depends on your need. So, you may withdraw 100 rupees, you may withdraw 500 rupees depending on need. Just because 20 units in Badarpur, Indraprastha, Rajghat, that does not mean we should ask all the 20 units to generate power, you may not need it. So, unit commitment problem stills you, for a given load whose units will be on and which units will be off. How it tells you, that is the solution of unit commitment problem, I am not going to discuss it today, I will discuss it when the time comes. Once we know the number of units, which are available and which can be loaded, the next problem is how much each unit should be loaded, that is called ED problem. Should it be, suppose it is 100 megawatt units, should you load into fully 100 megawatt or 50 megawatt or 10 megawatt or any other number? Depending on the need, depending on some objective function, economy, reliability, security, initial

voltage control, etcetera, etcetera. This ED will give you, which unit, which are available and willing to load, you, how much load will carry, that is solution will come from ED.

So, you can see, that whole power system control problem is a hierarchical one, hierarchical one, the moment, the way you pronounce or multi-level, 1, 2, 3, 4, 5 levels and this is a final solution, then you know, operator knows, which units will be on unit number 1, 3, 9 and how much time they will share the load, 5 megawatt, 50 megawatt and 8 megawatt, depending on their need, then this is the solution of the problem.

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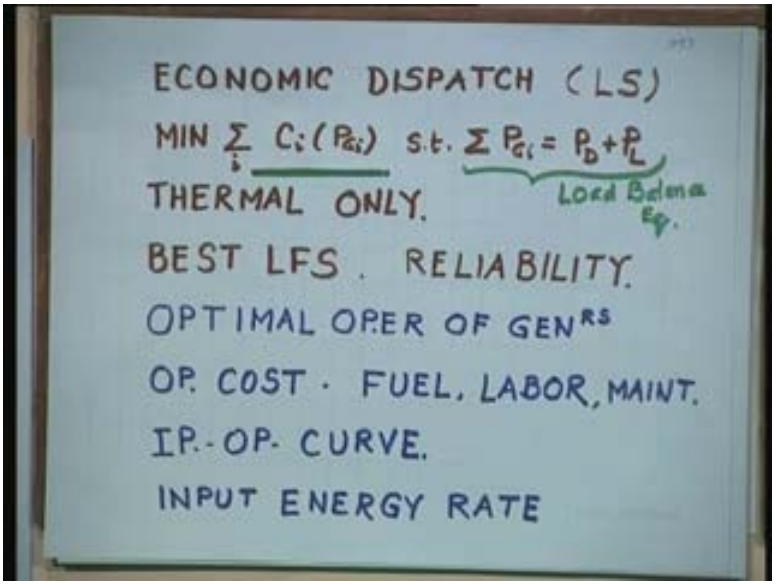

Let us consider economic dispatch problem. In some literature, in some authors, some experts call it load scheduling problem, others, it pronounced scheduling or scheduling problem, both are same, American pronounced schedules, we pronounce scheduling. So, load scheduling problem or economic dispatch problem is, the general problem is to minimize the cost of power generation, everybody is worried about the bill he has to pay every month or alternate months to DESU earlier, then DVB, now it is BSES, the private power company. Which bills comes to you, you may not know it because bulk, the institute pays for hostels, but individually, when you get settled in life, you may have to pay this bill and this bill is now quiet substantial. And there was a time when this bill used to be 30 rupees, 40 rupees, now it is 3000, 4000, 5000, almost equivalent to salary of somebody clerk, why it is so high? Because reforms, power reforms, now it is realistic bill, earlier it was highly subsidized, so you have to be very careful. That is why energy

conversion and energy management became quite important; you should not unnecessarily pay the money for energy, which can be saved.

What is this, the equation minimization of sigma of C i of P Gi, what is C i? Cost of ith unit for generation of real power P G at by same ith unit and sigma is all, i is for all generators subject to, this is a load balance equation, we have to generate only this much power, the total sigma, total power generation should be equal to total load plus losses. Losses can also be considered as a load. If you are a B.com or commerce student or management student, then whatever money is not coming, it is miscellaneous expenses, it is loss, loss to the company. However, it is an expense because that money is not with you, it is gone. So, this loss is no doubt, not a useful way of using power generation. All the same, there is a technical loss, there is a theft in the system, there is a leakage in the system; that is all losses. So, this equation must be satisfied subjective, is a constraint, is an equality constraint.

