Economic Operation and Control of Power System

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Hello and good morning everyone, welcome you all for the NPTEL online course on Economic Operation and Control of Power Systems. In today's class we will discuss an important topic which is unit commitment. So before we move on to unit commitment, I will just give you an idea about a very important constraint which is called as Ramp Rate Constraint. So one problem that is common to economic dispatch with respect to dynamic programming which we learnt in the last class is that the poor control performance of the generators. That means if you do not consider this constraint, ramp rate constraint, what will happen? The generators may lose the stability. They are connected to a system and there is a sudden change in the load let us say. There is a sudden change in the load, the generators have to adjust with respect to the sudden change in the load. The controllers would give a command, the automatic generation controller command so that they would change their generation according to the change in the load. But every generator has its own constraint in terms of how much quickly they can adopt to the such a change in command, generation command. So that is what is called as Ramp Rate Constraint.

So if the generators are large stream generator units, they will not be allowed to change generation output above a prescribed maximum rate limit. So for each generator there is a delta P by delta T. That means how much could be the change in generation with respect to the time. So and it is expressed in terms of megawatts per minute. If it is beyond this the expectation of the load demand, change in load demand is such that it would call the generator to change its generation beyond this ramp rate, this capacity delta P by delta T.

Then the system will have to you know shut down or there will be instability in the system. So the AGC must allocate the change in generation to many other units so that the load change can be accommodated quickly enough. That means so AGC there are so many generators which are connected and they will be generating some power in economical manner. If there is a change in load so the AGC generation controller would decide how much change each generator can inculcate such that the overall change of each generator would be matching with the total change in the demand. And they should do it in a very quick manner so that the frequency will not get disturbed.

Now I will take you a very standard example. All of us are very familiar with respect to this example. See on 9th April 2020 it was a peak time of COVID it just started in India. So Prime Minister Narendra Modi ji he called the entire nation to shut down their lights, home lights for 9 minutes at 9 pm. So and it though he just called but it was a big problem in the mind of so many power system operators.

It's not so easy as you simply switch it on and switch it off. That too the whole nation if they are coming together and switching off the lights and then switching on after 9 minutes. So within this 9 minute there should be the total the you know whatever the system is there they should not lose the stability because it will hamper the frequency if you change the load. If you switch off the load what will happen? There will be increase in the frequency. If you again switch on the load then there will be decrease in the frequency.

So you need to ensure that the frequency will be within the limit otherwise there are so many frequency operated relays that would switch off the whole system. So it was observed that the total reduction in demand is 31,089 megawatt such a huge change in the demand. In fact I was hearing from one of the pioneers in POSOCO. So, he was telling that earlier when the Modi made this statement that switching off and switching on so they called they had a meeting among POSOCO they are now called as grid India limited grid control India limited. So they are the one who control the overall power system basically in India.

And they called for the meeting to estimate what could be the change in the load. There should be an approximate estimation so that they can plan which generators to call and how much they can cater. So there was an estimation based on so many analysis like maximum 20,000, 15,000. So nobody could able to exactly come to the figure but the actual number was 31,889 megawatt beyond their imagination. That means the whole nation responded to the Modi Ji's call indirectly this was the result.

Now you see what happened the statistics. All India load demand started reducing from 8:45 pm and minimum demand of 85,799 megawatt was recorded at 9:10 hours. Subsequently from 9:10 hours because now they switched off now they are switching on. The demand started picking up and settled on around 114,400 megawatt at 10: 10 slowly it got it picked up. So you see the change in frequency 50.

259 hertz and minimum is 49.707 hertz. You can see here compared to the previous day this was a previous day curve. This was a previous day load curve. Now you can see there is a serious dip in the load.

Now how did they address this issue? They could manage the system rights and we did not lose the system stability though the frequency variation was seen we could not you know we ensured that the system did not went out of the stability. So they called the hydropower generators because through thermal they have some constraints even hydro generator has that capability to suddenly pitch in to the change in the demand and they took off I mean the generation they released from the hydro so that they maintain the frequency when the load was switched off and they immediately called the hydro generation then they increase the generation so that they maintain the frequency when the loads are switched on. So this is one typical case study which indicates the impact on the power system. When the cost curves are non-convex a small increment in load results in a new dispatch that calls for one or more generators to drop their output a great deal and others to increase a large amount. That means there could be some generators which may not be able to meet out the change in the ramp rate, change in the demand.

So they would be taken off and the other generators for capable to handle such kind of transients they will be allowed to manage the issue. The resulting dispatch may be at the most economic values as determined by dynamic programming but the control action is not acceptable and will probably violate the ramp rates for several of the units. The only way to produce a dispatch that is acceptable to the control system as well as being the optimum economically is to add the ramp rate limits to the economic dispatch formulation itself. While you carry out the economic dispatch problem formulation then only you create you put this constraints, ramp rate constraints such that at the end of the economic dispatch you have a set of generators they are able to manage the forecasted change in the load demand. So, this requires a short range load forecast to determine the most likely load and load ramping requirements of the units.

