Economic Operation and Control of Power System

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Lecture – 39

Good morning everyone and welcome you all for the NPTEL online course on Economic Operation Control of Power Systems. In today's class we will discuss about power system security. In the last class we discussed about load flow studies transmission line effects. So, then we will discuss about power system security aspects today. So, why power system security is very important? So, there are two live examples with us 2012 there was a big power outage in this country and there was huge socio economical impact that was seen. And in 2003 also in New York there was a blackout 50 million people lost their power, city swelters to a halt and rush hour cavos today.

So, this was the news in daily news in 2003. So, power system security is very important because the entire life is dependent on electricity. If there is a blackout there is a severe threat to the national security and also life of the people. Some emergency load somebody sitting in ICU and if there is no power you cannot imagine the life actually.

So, the main concern in power system operation is to minimize the operating cost no doubt, but very important operating factor is maintain system security. You give power at the most economical manner, but ensure that you also maintain system security this is the topmost priority of any system operator. So, system security practices designed to keep the system operating when components even fail some of the components even fail. For example, a generator must be taken offline because of auxiliary equipment failure. If there is a issue with one specific generator there is a fault within a generator then that generator has to be taken out, but we ensure that with proper spinning reserve I discussed about this spinning reserve in the previous class.

So, with spinning reserve the remaining generators can make up the deficit that is what we consider as there is n minus 1 continuously one generator out still system is supposed to cater to the requirement of the load. System is served without too low a frequency drop or the need to shed any load. So, there are two options if there is a line out if there is a generator outage then the either you have to shut down the load. So that you can meet out the remaining load with the available generators. The other option would be to maintain this proper spinning reserve such that you will not allow sudden frequency drop and yet you maintain the power system security and keep feeding the existing load.

So, the timing of initiating events that cause components to fail are unpredictable the fault when it happens how it happens we do not know right. The system must be operated so that any credible event will not put the system in a dangerous situation. Power equipment is designed to operate within known limits there are limits for each and every component. So, it is designed to operate within the known limits like protection devices automatically switch out equipment that exceeds the specified limits. There are relays and circuit breakers placed if there is a specific violation of the limits thermal limits or voltage limits or whatever then it is supposed to take out the take out the specific equipment.

If an event leaves the system operating within the limits violated the event may be followed by a series of further actions that switch other equipment out of service. So, what happens is if you continue to you know consider that faulty equipment within the system that will eventually lead out to the damage of other equipments in the system. If the process of cascading failures continues large parts of the entire system may completely collapse that is a system blackout. I keep remembering this example let us say if there is a cycle stand you know there is a cycle stand you might have seen so many cycles are present and you if somebody comes and puts a parks a cycle and he does not park it properly and that will fall on another cycle is a cascading failure series of cycles will fall down. So, if one bad element in a system can trigger the entire stability of the network.

So, N minus 1 rule is very important no single generation outage will result in so large a frequency drop that other generators will be forced offline. Any generator you pick up and you assume that if this generator is for time being taken out from the system whether still I am able to maintain the system stability in terms of voltage stability, frequency stability and other things. No single transmission or generation outage will result in other components experience experiencing such a large flow or voltage change that new limit violation occurs right. We should not allow the new limit violation to take place otherwise cascading outage may take place. So, there are three major functions of system security one is system monitoring, contingency analysis third is security constraint optimal power flow analysis.

What is system monitoring? It provides the operator with up to date information on the conditions of the power systems. This different monitoring devices placed over the transmission or distribution corridor to help a system operator to understand what is the system state like you place PMUs phasor measuring units and you keep you know RTUs and different monitoring devices CTS, PTs and all these things are placed such that you get a real time information about the system operating conditions. What is the voltage? What is the phase angle frequency and all these parameters? So, these are the critical vital elements required to understand the health of the system. So, that you can take appropriate action to ensure system security is retained throughout the operation of the power system. What are those critical quantities like voltages, currents, power flows and the state of circuit breakers and switches and also frequency generator outputs and transformer tap positions these are some of the critical parameters.

So, the measurements are sent to the control center central via the telemetry system and action is taken place. So, further the computers collect the telemetric data process and store them in the central system and display information for the operators right. The computers checks information incoming information against pre-selected limits and enunciates alarms in the event of overloads or out of limits violations. So, state estimation combines the telemetric system data with the systems network model to produce the best estimate of the current power system condition or state. See you understand the in real time you are collecting information through different means and there is a system where you are receiving this information and then you check the available data with the existing limits.

There are limits for each and every data voltage has specific limit, frequency has a specific limit. You ensure that they are within the limits and before that what you have to do is whether the data that you are getting whether is it a reliable data or not. Let us say there is a measuring device sitting, how much reliability, how much trust that you can put on this data that is also very important that is why we go for state estimation. There this the measuring device could be functioning well, but maybe next moment there could be some malfunctioning or there could be some errors. So, there is some mathematical procedure to understand whether the data that you are getting is it a reliable data or not.