Now, we are talking about thermal power plants only, why not hydro? Hydro hardly has any cost because the fuel used is water, which is free almost. What is best load flow solution? It can be subject to reliability, subject to, I am repeating this point again and again, cost need not be only factor, depends on you, but general public understands only cost because they have to pay money at the end of every month, at the end of 2 months.

Optimal operation of generators, optimization of cost, cost function, operating cost consists of what? Fuel cost, labor cost, maintenance cost, after all there are guys working in power plant, you have to pay their salary, you have to pay their bonus, you have to pay their LTC, all these cost gets added to fuel cost and maintenance is also cost. When you go to garage for your repair of your 2-wheeler or 4-wheeler, you do not have 3-wheeler anyway, unless until there is some, one of the student who is physically challenged, then there is a special, our person Gadgil comes in that 3 wheeler. So, otherwise, a normal person, you need that way 2-wheeler or 4-wheeler, well, then you go to the garage for maintenance, it is not free unless until it is the first 3 coupons; when you purchase a vehicle then you get those things, that is courtesy or complimentary. But normally, any, any maintenance, any repairs will cost you money, that has also has to be operating cost. In fact, what we are minimizing here is a total operating cost.

Fuel cost is a major factor now. That means I must know fuel cost curve, input-output curve, input-energy rate. What is my fuel? My coal comes from where? Is it Jharia, is it Chandrapur, is it Assam or is it Australia? We import brown coal from Australia and you will be surprised to know, sometimes that works out to be cheaper than using Bihar/Jharkhand coal from Jharia or Dhanbad. So, we also import the Australian brown coal and use it for power generation.

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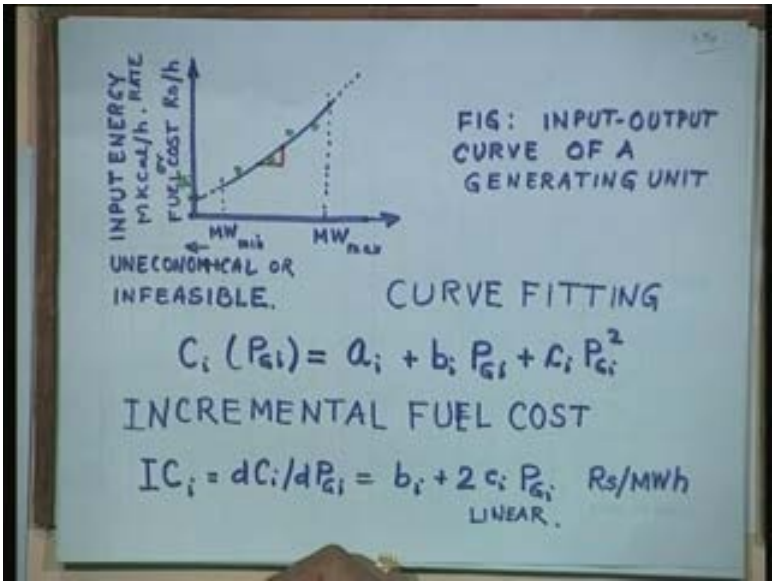

Let us see, what is this input-output business? Here is a curve I have drawn, the x-axis is megawatt generated, y-axis is input energy in million kilo calorie per hour, that is, rate per hour means, anything per hour is rate. Earlier, we used to use BT units, British Thermal units, but now we use I.S. units or MKS units, which is billion of kilo calorie per hour. If you do not understand this, you convert this into rupees and use fuel cost rupees per hour, which everybody understands. Once you say rupees, everybody understands what is rupees or dollars, pounds, euros, depending on which country's problems you are solving. If you read any American books, like Alguard and Stevenson and Burgan, all this will give you examples in dollars per hour; that does not matter.