That is what we have to do is first we have to do the load forecasting, see whether next you know next iteration before the next iteration of change in the generator outputs you see what would be the possible change in the load demand and then you ensure that these generators for which combination you calculate the most economic power output those generators can able to meet out this change in load demand within next possible time. So, given a load to be supplied at time increments t is equal to 1 to t maximum with load levels of P load and N generators online to supply the load that means total number of generators are i is equal to 1 to N and there some of the power output should be equal to the load and this should be equal at during all the change in load demands during all the time instants and each unit must obey ramp rate such that Pi of the power generation of the i th generator at t plus 1 instant is equal to the power generation of the i th generator at this instant plus the change in power expected with this generator due to the change in load and such that the change in power of each generator will be within the range of its ramp limits delta P i minimum to delta P i maximum because this is negative sign I have just indicated as delta Pi maximum. And we must schedule the units to minimize the cost to deliver power over the time period as F total is equal to. Now we have to minimize the total cost of all the generators during all possible change in load summation of generators should be equal to that summation of generation of the generator should be equal to the total load demand and that should be the that should be happening at the minimum cost and this should happen during all the change in load demands. So subject to the constraints, so summation of generation for during all the time instant should be equal to the load demand during all the time instants given by:

$$\sum_{i=1}^{N} P_i^t = P_{load}^t$$

$$P_i^{t+1} = P_i^t + \Delta P_i$$

$$\text{and } -\Delta P_i^{max} \leq \Delta P_i \leq \Delta P_i^{max}$$

Then we must schedule the units to **minimize** the cost to deliver power over the time period as:

$$F^{total} = \sum_{i=1}^{T_{max}} \sum_{i=1}^{N_{gen}} F_i \left(P_i^t\right)$$

$$\text{subject to } \sum_{i=1}^{N_{gen}} P_i^t = P_{load}^t \;\; \text{for } t = 1, \; \ldots, t_{max}$$

$$\text{and } P_i^{t+1} = P_i^t + \Delta P_i \text{ with } -\Delta P_i^{max} \leq \Delta P_i \leq \Delta P_i^{max}$$

This optimization problem can be solved with dynamic programming and the control performance of the dispatch will be considerably better than that of dynamic program with no ramp time constraints. That means if you consider ramp limits that would be the most practical means of considering any dispatch. You see how do you forecast the load? Because any human activity which follows some pattern, some cycle, most systems supplying services to a large population will experience cycles. Example transportation systems in general if you see because during the morning hours it is a working hours. So during transportation also they observe there will be lot of vehicle movement and in the evening hours also.

During day time even if you travel in metro and other places you do not find much crowd but during the between 7 am to 9 am or during late evening hours in Delhi metro and all you experience lot of crowd. Even communication systems. So specific time you see let us say you have to submit a kind of online application, get examination you need to submit portal. So during the last time of submission there will be hang in the system. You will not be able to submit because too much of over crowd towards the last end movement of the submission.

And similarly electric power system also have follow certain pattern. If there is a cricket match everybody wants to watch the cricket match. So there will be total increase in the demand. If there is a festival seasons so there will be so much of celebration and new year parties. So these are some of the occasions where it is already decided that there will be subjective increase in the load demand.

So you can see even in daily and weekly schedule also you can see lower power consumption are seen during the weekends. And the total load on the system will generally be higher during the day time and early evening time because people are staying in their home they will be switching on the loads. So these changes can be seen. And in the different types of loads industrial loads, commercial loads and lighting loads and every loads have their own pattern like industrial loads will be active during 9 to 5 pm usually typically. And commercial loads also have certain time durations and lighting loads especially during the late evening hours.

Loads will be lower during the late evening and early morning when most of the population is asleep and loads will be higher during the summer and winter extreme weather conditions especially someone who is staying in north India they can able to experience this. So there will be heating and cooling loads which are pitching in during summer and winter. Now you need to consider all these constraints also like ramp rate constraints and how the unit would perform for a specific change in the load demand. Now unit commitment is a more broader way of dealing a problem. It is beyond just economic dispatch.

So to commit a generating unit is to turn it on that is to bring the unit up to speed synchronize it to the system and connect it so it can deliver power to the network. So the first point is if you are committing a generator means it includes your synchronizing with the grid and then ensuring that that specific generator is available for that specific duration. You are committing it for that specific time and this generator will be available to meet out the load demand. It is quite expensive to commit enough units and leave them online. So there are so many generators you can commit all of them just to be on safer side but it will lead to economic problems.

So money can be saved by turning units off that means de-committing them when they are not needed. So you can de-commit those generators which need not have to you know play an active role in terms of meeting out the load demand. The problem is more difficult to solve mathematically since it involves integer variables. Committing means what either 0 or 1. So there is a integer end of problem.

