Economic Operation and Control of Power System

Prof Narayana Prasad Padhy

Department of Electrical Engineering

Director MNIT Jaipur and Professor IIT Roorkee

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Lecture – 34

A very good morning. Welcome you all to this NPTEL course on Economic Operation and Control of Power Systems. And today we will be focusing on lecture number 34, Transmission Effect and Issues. During the lecture number 31 and 32, we learned that the transmission system play an important role in carrying out transactions, especially energy transactions. The reason being, most of the corridors, that is transmission corridors, do have certain capacity to carry energy from one point to other. But due to economic operation or maximum saving or an effective broker mechanism in a pool environment, we always wish to transmit maximum power from the cheaper generating point to the costlier load point frequently.

And that is not possible until and unless the transmission corridors do have capacity to carry those energies. So there could be a violation in transmission line limits. And once there is a violation, then the cost of energy start increasing because you cannot carry cheaper energy to a important location. So we need to understand how transmission corridors can impact the economics of whole energy business and the challenges.

Now when you talk about transmission capability, we say each and every transmission line do have certain capacity to carry. Imagine a line, transmission line, which has capacity of 100 megawatt hour or 100 MVA. Then those limits need to be optimally utilized. And we can load the lines with some 5 to 6% excess, but it is not desirable. And if the line is loaded by 90%, then the next transaction will certainly impact the transmission limit violation.

And once you violate the transmission capacity, then the cost of energy become costly. So the first important variable is thermal power limitation of lines. That means each and every line can carry certain amount of power not to violate the thermal power limitation. As you all know, when we carry maximum amount of power, indirectly you are carrying higher currents and when the current is more, the temperature is high. Once the temperature is high, the lines start melting.

So we cannot afford a line to melt due to huge amount of energy being carried. So that is one limit you have to be careful. Thermal power limitation of the line is mandatory. We cannot afford to cross that limit at any given point of time. Next is meet first contingency limit.

That means if any time one of the transmission facility fails, then the energy that is expected to be carried through that corridor now need to be diverted to other lines adjacent to that point. So that means unexpected if one line fails, the other lines will be automatically overloaded. So if you say my system is contingent enough to take care of certain n minus 1 failures means at any given point of time, one device failure can be managed. We cannot shut the system because one corridor fails. We have to accommodate the rest of the lines through diverting those energies.

So if your system is satisfying n minus 1 contingencies, then probably your capability will further reduce because you are having a spare capacity to carry energy in excess during failure of some of the facilities. And the third one, very important, is the transient stability limit. The transient stability do not allow you to carry maximum amount of power which may completely disturb the system. So that also need to be taken care. Then we have voltage and VAR limitations.

So once you try to accommodate all those limitations, then my transmission capability will be properly defined once you satisfy A, B, C, D as it has been described just now. Now use line out as probability and maintain loss of load probability, LOLT. And expected unserved energy, that is EUV, levels for each transition equally play an important role in deciding transmission capabilities. Now what do you mean by flow gates? It's a very important point, flow gates. ISO, that is independent system operator.

What is ISO? For my, I mean, just for the benefit, let me explain. ISO is an independent body that manages all the energy transactions, generation and purchases of an utility without having any profit. For an example, looking into India, the Central Electricity Regulatory Commission can be named as an ISO who looks after all the state regulatory commissions of the country, engage the consumers and the generators in such a manner without making any profit out of these transactions. Now ISO completes a first contingency transfer analysis to identify flow gates. First contingency transfer analysis is performed for ATC, available transmission capability.

Path internal to ISO market footprints up to 10,000 megawatts. This is a specific case study. The first three limiting elements and their worst associated contingency combinations with an OTDF of at least 5% and within ISO market footprint are included as flow gates. Now what is total transfer capability? So there is a difference between available transfer capability, that is ATC, and there is a term called total transfer capability. So we'll focus on these two terms soon.

Now you have to use power flow to model those transfers. No overload should occur in the system as the transfer is implemented. No overload should occur in the system during contingencies the transfer is implemented. That means using PTDF and LODF for both lines and for flow gates to model and determine the total transfer capability values for areas and flow gates. Now total transfer capability will indirectly indicate how much power it can certainly carry.

But when you accommodate contingencies, security, stability issues, then finally the amount of power that you can carry is much less than total transfer capability and that becomes the available transfer capability for you. And now there is a definition available transfer capability, ATC, and available flow gate capability. Now let us focus on available flow gate capability. Megawatt transfer capability on a flow gate that remains available for additional transmission services above and beyond the already committed and approved uses of the transmission system. That means you agreed upon to carry X megawatt for the safe transmission, but still you have a scope of increasing that by a percentage and that is my available flow gate capability in addition to the existing transmission contracts.

