Economic Operation and Control of Power System

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Lecture - 31

A very good morning. Welcome you all to the NPTEL course on Economic Operation and Control of Power Systems. And today's lecture number 31 will be focusing on Power and Energy Interchange as a basic introduction. Now please recall that as of now we have learned how to optimize your generation units so that the total operating cost is going to be minimum. But to me it is not enough when you have multiple areas those who are carrying out their own economic dispersed operations or solutions. Assuming there are two different areas or two different states or two different neighboring countries carrying out their economic dispersed solutions and both the areas have been interconnected.

Importantly, let's say there are two, one example Rajasthan and Gujarat. Probably there are two different states. Those who carry out their own operation of optimizing their resources. However, there could be a tie line which connects between Rajasthan and Gujarat.

Now the question is, it is also important to carry out some transaction between one state to the other if the energy is economical. To me, if the energy is cheaper in Gujarat then those power can be moved to Rajasthan and vice versa. So that is known as interchange or exchange of energies and we'll focus on how this concept is going to work. Now why interconnect and interchange? First of all, why it is important to have interconnection? Interconnection is mandatory to exchange energy from one area to other. It is better to buy power from your neighbor if the neighbor can generate power cheaper than you.

That means to optimize your energy cost there is nothing wrong to get energy from other neighboring areas which has been interconnected to your own power system. Now interconnecting with neighbors has the advantage that they can supply power if your generation fails thereby increasing your system reliability. Due to some reason if your network fails probably you can get all the energy through your interconnected systems. So if you look India as a whole, each and every zone has been connected. Eastern zone, Western zone, Southern zone, Northern zone, North Eastern.

Everyone is interconnected because not even a given point of time. Any one of the zone feel isolated because if something goes wrong, if there is a sort, of last class we talked about outages. If there is an outages in any one of the areas then probably the other area can share some of their energy to make you more reliable. Now the large interconnected systems can regulate frequency and respond to emergencies better than isolated system. Now imagine in your area the load is more.

So what will happen? When the load is going to be high that means your frequency is going to be lower. So that means you can get energy from other areas to cater your own load so that your frequency can oscillate slowly and come closer to your standard value of 50 hertz. Now my argument or suggestion here, interchange or interconnection not only allow you to operate with cheaper economic operations of your generations but also it can increase reliability. It can also help you to regulate your frequencies. Now there are different level of interchange and they have been categorically divided into six levels.

One is energy, dynamic energy, contingent, market based, transmission line use as well as reliability. Now I will just get it one by one and see how interchange has been experienced through energy. Now when you talk about energy transaction the first one is known as economy A in which simple economy advantage of buying from less expensive generation sources means one can carry out transaction because it is cheaper to me. Now what is economy B? Schedule power interchanges to save further when scheduling generation using unit commitment. So when you carry out your unit commitment process sometime you say that you switch on this unit and switch off the other unit but those exercise you can carry out depending upon if there are cheaper energy sources available to you in your neighboring areas through interconnection.

Now the third one is unit sales. Buy a portion of large generating unit installed in another system and import its output means you occupy some of the generation in your neighboring area, generate power and then transmit your own area means you occupy the other zone of generation and get that energy to your area. The last one is diversity. Interchange with systems having different time of day peak load that means let's say in European Union or probably in Europe each and every country do have their own peak hours okay not necessarily all are experiencing the same peak hours. So if each individual country experience different peak hours then probably that could be energy exchange during the peak hours so that both of them both the countries can meet their peak without putting additional generation to meet out the peak demand.

Now if you move to energy banking, deposit energy and withdraw it later without accounting for sell prices. So this is also is possible today. Inadvertent, payback interchanges that occur due to lack of capacity or lack of fuel. Take or pay, make interchange energy available on a take or pay basis as is done with gas contracts. Jointly owned units, power plant has many owners who can control the share of the plant as it is their control area.

Remote demand, a load can be located in another area yet to be treated as if it is your own control area. Now let us move to contingent transactions, capacity. What is capacity? Another system can help cover your generation's capacity reserves. Emergency, an agreement to have a neighboring system supply power in an extreme emergency when your generation cannot meet the load. Spinning reserve, I talked about spinning reserve in the past but still another system can help cover your spinning reserve, ready reserve.

