Economic Operation and Control of Power System

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Hello, good morning and welcome you all for the NPTEL online course on Economic Operation and Control of Power Systems. In today's class we will discuss about the continuation of unit commitment. In the summary what we have discussed in the last class is economic dispatch is a subset problem of unit commitment. Let us say you have 100 units possible to operate and meet out the low demand, what are the possible combination within this 100 units which can give a best economical solution that is what a unit commitment problem is all about. So, unit commitment problem is a more generalized version of a economic dispatch problem. Now there are certain constraints that need to be included when we solve a unit commitment problem.

So, they can be considered as here primary constraints enough units are committed to supplying the load. The most important constraint is whether there are sufficient units available to meet out the load demand or not. And second is this very important spinning reserve constraints. What it suggests? Spinning reserve means the total amount of generation available from all units synchronized that is spinning on the system minus the present load and losses being supplied.

That means there are some n number of generators required to meet out the load demand plus losses. Still above n number of generators how many generators are available in the system such that they can meet out the expectation of the system in case of a failure of any one of the generators. So what is the total reserve available in your system to meet out the emergency conditions, to meet out sudden changes in the system parameters. So, that is what is called as spinning reserve. Now it protects the network from an unexpected loss of one or more generation units.

Due to any reasons if there is a loss in of operation of any any one of the generators whether system still able to operate in a stable mode supplying the loads that is what spinning reserve deals about. Now there are certain rules with respect to the spinning reserve. Reserve must be given must be a given percentage of forecast at peak demand. Suppose there is a sudden change in the demand and it reaches a peak demand right. So, and what is the forecasted peak demand based on that there should be some percentage of generation available as a reserve to meet out the expectation of the system.

Now reserve must be capable of making up the loss of the most heavily loaded unit in a given period of time. Suppose there are n generators there is one specific generator which is of higher capacity or if it is overloaded considering n minus 1 contingency. That means if that generator is due to any reason taken away from the system whether still with the support of spinning reserve can be able to sustain the system in terms of maintaining the generation is equal to load right. So, reserves must be spread out around the system to avoid transmission limitations, bottling and permit parts of the system to run as islands. That means it is not that you know spinning reserve is kept at one corner of a system.

If that is the case then what happens there is also a thermal capacity of the line that need to be considered. So, if there is a loss of generators in another part of the network and due to the limitation of thermal capacity of the line if you cannot able to push in the power though you have reserve available. But you are not able to pump the power to another part of the network which is actually need of power due to the failure of let us say one of the important generators or overloaded generator then that spinning reserve has no sense right. Because it is situated or localized at one specific corner of the system itself. So, it should be distributed all across such that we can also take into consideration the thermal capacity of the lines.

So, reserve requirements is calculated as a function of the probability of not having sufficient generation to meet the load demand. Not only must the reserve be sufficient to make up for a generation unit failure, but the reserves must be allocated among fast responding units and slow responding units. So, you have fast responding units and slow responding units. We discussed about delta P by delta T the ramp up constraints. So, among those units you should you know pick up such units which have a combination of slow and fast responding units as a combination of spinning reserve.

Now, let us take a example to understand. It is a power system consisting of two isolated regions. We call it as a western region where there are three units which are running 1, 2 and 3 and there is a eastern region where there are two units, units 4 and 5. Now transmission tie lines join the regions and may transfer power up to a maximum of 550 megawatt in either direction. So, these lines are called as tie lines.

So, there are two isolated regions, they are connected using tie lines and the capacity of this tie lines is 550 megawatt in either direction either from eastern to western or from western to eastern region. Now, there are certain data which is given with respect to each region. In western region as I told there are three units, unit 1 the capacity is 1000 megawatt and unit output is 900 that means it is operating at 900 megawatt, but its total capacity is 1000 megawatt. Similarly, unit 2 is operating at 420 megawatt whereas its capacity is 800. Similarly, the unit 3 is capacity for 800 megawatt, but it is operating at 420 megawatt.