Why there are 2, 2 limits shown here - megawatt min and megawatt max and within this range, there is a solid curve beyond this and below this dotted curve, any generator you take, if it is operating, it has to operate at certain minimum generation, otherwise what is a point in starting that (( )). If you are going in a car or on a 2-wheeler, you have to go on

a certain minimum speed, you cannot make it less than that, otherwise it will be highly fuel inefficient. I have seen many people, while talking to somebody, their 2-wheeler is already on, they do not want to (( )) because they do not want to use kick again, no physical activity they want to do, otherwise they do not think 2-wheeler is not going ahead, it is not consuming fuel, it is consuming. Similarly, you cannot have a generator on and yet no power generation, 0 power generation. Then, why you have to keep it on unless until it is use as a spinning reserve or hot reserve, that is, as soon as some unit fails, you switch on that load to this unit. That is a separate thing; these are called stand-by generator or spinning reserve or hot reserve or whatever. If it is off, it is cold reserve. That means, the car is in the garage, you have to open the garage, you have to open the car, nowadays 2, 3 locks, so it takes time and bring out of the garage and then, you know, if it is cold, it means sometime to start. So, it is called cold start of time, another is hot start of time. So, start of time will vary depending on the state in which the unit is.

And if it is, your sole is, even coal is lying at the station, you have to go the station, from that goods train you have to bring that coal, you have to put in pulverize unit, then you have to pulverize it, then it will come to the boiler. So, God knows how much time it will take. Even it will be technically infeasible to generate slightly less than the particular number, forget about economic. Similarly, maximum, if it is a 100 megawatt unit, you cannot generate 500 megawatt, otherwise a miracle, nobody will purchase, you know, bigger size units if you can go to, for sometimes yes, you can have a, you know, 125 percent rate you can work, but not all the time. So, you may go slightly more than rated value, but not for all time to come, otherwise you changing the rating, do not call it 100 megawatt, call it 120 mega watt if you are able to generate all the time 120 megawatt. So, that is why, there are 2 limits.

Now, how do you get this curve? By performing experiment what (( )) perform, input a coal, burn it, see what is steam output and then, how much power output you got and you get certain points as usual. When you do your experiment and then you pass a curve in your laboratory experiments, which you might have done in undergraduate, as well as, post-graduate. Some people draw the curve first and then draw the points, then that is a separate issue, we are (( )) discuss this in this class. So, we assume, that you have drawn the points first and then drawn the curve later; this is called curve fitting techniques. Now, in literature, numerical analysis course, there are chapters on curve fitting

techniques. Now, there are various techniques, which can be used, least square fit is the best.

Now, this is the equation, cost of power generation at ith unit generation, power is P Gi and if you feel, that you can fit a qualitical here, then this is an equation. Now, this is a model of the curve a i b i P Gi plus C i P Gi square. Here is C, there is also C, if you feel you get confused, you can make it d so that there is no confusion, otherwise this is small C, this is a capital c. But if you feel that you can get confused or my handwriting is bad, which you may not understand, use d here; luckily there are 26 alphabets in English language.

What is this a i? This is, this, this, the intercept on y-axis is a i, that means, this much cost you have to give or incur even if you generate 0 power. There is maintenance cost, there is labor cost and even to keep running generator at no load, you need steam. You must have done no-load test, no-load losses, why there should be losses and no load? Because they are transformer or a generator or a motor does work, does run no-load speed, in fact, no-load speed is highest speed. As soon as the load speed drops, whether, whichever motor it is, as you can see in your house, if you have started one lamp, if you start another lamp gets dimmer because you are loading the system by putting another lamp. Hence, this is a i and this is the cost. When P G i is 0, then you have P i P G, this is obviously a question of second order equality question.

What is incremental fuel cost? Incremental fuel cost is very important term, that if you add delta x in generation, what is the increase in fuel cost, that is, incremental del C by del P G or d C by d P G. So, I take a 1st order derivative, I take a partial derivative, partial differential equation to my (( )) Gorakh Prasath book or (( )) you know, complete total differential equation, full differential equation d C i per d P G i partial can be converted to fully differential, why? Because the cost in Panipat is nothing to do with Sonipat. So, partial differentiation can be made full differentiation and this is equal to a i constant 0. This is b i and this is 2 C i P G i rupees per mega watt hour. If this is equality, obviously this becomes a linear one order low order and hence, this curve I have plotted.