Another system can help you cover force outages with generation that is ready to start up on short notices. Now the next one is market based transactions. Towards market based transaction, there are many areas that you can explore where demand side management is one area. You can explore on particular broker, energy broker in North America or in some other country and you can also study different energy system operators like PJM, NYISO, MISO, NEISO etc. So they are all independent system operators operating in North America for a very long time.

Now when you talk about transmission used transactions which is a very very interesting topic, how can I sell some of my transmission system capacity for others to will power across my system. Now the question is, if I like to get energy from my neighboring area, I need facility or I need capacity to carry out those transactions. Now let's say if the transaction, the transmission corridors which are responsible to carry energy from one location to other and if they are already occupied to its maximum capacity, even cheap energy is available to me in my neighboring area, I cannot get it back. So what we need to do, if I wish to wheel some of my power from one area to other because it is cheaper, because it is reliable, because it is you know helping my frequency to go up, whatever it is. But to do that I have to create transmission system capacity for that.

Now when you create the transmission capacity, why someone will share its own transmission capacity to benefit others? That means we need to pay for that. If someone is exchanging or sacrificing his transmission capacity for you to carry out wheeling of energy, then you need to pay some money and for that calculation we need to have different models. The first model is postage stamp method. That is cost are averaged over all transactions. So we know the transmission cost, we know per unit transaction what would be its cost and accordingly the transactions will be charged a fixed amount of money.

It is something like you why it is postage stamp? If I post a letter from Jaipur to Delhi or Jaipur to Chennai, the cost remains same. Or Jaipur to Mumbai, everywhere across the country if it is 20 kilometers or 2000 kilometers, the cost of postage stamp remains same. So that is a very uniform, but that is not very motivational. That is not encouraging people to be smart enough. So there are few algorithms which have been developed by different researchers to make sure that you sacrifice your corridor for others to have benefit and you get some money or their profit to be shared to you because of your transmission corridor they have used.

But what would be the cost? How much they have to pay? That need to be scientifically calculated. As of now we normally go with postage stamp method which is not very efficient. Today India is also adopting megawatt mile method which is a very interesting one. But people are also talking about MBMI method, megawatt plus MVAR method, reactive power exchange method. So there are many methods available.

Now moving to rupees or dollar per megawatt mile, each transmission line is assigned a cost per mile. So that means if you carry the energy for a mile, means the mile of length of corridor cost is known to me. And I can calculate if the life of that corridor is 25 years or 50 years, I can calculate the cost per year and then cost per day, cost per hour and then per megawatt I can calculate how much money they have to pay to use this much percentage to my corridor. Each transmission line is assigned a cost per mile. Each transaction must be assigned to each transmission line and multiplied by the line cost, rupees or dollar per mile times the megawatt of the transaction they carry.

If I know in this area or in this corridor if it is 5 rupees per mile or per kilometer, if I have to carry a 100 megawatt, then 100 times 500 rupees per mile carrying out 500 x megawatt need to be charged. So it is basically megawatt multiplied by the rupees per kilometer or rupees per mile or dollar per mile times will give me the real cost of my transaction. Towards transmission facility. Now this one term is known as jointly owned transmission, JOT, require control over the flow to reflect the contract. Now moving next, there is an important issue known as locational marginal pricing to cost transmission use.

So if you use a transmission facility in a real time, because it's very, very complicated system, we have millions of buses, energy is going from one location to other across the country, how do you calculate who is responsible for what? The total cost is billions of rupees and then that need to be distributed among millions of customers. It is one of the largest complicated problem I can foresee in the world today. Now locational marginal pricing to cost transmission use in very important area. First of all what we say, to transmit power because you wish to transmit x megawatt power from a bus I to bus G, that is the transmission exchange you like to carry out. Now when you inject power at a particular bus, that is you are selling the power at bus number I and someone is ready to buy power at bus number G or you are injecting at Jaipur and someone is drawing at Ahmedabad.

So when you inject at Jaipur, the locational marginal price, the injection cost LMP at I to bus is known to me, that is the sell of power in the system and someone is drawing power at Ahmedabad, so that means the buying power cost, that is LMPJ is also known to me. So what is the cost of transaction between Jaipur to Ahmedabad is the LMP, locational marginal price at Jaipur minus the locational marginal price at Ahmedabad, that is LMPI to LMPJ. The difference multiplied by the transaction, if it is 100 megawatt multiplied by 100 will give me the cost of transaction. Okay, hope, dear students you are very clear what I am talking about. Now looking at a very numerical example, locational marginal pricing example, we are interested to sell transmission so that a transaction of 20 megawatt can be accommodated between bus number 3 to 4.