The reason being the total load to be met out at western region is 1900 megawatt and what is the spinning reserve available? You can see here, unit output is 900 so that means 1000 minus 900 is 100, this is a spinning reserve available and in the case of unit 2, 800 minus 420 is 380. Similarly, unit 3, 800 minus 420 is 380. Now total you have, what is the total spinning reserve available? 860 megawatt, 100 plus 380 plus 380. You have total 860 megawatt of spinning reserve available at the western region. And there is a regional generation of 1740 megawatt.

If you just add these three put together 900 plus 420 plus 420, it is 1740 that means the regional load is 1900, But the total generation that is brought out from this combination of unit 1, 2 and 3 is 1740 megawatt that means there is a need of 160 megawatt. So that is been taken from eastern region. Though western region by itself is capable of meeting out the load demand because total capacity of the western region is 2600 megawatt. The total capacity is 2600 megawatt and the regional load is 1900 megawatt. So you can meet out easily by western region itself but due to some reasons we found that economical operation or whatever.

So this particular case scenario suggests that there is a tie-line power exchange which is happening between eastern region and western region that means a 160 megawatt of load is been met out by using the power from eastern region. Now let us see what is the condition in eastern region. There are 2 units 4 and 5 and the unit capacity is 1200 megawatt. Capacity of unit 4 is and it is producing a power output of 1040 megawatt. So 600 megawatt is a capacity of fifth generator and it is operating at 310 megawatt.

So put together the total regional generation at this point of time is 1040 plus 310 which is 1350 megawatt. So what is the spinning reserve? Spinning reserve is unit capacity minus the unit output. So 1200 minus 1040 it gives 160 megawatt for unit 4 and 600 minus 310 which is 290 megawatt for unit 5. So total spinning reserve available is 390 450 megawatt, 290 plus 160 which is 450 megawatt. Now what is the regional load? That means that load which is dedicated to eastern region itself that is 1,190 megawatt.

You are generating 1,350 megawatt but the regional load is 1,190 that excess 160 is meant to supply the requirement of western region. Got it? So this gives the total summary, the total capacity, total unit power output you know put together eastern, western region. So what are the figures that is been given here? Now this is the operating scenario. Now let us determine the spinning reserve, now in case of whether the available spinning reserve is sufficient or not with respect to western and eastern region. So in western region, what is the generation of the largest unit which is 900 megawatt.

The largest unit capacity is 1000 megawatt but it is producing the power of 900 megawatt in western region. Now let us say this unit is due to any reason taken away. That is what is the objective of spinning reserve even if the most loaded unit is been taken away whether still you can meet out the low demand or not. Let us say 900 megawatt capacity is been taken out. Now what is the available spinning reserve? If unit 1 were to be lost and unit 2 and 3 were to be run at its maximum capacity then you can see here.

So what is the load actually? The regional load is 1900 megawatt. The regional load is 1900 megawatt and 900 megawatt is been as was supplied by unit 1 and that is been taken away. Now the capacity of, the maximum capacity of the units available is 800 plus 800, 1600 megawatt. So that means 1900 minus 1600 is 300 megawatt. What is the capacity of the tie line? This is 550 megawatt.

So that means the capacity of line is 550 megawatt. So the load requirement is just 300 megawatt in addition that can be easily met out. Now let us speak about the eastern region. Now generation of largest unit is 1040 megawatt. Then available spinning reserve is if unit 4 were to be lost and unit 5 were to be run at its maximum capacity.

So there is, then you can also see here. Let us go to the previous case. So this 1040 is been taken away. So what is the total capacity of the other generator which is 600 megawatt, right? So 1190 minus 600 is how much? Total 1190 is the load demand at the eastern region.

Now it comes out to be 590. What is the thermal capacity of the line? 550 megawatt. That means 590 is the capacity is in the eastern region, right? But the line capacity is 550. So you cannot meet out with the regional, you know, the power transform from western to eastern region. Though western region has a capacity here. You can see here, western region what is the load, actual load is 1900 megawatt.

What is the total generation capacity? 2600. That means 700 is there. It can easily meet out with the 590 megawatt of capacity required at the eastern region. But the load has, the line has a constraint, it can only pitch in 550 megawatt. So that means what you need is a spinning reserve of additional 40 megawatt of new generation within the eastern region.