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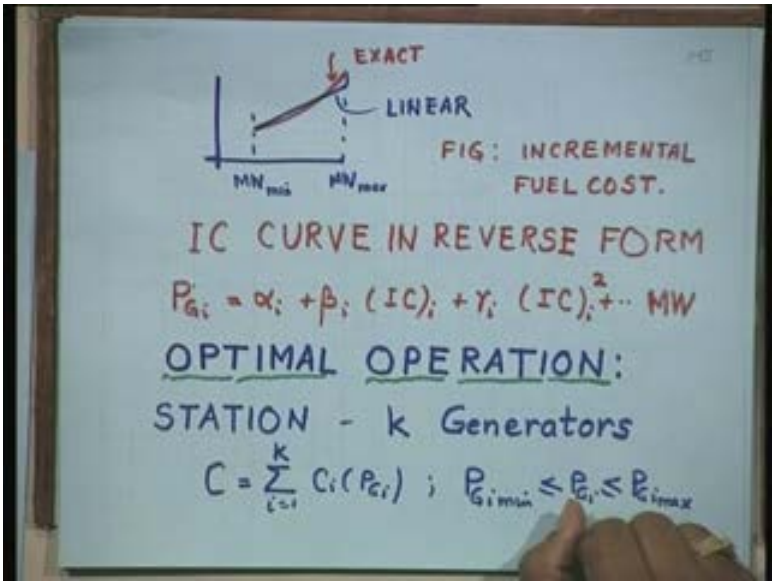

In the next slide, if it is exact, it will be a non-linear because your original equation is not quadratic, you are making it quadratic; it can be cubic; it can be any order depending on a particular power plant. Similarly, here, if it is not quadratic, the 1st order less will also be non-linear, but if it is quadratic, this will be a linear curve. Again, we are interested in drawing this linear curve between 2 points, megawatt minimum and megawatt maximum. I have already explained you in detail what is minimum limit and what is maximum limit. So, this is the figure drawn for incremental fuel cost, some people call it IC curve, incremental cost curve. If you want to draw this curve in a reverse form, so P G i is equal to alpha i plus beta i of i C dash i plus gamma i i C i whole square plus so on, in megawatt. Now, I am coming to optimal operation. So far any problem?

Now, I am going to apply optimization technique, I want to optimize mine operation. I am considering a particular station; let us say Badarpur and how many units are there? k unit and generator are used interchangeably, actually unit means what? Boiler plus turbine plus generator is called unit, a generating unit, all 3 together is called unit. Let us assume there are k units in Badarpur, so the equation to be minimized is capital C, cost, is equal to sigma i equal to1 to k C i P Gi subject to, again you see, the megawatt, minimum mega watt to maximum mega watt, P G i has to vary between P G i min and P G i max. Now, I do not need to explain this constraint equation, this is inequality constraint, the load-balance equation is what is equality constraint and this is inequality constraint.

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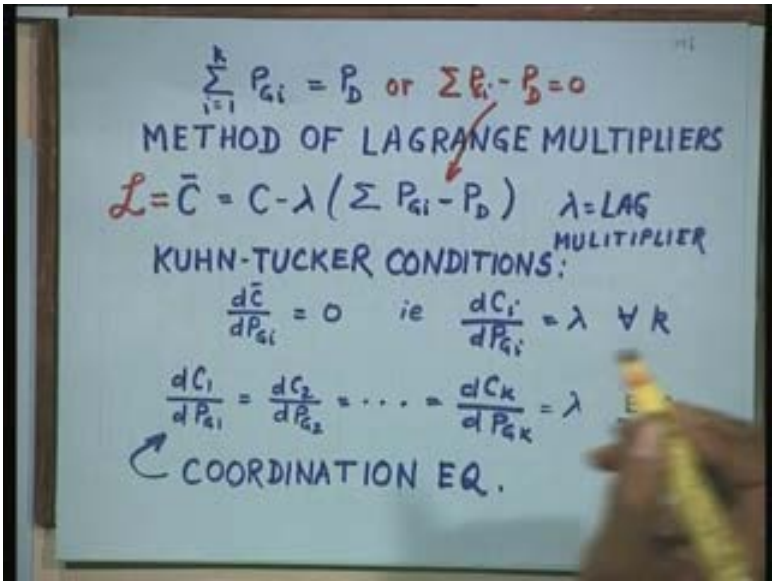