So that is generating units must be either all on or all off. So let us compare between economic dispatch and unit commitment. Economic dispatch assumes that there are n generator units already connected to the system. The purpose of the economic dispatch problem is to find the optimum operating policy for this n generator units. Whereas unit commitment means given that there are a number of subsets of the complete set of n generators generating units that would satisfy the expected demand.

The purpose of unit commitment is to find which of these subsets should be used in order to provide the minimum operating cost. Now let us say there are 10 generators and let us say you can meet out the load demand using just 3 generators. Now which are those 3 generators which can give an optimally economic solution including the technical constraints such that if change if there could be a sudden change in the load these generators should also able to meet out sudden change in the load and they do not violate their ramp rate limits. The solution procedure involve the economic dispatch problem as a sub problem. So economic dispatch is a sub problem of a unit commitment.

Now you choose 3 generators then you find out economic dispatch what could be the best generation for these generators. Now let us take an example. Determine the economic operating point for the 3 generating units when delivering a total load of 550 megawatt. Now this is the characteristic curve and the fuel cost of each generator is given.

Now you get the fuel cost of each unit. Now to solve this problem simply try all combination of the 3 units. Some combination will be infeasible if the sum of all maximum megawatt for the units committed is less than the load or if the sum of all minimum megawatt for the units committed is greater than the load. Let us say that 3 units, the possible combination are 2 to the power of n, 3 means 8 combinations. So, 000 and 001, 010, 011, 100, 101, 110, 111, these are the possible combinations. Now which of these generator combination would give you the best economical solutions such that they should ultimately meet out the load demand.

00 means that they do not exist. Even 001 means just one generator is present. Now you ensure whether this one generator is capable of meeting the load demand or not. If yes then that is considered. Otherwise you should first freeze out or select those particular combination which can really meet out the load demand. Among those combination now you carry out economic dispatch for each of them and the most economical combination would be chosen for the dispatch and you can commit those generators only.

And there could be another case, it is not only minimum, even the maximum generator combination. Let us say if sum of all minimum megawatt for the units committed is greater than the, it should be also greater than the load demand. That means the minimum generation of each generator should be also greater than the load demand. For each feasible combination the units should be dispatched using the techniques of equal increment cost. Now you see here there is a maximum generation, minimum generation given for each generator.

Each possible combination of units. Now 000 means maximum and minimum is 0 and 0.

001 means just unit 3 is present and you have to consider the minimum and maximum generation of that unit itself. And let us say you have two units, let us say this combination where you have unit 1 and unit 3 available. Then you include minimum generation that means summation of minimum generation of unit 1 and unit 3 put together will be 200, maximum generation would be 800. Now first three options are directly infeasible because the load demand is 550 megawatt.

Now put together maximum generation is just 400 megawatt, it is not possible. Now from this combination onwards you have you know how many? 1, 2, 3, 4, 5. 5 possible subsets can meet out the load demand. Among them if you calculate, if you find out the economical dispatch, now you calculate, you obtain economic dispatch for all each combination. Now once you have economic dispatch for all three, all these 5 possible subsets you get to know that this solution is the most economical one.

That means just by turning on unit 1 you can meet out the load demand and that would be most economical also. You need not have to consider turning on unit 1, unit 2 and unit 3 and that would give a much higher cost. Note that the least expensive way to supply the generation is not with all three units running or even any combination involving two units also. Just one unit can meet out the load demand. Rather the optimum commitment is to only run unit 1, the most economical unit.

By only running the most economical unit, the load can be supplied by that unit operating closer to its best efficiency. If another unit is committed then you are forced to move from the optimal point to the suboptimal point. If the operation of the system is to be optimized, units must be shut down as the load goes down and then recommitted as it goes back. A simple priority list scheme can be used to solve the unit commitment problem basically. You see assume that the load varies from a peak of 1200 megawatt, this is the maximum to a value of 500 megawatt, this is 500 megawatt.

Then to obtain a shutdown rule simply use a brute force technique wherein all combinations of units will be tried for each load value taken in steps of 50 megawatt from 1200 to 1000 megawatt. Shutdown rule is when load is above 1000 megawatt because it is a maximum load, you need support of all three generators. Run all three units, if it is between the range of 1000 to 600 then only two units are sufficient. If it is below 600 megawatt possibly you can operate with just one unit. So the unit commitment schedule derived from the shutdown rule as supplied to the load curve of figure 1 is shown below.

This is the unit commitment where you switch on the load, you just consider unit 3 when the load is above 1000 megawatt, you consider unit 1 and 2 when it is between the range of 600 to 1000 megawatt and you just consider unit 1 in the case of load less than 600 megawatt. Now the results of applying the brute force techniques are as given below. You can see here above 1000 megawatt all three units are present and above 600 megawatt only unit 1 and 2 are considered.

Below 600 megawatt just unit 1 is considered. That is it. Thank you very much. .