Now what is capacity benefit margin? That is CBM. So capacity benefit margin is a form of transmission transfer capability preserved by the ISO for load serving entities, that is LACs, within a BAA to enable access by the LACs to get generation from the interconnected system to meet generation reliability requirements. So capacity benefit margin is related to your reliability with the help of transmission from the other entity next to you. Now the third term which is known as transmission reliability margin, amount of transmission transfer capability necessary to provide reasonable assurance that the interconnected transmission network will be secure. And that is known as my transmission reliability margin.

Now let us focus what is ATC. As I told you ATC is nothing but the available transfer capability. For a transmission corridor ATC will be the total transmission transfer capability, TTC, minus CBM, that is capacity benefit margin, which is related to reliability contingency studies, minus TRM, which is transmission reliability margin, and minus ATC will give you the value for your ATC. So CBM, TRM, ETC are the margins required for stability, reliability, and previous commitments. So the line may be having the capacity of 100 megawatt hour or 100 MVA, but in reality it could be 60 or 70 megawatt hour or MVA, depending upon your margins that you have settled to for the smooth functioning of any network.

Now process of using AFC. Transmission service request, TSR, is entered through an internet based database, that is the ISO, we call it OASIS, open access same time information system. TRS is an interchange contract defined by a point of receipt, POR, or point of delivery, fault. TSR are classified by the status study, accepted, refused, and confirmed. Each form TSR request goes through an ATC or AFC check.

Now if you have a system which has many transmission lines connected to it, now whenever there is a new customer wishes to carry out its own transaction from bus number I to bus number we need to introduce the transaction artificially and run the program to make sure none of the transmission line is being violated its ATC. If it is not being violated, then only that customer will be encouraged to carry out the transaction in real time. Now one more important factor is known as spot market. So stores enter bids to buy and generators enter bids to sell bids to market. The bids become part of an OPF to model an auction based on bids.

Now OPF is used within a unit commitment to schedule generation for 24 hours for example. Now in case of the energy broker, as I told you, they will get the bid price from the generator companies as well as the consumers and arrange them actually in a ascending order as well as in a descending order and they will go for the cheapest generation to the costliest load and try to match them to make maximum profit. However in case of the spot market, the fashion is similar but it is operated not through a broker but a central entity and that market is known as spot market where all the consumers as well as the generation companies will bid their price and based on a natural match the companies those are ready to offer cheaper energy and ready to buy costlier energy blocks will be entertained. Now optimum operation with price elastic loads. So as you all know that most of the consumers are priced elastic in nature.

That means if the energy cost is more then we start consuming less energy but if the energy cost is less then we naturally start consuming more energy and that concept is known as electricity price elastic. Now there are few loads those who are price dependent once you say the energy is very costly to you because you are trying to match a costlier customer to a cheaper energy generation company. So if the price is too costly for consumers then they will behave differently and start consuming less energy. So when they consume less energy then your generation which is available to you will be underutilized. So you have to be very careful and you have to consider the impact of elastic loads during your simulation.

Now maximum worth of a load served and minimum cost of generation while meeting all transmission constraints. Now since the optimal power flow is a minimization then the OPF objective becomes minimizing the consumers cost minus the generation cost that is:

$$\sum_j F_i(P_i) - \sum_j W_j(P_j)$$

where Wj is the load worth function expressing how much load will be purchased at the standard price. Now we have to optimize the generation and load auction. So we have to minimize the generation minus W load and we have to also make sure the P generation equal to my P load. Now the Lagrangian function that need to be created which is:

$$\min F_{gen}(P_{gen}) - W_{load}(P_{load})$$

And

$$P_{gen} - P_{load} = 0$$

$$L = F_{gen}(P_{gen}) - W_{load}(P_{load}) + \lambda(P_{gen} - P_{load})$$

You have been taught how to optimize a Lagrangian function in the past and probably a optimized market environment problem also can be solved similar to our classical economic dispatch problem. Now the similar you can differentiate equal to zero and the demand price curve representation where you have to make sure dF of generation upon dP generation equal to dW load upon dP load.