This is what I told. There should be a spinning reserve distributed across the total regions, available regions. With the exception of unit 4, the loss of any unit on this system can be covered by the spinning reserve on the remaining units. Now, let us discuss other constraints as well. Thermal unit constraints. A thermal unit can undergo only gradual temperature changes.

Results in a time period of several hours to bring a unit online, right? So, every generator has its own thermal limitations. So, we will discuss about these two important times which is minimum uptime and minimum downtime. That means what is minimum uptime? It should not be turned off immediately. That means, let that us say due to some reason you come out with a case study where you suggest okay, let me switch off this unit for a specific time because load is coming down, I can switch it off. But after some time the unit may, the load may come up again, the load may come up again.

But if you switch off this generator, then you need also time to switch it on. So, then considering all this, you should see what should be the minimum uptime before it can be turned off immediately, right? That means you need to turn off the system immediately. In the first instance, there is a load which is coming down. Let us say this is a load profile which is coming down, right? What minimum uptime is suggesting? Let us say this is the load curve which is coming down. You want to switch off the generator at this point of time.

But your generator has some limitation. You cannot immediately switch it off. It takes some time to switch it off also. So, that is called as minimum uptime. It should be remaining in a system for some time before it can be turned off. You cannot allow it to turn it off immediately.

So, then you cannot consider that you need to turn it off because it is not possible to turn it off and meet out the expectation. That is minimum uptime. What is minimum downtime? Once decommitted, there is a minimum time before a unit can be recommitted. It is just the opposite.

Now, you have turned it off. The system, there is another generator, but it has the higher downtime. That means, now you need to switch on the generator and it takes some time to switch on the generator. It has some downtime. But you want to switch it on immediately. But the generator is suggesting it is not possible to turn it on and it takes more time to turn it on.

So, then that is called as minimum downtime. Minimum uptime is relevant to the turning off process. Minimum downtime is relevant to the turning on process. Got it? And there is another constraint which is crew constraint. In crew constraints, at a multiple unit plan, there is usually only enough personnel to start one unit at a time.

There is a limitation of manpower also. So, that is crew constraint. And a certain amount of energy is expended to bring a unit online. This is another important thing. So, if you turn off a system, it takes some time, some energy to bring the system to you, you need to heat up the boiler. It consumes some energy before it can come to online and start feeding the power.

So, what is the energy consumed from being turned off to turned on? You know, what is the total energy consumed before it starts feeding the power into the system? So, and to slowly bring up the temperature and pressure, what are the energy, the energy is consumed to bring up the temperature and pressure. And this energy does not result in any power delivered from the unit. And the energy cost is brought into the unit commitment problem as a startup cost. So, total energy required to bring the system from off state to on state and that whatever cost associated with that, that is called as startup cost. And startup cost, the startup cost can vary from a maximum cold start value to a much smaller warm start value if the unit was only turned off.

There are two important terms that you can observe here. One is cold start value and warm start value. What is cold start value? Now, cold start means the unit has turned off long before, long before and it is totally into cold state and there is no heat in the system at all. Now, it takes lot of energy to bring that kind of cold system back to the normal operation where it can start feeding the power.

So, that is what is considered as maximum. It means the cost associated with cold start value is maximum. Whereas in the case of warm start value, you just turned it off. That means still there is some energy left out in the system. So, the additional energy required to pitch in the generator so that it can start operating is lesser as compared to that of a cold start value.

That is what it is mentioned here. Now, warm unit is a recently turned off unit with latent heat that is near the normal operating temperature. So, there are two approaches, startup cost, two approaches available to treating a thermal unit during its downtime. You understand? Startup cost is associated with downtime, right? And there are two approaches. One is cooling and another one is banking. What is cooling? Allow the boiler to cool down and then heat it back up to operating temperature in time for a schedule turned on.