We we put some weightages and there is a systematic procedure I will discuss in detail about state estimation, but this is a mathematical understand to have a second level of validate validation proof to ensure that the data you are receiving is a valid data or not or it could be a bad data. And then you check with the limits and still the if the data that you have received the voltage and frequency they are within the limits then you can consider that system is safe otherwise you give alarm and then take the next actions such that you know the system stability will be maintained. So, combining monitoring functions with supervisory control actions forms a supervisory control and data acquisition this is called as SCADA. You collect the data supervisory control and action will be taken place this is SCADA system. So, across the entire country the SCADA operators will be there they would ensure the system will operate very properly.

So, regional load dispatch center, state load dispatch center and finally, national load dispatch center NLDC. So, the different levels a hierarchical control action will be taken place. So, that the entire national power system security is not violated. So, next is contingency analysis first is monitoring next is contingency analysis. So, this is the second important function of system security.

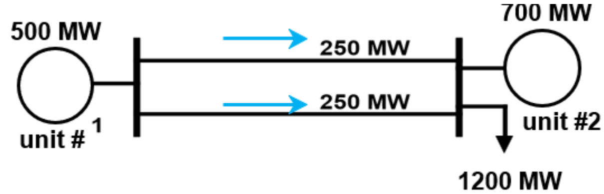
So, it allows the system to be operated defensively. Many problems in power systems can cause serious trouble within a rapid time period and the human operator cannot respond fast enough. So, this leads to cascading failures. So, models possible system troubles before they arise. So, using a model of the power system a computer algorithm predicts future operating states and gives alarm to any potential overloads or out of voltage limits.

There is a famous saying in English like prevention is better than cure. So, this is what we are planning here forecast the future issues and ensure that you know you are ready to receive those kind of critical contingency events. So, security constraint optimal power flow is a third important function. So, this analysis provides a solution to the optimal dispatch of generation with a large number of system constraints. Other adjustments are made to the dispatch schedule.

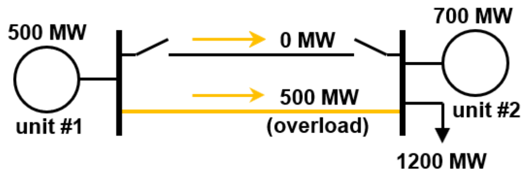
So, that a security analysis results in no contingency violations. The power system may operate in any one of the four states. There are four different states that we have thought of presenting before you. So, first is optimal dispatch. The state of the system prior to any contingency event ok here the optimal with this is optimal with respect to economic operation, but may not be a secure solution and post contingency that means state after contingency has occurred.

This condition has a security violation there could be line violation, line overload or voltage limits can be there. Here you see there is security dispatch and secure post contingency. Already there is a term secure attached to it that means the system is under security that you can assume. So, state at no contingency with dispatch schedule corrections to account for security violations and secure post contingency means state after a contingency with no resulting security violation.

So, I will illustrate them. First is optimal dispatch. Let us take this is a system:



There are two generators here you can see here. One is 500 megawatt and 700 megawatt unit 1 and unit 2 and there is a line there are two lines each has a maximum line loading capacity of 400 megawatt right and there is a load which is connected at bus 2 which is 1200 megawatt.

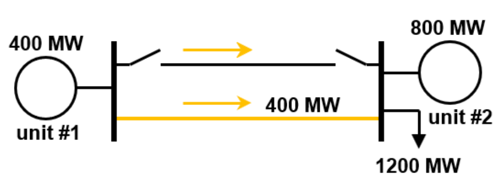


Now, what is happening? So, there is 700 megawatt being supplied by the unit 2 remaining 500 megawatt is supplied by unit 1.

There are two lines so it is divided across them 250 each. Each line loading capacity is 400 megawatt right. So, there is no violation here optimal dispatch is happening. Whereas, in the post contingency you can see consider that a transmission line has opened because of a failure. If there is a this first line is gone, but what is happening? Now 500 has to flow through only one line, but there is a overload.

Next secure dispatch. Now what is happening? Unit 1 generation set to a maximum secure line loading of 400 megawatt. Now what we have done earlier the unit 1 was supplying 500 megawatt. Now reduce the generation of unit 1 to 400 and increase the generation of unit 2 to 800. So, what is happening? So, even if there is a possibility of line violation still this cannot happen the violation cannot happen 200 each is being supplied from the each line right.

Now what is happening? Consider the same contingency resulting in no violation.



If there is a violation in the line what is happening? If there is a line outage what is happening? Then because you have reduced unit 1 now 400 is being flown from bus number 1 to bus number 2 and there is no violation in the power flow of the line. So, system security is maintained in this case. So, remains post contingency line overloading is avoided by adjusting the generation on unit 1 and unit 2 before an event. Before an event itself we have adjusted it. So, this is the essence of security corrections.

So, programming tools that make control adjustments to the pre contingency operations to prevent violations in the post contingency condition are called security constraint optimal power flows or SCOPF you understand. So, there are certain programming tools that will make appropriate control actions such that before the contingency itself we will take appropriate actions to ensure that post contingency condition there is no limit which is being violated. So, then there is generator outages we spoke about line outages. So, the three possible reasons can we say there power imbalance between load and generation right and there is a drop in frequency. This can have effect on other generators.