$$\frac{dL}{dP_{gen}} = \frac{dF_{gen(P_{gen})}}{dP_{gen}} + \lambda = 0$$

$$\frac{dL}{dP_{load}} = \frac{-dW_{load(P_{load})}}{dP_{load}} - \lambda = 0$$

Where, $\frac{dF_{gen(P_{gen})}}{dP_{gen}}$ and $\frac{dW_{load(P_{load})}}{dP_{load}}$ are the supply price curve and the demand price curve resp.

$$\frac{dF_{gen(P_{gen})}}{dP_{gen}} = \frac{dW_{load(P_{load})}}{dP_{load}}$$

Now if you plot the characteristic between power and price you can see that there is a supply curve and there is a demand curve. So if you arrange costlier consumers versus cheaper generator you will get a clearing price point where all the consumers ready to pay more than what is being sold then only they will be successful and rest of them will be declined. For an example if the energy cost is rupees 10 and if I am ready to buy for rupees 8 certainly I will be discouraged and similarly if the consumers cost is 10 someone ready to buy for rupees 10 and you are selling with actually rupees 12 that combination is not going to work.

So the intersection between supply curve and the demand curve is known as clearing price and sometime popularly known as market clearing price. Clearing price is where the supply price and the demand price are equal for the same amount of power. So let's focus on a very interesting example considering generator 1, 2, 3, 4 and with different cost coefficients of A, B, C and with minimum and maximum capacities. Now it is a 6 bus system basically so if you see those cost characteristic it will tell you that the P minimum is the 50 for first generation, 37.5 for the second and 45 for the third and the P max is going to be 200, 150 and 180.

The generation and load bid functions are available to me that means one consumer may say I am generation company may say I am ready to sell my energy with this characteristic and this is my block that I am ready to sell. Now the cost characteristic that is F of P is given by A plus BP plus CP square we have already discussed in the past and similarly the load consumer also may offer a cost characteristic which is non-linear that is A plus BP plus C square load CP square load. Now if you see there are 6 buses where generations are going to be 72 to 180 and 108 and rest 3 of them are not encouraged similarly in case of load the 3 load points 4, 5, 6 they are interested to have 100, 100, 100 each. Now the question is to satisfy the 3 consumers of 300 megawatt I need to accommodate 3 generation companies with 3 different loading depending upon their costings and finally when there is a match the lambda of the system which has to be equal that is 12.44 for an example if there is no line limit.

If there is no line limit what happens the optimal generation cost or the value of lambda that we used to obtain in our economic dispatch remains same across all the buses because there is no transmission losses considered in this problem. But if you consider the transmission losses or line limit then the lambda is not going to be same across the board. So for example if you say 2 to 4 and 3 to 6 are hitting the limit to 60 megawatt then probably the generation and load match will now differ and due to that difference the lambda at each and every bus will be slightly different. So what we wish to conclude here if the problem is having some constraint in line limit violations then the lambda that is the energy cost rupees per megawatt hour will keep on increasing as and when you violate line limits. The bus lambda is now different and not all loads are served.

So when there is a line limit violation that means you cannot satisfy all the consumers and there could be a curtailment on your loads. Now interpretation of bus lambdas from an OPF with generation and load weights. The lambdas are prices at each bus as you know called the locational marginal price LMP. The generators are paid the LMP at the generator bus.

The loads must pay the LMP at the load bus. The market operator collect the load payment and pays to the generator. When lines are at limit and lambdas differ there will be a surplus which is used to pay for financial transmission right that is called FDR payments. So when the lambdas are not sale then you start gaining profit and that will be used for your financial transmission right payments. Now an independent generator can purchase an FDR as an insurance policy against the possibility that the transmission system will not allow a desired transaction from a point of delivery to a point of receipt. So that means you can also ensure your transaction to make sure that if you bid for a particular transaction it must be taken care if not then you will be paid certain insurance money because you are not successful in your transactions.

There is one important concept known as security constraint unit commitment that means you will be committing all your units for a day for an example 24 hours but also you make the system is secure that means you are not violating any line limit or any device maximum minimum limits. Now bids from the generators and loads for 24 hours period starting at midnight of the next day are collected. The unit commitment uses a security constraint OPF within the unit commitment to dispatch generation and load so that the supply demand curve is met for each hour and the security constraints are met. You see unit commitment is an optimization problem but in the process of cost optimization you cannot violate certain security constraints. So if you have to protect your security of the system and as well as you to minimize your cost and that is known as security constraint unit commitment problem.

The results is a unit commitment for the 24 hours period and the LMP values for each hour for each bus. I think with this we stop here today. Thank you very much for your kind attention.