And banking means provide enough fuel to supply sufficient energy to the boiler to just maintain the operating temperature. So, I will give you an analogy with respect to a two wheeler. Let us say you are, we are all, we have all experienced. You are riding on a vehicle and there is a signal, right? There is a signal, there is just 30 second. You do not turn off your vehicle, right? You just keep it operating.

Rather, let us say the railway crossing is happening and in 15 minutes you feel like it is a long time. So, you turn it off, then turn it on. Because for a small time keeping the vehicle on is more economical because once you turn it off, it consumes more fuel to start the vehicle. You understand? So, if it is a long time, then it is better to turn it off. If it is a small time, it is better to keep up vehicle in the on condition.

So, that is what is cooling and banking. Cooling means you are turning it off. So, in a way you can easily come to a conclusion this is used, this approach is followed when there is a long time available you know for the system to bring it on. Banking means, so you keep the system in a on condition. So start up cost comparison you can see here.

Allow the unit to cool down. The start upcost function, this is the expression Cc into 1 minus e to the power of minus t shut down by alpha into F fuel plus C fixed. This is a expression associated with what is the total cost involved in cooling. You can see here alpha means there is a thermal time constant for the unit. That means every unit has its own time constant. It has its own time constant or inertia you can say before which it can come to a cold platform, totally cold platform.

That means if the thermal constant of the unit is very large, then it will try to retain the heat as much as possible. That mean it will not come to a you know low temperature immediately. It has some opposition. So then you can see mathematically also you can see here if alpha increases this whole expression value decreases. And this is multiplied by just fuel cost and there is some fixed cost also.

That means if thermal time constant of the unit is very large, then the cost associated with cooling is less. You understand that? Let us say there are two units. One unit has a alpha is equal to 1. And another I am just taking an example.

Another unit has alpha is equal to 2. So that means the time constant of the second generator is large compared to the time constant of the first generator. This is unit 1, this is unit 2. That means if you have to turn it off at all compared to cooling and banking, you decided let me shut down the system, completely shut down the system. And there are two units possible or available in your premises to turn it off.

You can make a choice between unit 1 or unit 2. Then it is better to make a choice of unit 2 because turning off the unit 1 requires more energy or in a way increases startup cost more as compared to the turning of the unit 2 where startup cost is less. So this is what I was explaining you. The banking is input sufficient energy into the boiler to just maintain the operating temperature. It is like keeping a vehicle in a zero state, not moving but it is turned on. You can see here there is a fixed cost and banking cost for a long time if you keep on, if you keep the vehicle on, the cost also increases.

So, you can see here after certain point, we call it as breakeven point, you see cooling is more economical as compared to the banking and as the duration increases. There are some other constraints also like transmission security constraints can also be used. Fuel constraints, this is practical. Sometimes fuel constraints means if there is a limitation in the fuel supply, we also hear this news.

Many coal, thermal power plants, the coal supply is not available. Then you cannot generate the power if you do not have fuel at all. That is one of the constraints. And must run, some units are given a must run status during certain times of the year for voltage support on the transmission network or for the supply of steam for uses outside the steam plant itself. There are certain units that need to be operated because there is also local power consumption.

Even though there is no load, still there are certain local consumption. So then apart from that, in order to maintain the voltage profile constant, though you may not be injecting an active power, there is a requirement of reactive power in the system. So that must run, some system, some generators need to run during all the time. So that is So that is must run condition. And there is a hydro constraint.

This economic dispatch problem is not just limited to thermal scheduling. There is also hydro thermal scheduling because hydrogen, sorry, hydro power plant is very important for any system. Without hydro, you cannot meet out the load demand. So scheduling of hydro and a thermal power plant to meet out the load demand where hydro power plant has its own constraints and because it has so many environmental constraints also and thermal power plants has its own constraints, bringing two different constraints put together, the problem complexity will further increases. So hydro thermal power scheduling is more complex, but it is more practical and relevant.

And there is system air quality constraint. This is another important thing. Now because thermal power plant, their fossil fuels, they inject lot of carbon monoxide, carbon dioxide emissions will be there. So this is another important thing that how much air quality that it would reduce and that constraint also we need to be taken into consideration. So now we will discuss about the solution methods. Typical utility situation involved in the commitment problem is there must establish a loading pattern for m periods. So there are m periods, they said 10 periods of time during which the load keeps varying.