Here, this balance equation is no losses because they are only considering Badarpur, there is no transmission no transmission process. So, sigma of P G i must equal to load, which is coming on Badarpur. Who will give this value of P D load dispatch center? I requested you to go and visit load dispatch center across the road at (( )) Sarai and that is worth visiting. If you do not visiting your (( )) take in power system and even in control system is of no value. Well, all controllers are there, are control system there working beautifully system, so tell your coordinators, whatever, you go there and take a, later fix up an appointment and have 2 hour visit fixed. So, near, should not be case of so near yet so far. Kindly, make it before you leave this campus. So, you must visit there load dispatch center in (( )) Sarai.

What is method of Lagrange multipliers? This method was proposed by 2 gentlemen called Kuhn and Tucker. You will be wondering, why nowhere in literature any Ram, Sham, Govinda appear, do not, Indians do not work except Raman effect in physics or Jagdish Chandra Basu's that effect, that even the trees have life that he proved. If you, and if you, more, have you ever read anywhere, that GhanShyam Prasad equation or some, you know, particular theorem; I do know what we are doing, Olympics – 0, 0, 0, but for some Rathore, 1 silver, earlier some, you know, Leander Paes won 1 bronze in 96, 2000 some Malleshwari, somebody, some weight lifting, it is really shame for the country of what, 1000 million, 1 billion, and no manner, only cricket, that useless game,

waste of time. Only 8 fools play that and you get 50 lakh for playing such a game, anyway, I do not think, that is a subject matter of this topic.

So, Kuhn, Tucker, the 2 gentlemen who presented this paper in 1953 conference and they say, what you do, they form a Lagrangian, this C bar can also be written like this, you need not write C bar because that again gets confused with this C, so it is better to write like this. Lagrangian is similar to pound sterling without that dash, if you put dash here it becomes a pound sterling, it is not pound sterling, it is Lagrangian. Hence, how do you define this? The original cost function, which is C minus the Lagrangian multiplier times the equality constraint, this is equality constraint, this I can also write as, same thing. So, this is equation I have written here, lambda is called Lagrangian multiplier. This lambda has again 4 names in literature control system, people should know adjoint variable, coal state variable, Lagrange variable, I do not know whether you have read this; have you done optimal control? So, you must have done this, you kept on sitting quiet, you have also done it somewhere, optimization technique. So, this is Lagrangian multiplier Kuhn, Tucker condition says, that this, Lagrange, Lagrangian with respect to all, then add to give here.

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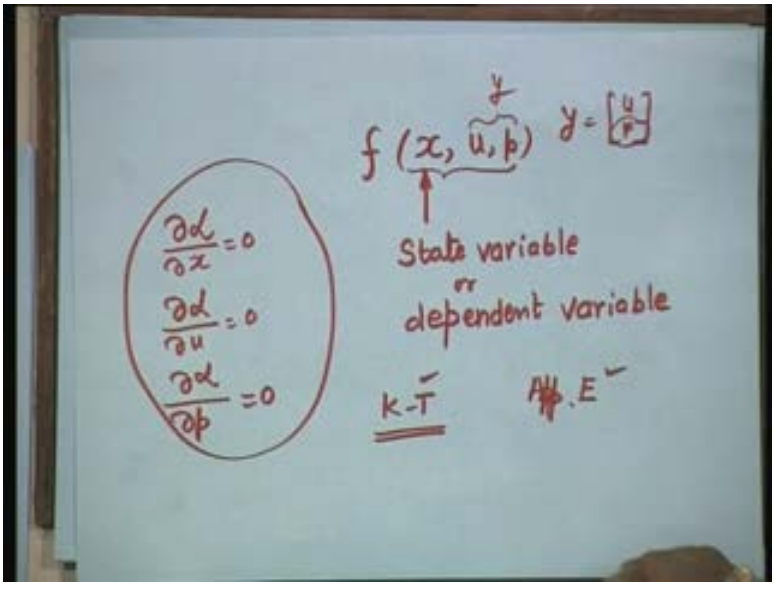