Assume that bus number 3 is Jaipur and bus number 4 is Ahmedabad, so we like to push 20 megawatt at Jaipur and we wish to withdraw 20 megawatt at Ahmedabad. So from the figure 31.1 as you could see it is a system of 6 bus and having different generators at bus number 1, 2, 3 and each and every bus most of them are interconnected through transmission lines and having couple of loads located to bus number 5, 4 and 6. Now if I am interested to inject 20 megawatt at bus number 3 and wish to draw the same amount of power at bus number 4, so that means I have started utilizing the facility because this energy has to flow a different way, you know, it can come this way or it can come this way, alright. So any corridor that it will be using to transfer that power, so that means you are using that facility, so we need to know how much cost one has to pay to carry out this transaction, that is a very, very important question.

Now moving further, moving further, I think this example all of you please concentrate, locational marginal pricing example. Now there are two issues here, one now each and every line, okay, ideally we do have a MVA capacity, we call it is maximum and MVA minimum capacity, means each and every line can carry X mega volt ampere of power maximum, that means when you carry out 20 megawatt transaction it is not necessary that all the lines are capable of carrying that transaction if they are very close to their maximum capacity. Otherwise they have to route their power to some other direction so that the customer at bus number 4 can achieve the 20 megawatt which has been sold at bus number 3. Now to start with let us assume that each and every energy corridor is capable of carrying enough power and there is no limit violation, okay. So you can see that no transaction and no line limits, that means you are not carrying out any transaction, neither you are experiencing any line limit in those corridors.

That gives the last column which shows the lambda at different buses, bus number 1, bus number 2, bus number 3, 4, 5, 6. So what does it mean? For example, 13.1902 is the LMP at bus number 5, that means if I have to inject power at bus number 5 that is this one, LMP I will be my 13.1902, am I right? And if I have to draw it at bus number 2 which is going to be 12.4572 that means if I am drawing this at bus number 2, this one, then LMPJ will be my 12.4572. So if you are carrying out 10 megawatt of transaction or 100 megawatt of transaction, 13.1902 minus 12.4572 multiplied by 100 will give me the cost for 100 megawatt transaction between bus number 5 and bus number 2. So this is the fundamental, okay.

Now move to a real example. With 20 megawatt transaction between bus number 3 to 4, okay. So you know the cost at bus number 3, you know the cost at bus number 4, you can get the differences and multiplied by 20 will give you the transaction cost. Now one interesting phenomena, without any transaction you have to meet your loads. So when you meet your load, then you have to run your generators based on your economic dispatch with load flow and when you do that you will obtain the operating cost which is 4232 rupees or dollar per hour that is the cost you get for your running the system without any transaction. Now when you carry out 20 megawatt transaction, now the cost has increased to 4247.

I mean to say that when you introduce any transaction, then your operating cost if it increases, if it increases, then who is responsible for that additional cost? The transaction who has forced my operating cost to increase from 4232 to 4247, the transaction 20 megawatt who is responsible for that. So this additional cost need to be transformed or transmitted to this transaction alone to bear the additional cost because for which or whom I have my operating cost has increased. Now one important phenomena is quick, very interesting that most of the lines, those who operate within its operating limit may violate because of those transactions and one line that we see here, line number 224 which is now experiencing 77 megawatt. Imagine if the line flow is 60 megawatt, if you ignore the constraints of line flow limit, then probably this cost is enough. But if you force no, I cannot carry more than 60 megawatt between line number 2 and 4, then this cost 4247 will further increase. We'll see in the next example. Now with transaction and with line limit checked, limit hit line number 224 which is supposed to be 60 megawatt but now it is getting 77 megawatt. So if you force the line to carry only 60 megawatt between bus number 224, then the cost is now moved to 4296. What does it mean? A very ideal case, a very ideal case, you experience the cost 4232 and when you carry out a transaction, you experience 4247 but if you also put line limits, then the cost will further increase that is 4296 now. So as you have seen, if you have to maintain the line constraint as 60 instead of unlimited, no constraint to your line, the cost has increased up to 4296 and you obtain different LMPs with line flow constraints. Now you have to calculate the transaction which is supposed to be between the bus number 3 to 4, so I have to calculate what is my LMP at bus number 3 and LMP at bus number 4 and I have to take the difference between these two.