So you need to establish a loading pattern first. And having n generation available handy at your premises, they are available to commit and dispatch. Now the m load levels and operating limits on the n units are such that any one unit can supply the load demand and any combination of units can also supply the load demand. As we have already discussed, let us say there are 3 units, even one unit can also meet out the load demand or 2 units can also meet out or 3 units can also meet out. Now what are the possible combination, possible you know combination of solutions available.

So we follow brute force method. Now what is the total combination of investigation, 2 to the power of n minus 1, n is the number of generators that I have already told you. Now for the total period of m intervals, so such 2 to the power of n minus 1 combination is available for m intervals where the load is changing. For each interval, you need to have a 2 to the power of n minus 1 combination to be dealt. So what are the total number of combination now for m intervals having n number of generators, it will be 2 to the power of n minus 1 whole to the power of m. That means if it is a 24 hour for that means if it is a next day dispatch, 24 hours hour to hour dispatch is there, right.

Made up of a 1 hour intervals, a 5 unit network becomes how many combinations? 6.2 into 10 to the power of 35 combination, such a big mathematics. If there are 10 generators, you know too big, for 20, 40 it is very very big actually. In practical system, there are hundreds of generators and let us say you decrease the time interval also.

For example, half an hour interval, then further increases. How do we solve? We will see. So most talked about techniques are priority schemes, dynamic programming, Lagrange relaxation and mixed integer linear programming MILP. Let us discuss about priority list methods. It consists of a simple shutdown rule based on a priority list of units, right. Obtained by an exhaustive enumeration of all unit combinations at each load level. For each load level you find out what are the possible combinations or can be obtained in a much simpler way by noting the full load average production cost of each unit.

You need to find out what is the full load, total load average production The cost for each unit. I will discuss an example to help you understand in a better way. Full load average production cost is the net heat rate at full load multiplied by the fuel cost. So, typical shutdown rules are at each hour when load is dropping, determine whether dropping the next unit on the list leaves sufficient generation to supply the load plus the spinning reserve requirements.

If the load is dropping, that is what I told in the beginning. You are allowed to you know bring down a specific generator only if the remaining generators can able to meet out the load demand plus the spinning reserve also, right. Now, if the supply is not sufficient, keep the unit committed. Though it may be economical to bring it down, but still you keep the unit commitment. The first priority is to meet out the technical requirements.

Then comes the economical requirement, optimization. Now determine the number of hours before the unit is needed again. If the time is less than the minimum shutdown time for the unit, keep it committed. Though it, let us say though it you are allowed to you know to turn it off, right. Then you see how much is the minimum time required to bring it on. If the time is less than the minimum shutdown time of the generator, then do not you know bring it down.

You come you continue operating this generator basically, right. And perform a cost comparison. Some of the hourly production cost for the next number of hours with the next unit to be dropped being committed. Then some of the restart cost for the next unit based on the minimum cost of cooling the unit or banking the unit. So, the three possible combination you continue the unit in a in a on mode that means you are generating the power. This is you are generating the power you are not turning it off, right. And there are two possible combination of even if you turn it off, you check the economical operation which one is the most economical among all three.

The second possibility is you now you turned it off. When you turned it off there is a cost associated with cooling and banking. There are two approaches. Either you totally turn it off or you continue operating in a neutral state.

You are not feeding the load. The first condition is you are feeding the load also. Banking means you are the generator is on in the system, but it is not feeding the load. Cooling means the generator is totally off and it is not of course not feeding the load. So, among three you see which is the most economical, right. First you see the technical constraints.

These are all technical constraints and this is a cost comparison. Let us take an example. There is a fuel characteristics given for three units and they have their minimum and maximum generations. Now the full load average production cost you need to find out. What is full load average production cost? So, at the maximum generation that is 600 megawatt, you see what is the cost. That means you put P1 as 600 and you get some number as per this expression.