x, u, p function of let us some.., heavy breakfast today, heavy breakfast? Sleeping! So, what is x, what is u and what is p? x is a state variable or in literature it is also called dependent variable, like you are dependent on your parents, that is why you remain

dependent till you are 18, after 18 you may revolt, say I am independent today onwards. In fact, in foreign countries, in western countries, when you became 21, there are some celebrations, that means, you are liberated. This u and p together are called y independent variable, which can be controlled, but I have no money, no intention to control everybody. So, I control only a subset of y, which is divided into u and p. So, u is a control sub-vector and p is a constant or disturbance variable. I do not want to test this p, I assume it to be constant and you can make it more and more complicated, stochastic, white noise, color noise and so on, so forth. This control, people must have studied that, as far as I am concerned, p is a constant, I am not going to touch it, I am not going to control them, that is why, I have divided x, u, p.

So, the Kuhn-Tucker condition are indeed Lagrangian with respect to x should be 0, Lagrangian with respect to u should be 0, Lagrangian with respect to p should be 0, these 3 together are called K-T conditions and the details about this is given in appendix E in the book. In case you get more interested, you should develop, cultivate the habit of reading books, journals because you are a post-graduate student, you are not undergraduate. So, that is, even cow's essay nursery boy or girl also writes and people do PhD also. So, you might have done this topic in undergraduate, but here you do it in a different way, different style, so you should read what is a Kuhn-Tucker condition, what was the original paper of Kuhn-Tucker is given in this particular appendix, read it, understand it and that is what value edition.

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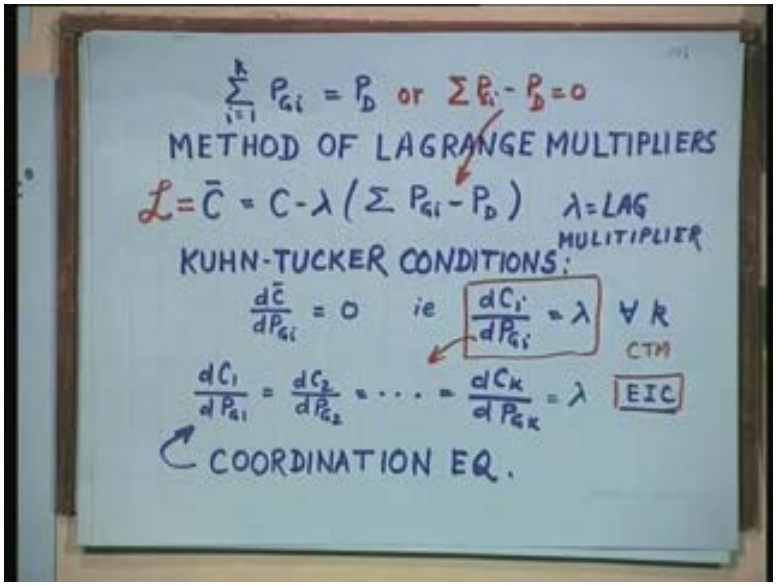

Here, unfortunately or fortunately, here we have only 1 variable P G, that is, u control. We have to control power generation, how we control by varying the steam input. So, only 1 derivative, put equal to 0 and if you solve this, you get the solutions. The next step, you get this solution, such a simple problem, del C i by del P Gi minus lambda 1, from here you get 1 minus lambda can be shifted to right hand side, you get this equation for all k, this is CTM; CTM means commit to memory. You can expand this equation into this, del C one, d C 1 upon d P G1 is equal to d C2 upon d P G2 is equal to d Ck upon d P GK is equal to lambda and this is called equal incremental cost, this is incremental cost, all such incremental cost when they are equal, we say we have achieved economic operation. This equation is also called coordination equation in literature. Suppose, I want to, I give you a question, derive coordination equation for economic operation, so this is the equation you have to derive.

I think, today we will stop here. Any problem, any difficulties so far? Anything you want to ask? No, then we will finish.