If there is no constraint of the line flow, then the bus number 4 is experiencing 13.2494 and bus number 3 is experiencing an LMP of 12.376 and hence 13.2494 minus 12.376 which is 0.8734 is my unconstrained LMP difference and if you carry out x megawatt of power, then this value need to be multiplied with x mega watt. Now if you consider constraint that is your case number 3, now the LMP at bus number 4 is 16.4177 and the LMP at bus number 3 which is 12.2015 and the difference is 4.2696. So I have to multiply x megawatt with constraint. Now what we are going to conclude here, the conclusion is the cost of transaction increases significantly if you are putting constraint on your line flow limits. Because of the line flow violation, now the cost of transaction becomes very, very significant. The system is not allowing you to carry out a transaction but you wish to have the transaction so you keep on paying more money because you are violating the line limit because of these transactions. Now the second question which is very, very important, if there is no constraint then the cost is as cheap as 0.8734 which is almost one fifth of the total cost. Now what we need to do, so what we have learned out of this discussion that as and when the constraints are being violated that means the cost of transaction become higher and higher. Now if you move to economy interchange example, this is another interesting area where we talked about a system where the transaction was between one bus to another bus within a single area but here we are talking about two different areas. Now it's a quite complicated system, 31.2 where we have area number one and we have area number two.

So previously we are talking about Jaipur to Ahmedabad. Now we are talking about Rajasthan versus Gujarat. So let's say this is my Rajasthan and this is my Gujarat, two different states exchanging power through different connections of transmission corridors. And there are a bit of cost characteristics belongs to area number one and area number two as you could see the ABC coefficient averaged for area number one and two is known to you and the P minimum, P maximum is also given to you. That means the area number one can handle energy between 300 to 1200 megawatt, the area number two can handle energy between 360 to 1470 megawatt. So this is what the descriptions, area number one the load is 700 megawatt, maximum total generation is 1200 megawatt, minimum total generation is 300 megawatt.

Similarly the area number two has to, you know the load is 1100 megawatt, the maximum total generation is 1470 and the minimum total generation is 360 megawatt. For each area you can carry out algorithms and obtain what is my incremental cost and you can also calculate the production cost for each area. So similarly for area number one, area number two, two different economic response problems and you can get this cost. Now if you operate them combinedly, total operating cost is close to 36.326. Now what we want to highlight here, the kind of benefit that we can get because of exchange of energy. Now one area is experiencing a different cost characteristic, different incremental cost, different loading behavior. The other area is experiencing different load requirement, different incremental cost and different cost characteristics. Now when they are interchanging power, so probably they can act as a single system and probably they can bring some benefit in a, you know financially to exchange some of the cheaper energy from one zone to other. Now if you look into the area number one, now actually the, because previously we decided to have the load of actually 700 plus 1100 that is close to 1800, all right.

Now it's the same 1800 when there was exchange, they have been distributed as 986 and 814 So seems to me that the 1100 capacity, you know is being now reduced and 700 being increased little bit and you could see the incremental cost of the area one and two become same. Previously they were different but through interchange, exchange become a single area, they become exactly same. Now what has happened? By combination, interchange power that is 286 megawatt from area number one to area number two and similarly the total generation of entire system which is now become 800 megawatt, 1800 megawatt and the total operating cost for both the areas become 35.748 dollar per hour. So additional 286 megawatt transaction took place because of the interconnection or interchange.

Now what exactly happened to area one cost wise? Without the interchange it was 13.741 and with the interchange now the cost has increased to 90. So there is an increase in cost which is 6036. Now in case of area two without interchange it was 22585, with interchange it reduced now because it started producing less power.

So now it reduced by this one. So there is an increase in cost and there is a reduction in cost and you could see the overall benefit is rupees or dollar 578 and that is happening because of exchange of energy. So what exactly happened? We want to conclude if you operate independently you may have to pay more money but when you exercise through interconnection then probably along with reliability and frequency improvement you can also save lot of money because of energy exchange from a cheaper zone to a cost lower zone. With this we come to a conclusion.

Thank you very much for your attention. Thank you. Thank you. Thank you.