Now you find out average cost that means total cost divided by 600. You got it. And you do it for the unit 2 and unit 3 based on their maximum capacity 400 and 200. Then you see per unit megawatt of generation which is the cheaper. And it clearly says the strict parity order indicates you first give parity to unit 1, unit 2 because it is 9.4010. Then you go for unit 1 much cheaper, then you go for unit 3. Now the commitment scheme goes like this. Ignoring minimum up, down times and start up class for forgetting all these things is a most fundamental one. So, if among all the combinations you see here what is the minimum megawatt of generation? 150 plus 100 plus 50 that means 300. Maximum is 1200. Similarly, if unit 1 and 2 are there minimum is 250, maximum is 1000.

If unit 2 is there minimum is 100, maximum is 400. So, if the load is going below 400 then unit 1 can be taken off. Here unit 1 is shut down at 400 megawatt leaving just unit 2.

Got it. So I am just summarizing. Most priority list schemes are built around a simple shut down algorithm. At each hour when load is dropping determine whether dropping the next unit on the priority list will leave sufficient generation to supply the load plus spinning reserve requirement. This is what I have already told. If the load is decreasing among the priority list you check whether dropping a particular unit still whether you are able to meet out the load demand or not including the spinning reserve. If not continue operating it as it is if yes then go to the next step.

That means if let us say bringing the unit down you cannot meet out the load demand. Even though if you meet out the load demand plus losses the spinning reserve may not be met. Then you do not have to take the risk. So it is better to continue the system. Even the load is dropping. Now what next step is suggesting? Let us say you have sufficient reserve available you can you are allowed to turn it off.

Specific generator you are allowed to turn it off. Then you see other constraints. Determine the number of hours H before the unit will be needed again. That means you have a peak load forecasting in the beginning I told. You see in next moment or after some hours what is the load? If load is again bringing is increasing. If the load is increasing and there could be an requirement of this unit which is which you are planning to drop that need to be brought in again to meet out the future load requirement.

You check that. First you check the number of hours how what is the total number of hours before the unit will be needed again back in the system. That is assuming that the load is dropped and will then go back after some hours later. Then if number of hours is less than the minimum shut down time for the unit. Keep the commitment as it is and go to the last step if not go to the next step. That means though you are allowed to turn it off but because the load is bringing load is increasing again but it has a constraint where it need to run for specific time it need to be switched off for specific time.

There is some time before which it can be turned on. The minimum shut down time basically. So the shut down time is more compared to the number of hours before which it is required on the system. Then you cannot meet out the load demand because it has it requires more time to bring it on. Then what you do you better to continue to operate.

Otherwise you have another option. You can cut down the load but that is not good. So you cannot cut down the load. All the first priority is to meet out the load requirement. Yes? Now what is the next step we suggest? Now that problem is also not there. That means you can bring it down and then even if you bring it down if the load again increases if suppose still the shut down time is less than the number of hours before which it can be brought it back into the system.

Then now you still whether you find out whether it is economical to bring it down or not. Now technical constraints are met. Now you check with the economical operation. What economical operation is there? Now economy means cost. Now you calculate the cost, two cost. The first is the sum of the hourly production cost for the next h hours with the unit up.

Considering you are not bringing down the unit, the unit is up means it is speeding the load. You are keeping the system as it is. You find out the cost. Then recalculate the same sum for the unit down and add in the startup cost for either cooling the unit or banking it. Now you can considering unit is up and it is speeding the power that is one cost. The second cost is now you are bringing down the unit back, you are switching off the unit basically and then you also find out the cost associated with cooling and banking.

Then you check if which is the most economical. Whether continuing the system generated to switch on and feeding the load that is most economical. If not then whether bringing back the system to the off and in off state which is most economical further whether cooling or banking. Totally turning it off or keeping it in a neutral state. Whichever is less expensive, there are sufficient savings from shutting it down the unit.

It should be shut down otherwise keep it on. Repeat this entire procedure for the next unit on the priority list. If it is also drop go to the next and so forth. You do it for the next iteration also. That is it. So various enhancements can be made to the priority list scheme by the grouping of units to ensure that various constraints are. So, that is it for the today's class. Thank you very much.