If there is imbalance between power then one generator could be overloaded another generator may not be much loaded and there is a drop in frequency then the remaining generators have to cater to the requirement. If there is one drop in generator because of which there is a drop in frequency and there is in a burden on the rest of the generators there is a effect on other generators and there is insufficient spinning reserve is available or generate other generators can go out due to drop in frequency. This is lack of spinning reserve is another reserve right. So, changes in line flows as generation is shifted to other generators. So, lines can be overloaded or bus voltages drop due to flow changes and loss of generator where support.

So, if there is a damage in one line or increase in line flow at one specific line then they may get overloaded and voltage drop can happen. I will you know go through some case studies also and there is a line voltage means flow shift to remaining lines. Remaining lines can overload reactive losses increase on the remaining transmission lines right because I square R loss increases in that line and then bus voltages may drop below acceptable limits also because of drop voltage drop. So, let us you know discuss something about reactive effects on reactive power effects of transmission line outages transmission loss means transmission line outages. So, reactive loss on transmission system increases due to increased line current flow during transmission line outage.

See this is the line loss I square L x L right. Now reactive power injected into the system from line charging capacitance decreases as the bus voltage drop during line trip. If there is a line trip there are line charging capacitance present in a long transmission line you might have seen there is a charging capacitance between present between ground and a transmission line. So, there is a line charging capacitance present because that line is out now that line charging capacitance is also not present. That means from between the from there is a transmission line.

So, from end of line to end of line starting point of the line to the ending point of the line there are some significant amount of charging capacitance which was present. Now that is not present, that is been taken out. So, this represents that power capacity V square by x or V square into susceptance. So, from at the starting point and at the ending point.

So, now this is been taken off. On one side there is a increase in line loss because one line is been taken out remaining lines there is a increase line loss and there is because of absence of charging capacitance the capacitance which would have supported for reactive power that is been taken off. And then reactive injection from fixed capacitors there is also a physical fixed capacitors present within the line and that is also not present because the line itself is not present. So, that is also not able to meet out the expectation. On one side there is a increase in reactive power flow through one line and and because of its loss is increasing and other side there is a lack of reactive power support because of absence of charging capacitance and this shunt capacitors present in the system. So, what happens? Increased VAR loss and decreased VAR injections into the system may cause generators to hit their VAR limits because the support FACTS devices shunt capacitance are not present.

Now generators will be overburdened because load remains the same generators will be overloaded and line the remaining existing lines that will also get overloaded and because of which there is further increase in line loss and this is a cascaded failure. And ultimately it will result in generator terminal voltage to drop making it even worse. If voltage drop increases then there is further expectation from generator to increase the reactive power okay. As a consequence of several major widespread blackouts in an interconnected system operation priorities have evolved. Operate the system so that power is delivered reliably right.

Within the constraints placed by reliability considerations operate the system most economically. It is highly uneconomical to build a system with sufficient redundancy to eliminate this possibility of dropping a load, but it is also not possible to keep 100 percent reliability factor in any situation. Let us say 1 N minus 1 contingency is acceptable, but let us say you cannot prepare your system for N minus 4, N minus 5, N minus 6 you cannot have such sort of spinning results present that is highly uneconomical. So, there is sort of tradeoff should be there. So, no guarantee for 100 percent reliability in no country can give actually to such an extent.

So, systems are designed and operated to have sufficient redundancy to withstand all major failure events, but not for the consideration of 100 percent reliability. So, within the designed and economic limitations the system operators try to maximize the reliability of the system at any given time. Considering economical limitations and also design limitations will try to maximize the reliability to the best possible extent. Usually a power system is never operated with all the equipment in service at one time. You see here there could be occurrence of failures and maintenance some of the equipments may not be there.

So, always it is planned to you know augment consider this absence of certain equipments and there is reserve capacity is present. So, that is there, but not for 100 percent failure. So, the operators are concerned with possible events that cause trouble on a power systems. So, therefore, two types of critical events that is expected one is line outages and there is a generator unit failures. So, line outages and unit failures cause changes in power flows and bus voltages which impact the remaining system equipment.

So, consider the 6 bus network. A typical constraint of the system is the maximum loading that a transmission line can carry. This is expressed in MVA. The flow on a line may increase due to contingency in the system that due to line voltages or generator unit failure. Other operating factors that are impacted include the bus voltage and the generator output to make up the load capacity. So, how do you make up the load capacity? If there is a outage then one single generator or a slack generator may pick up all the lost generations or the generators may share in picking up the lost generation.

There are multiple generators either collectively they can share or one single generator may be asked to meet out the expectation. So, I will take the example. This is a 6 bus network. You see here there is bus 1, bus 1, bus 1, bus 2, bus 3 and there is a bus 4 here, this is bus 4, there is a bus 5 and there is bus 6. At any given case this is the voltage profile you see at 240 volts, 240 kilo volts.

Typically 240 kilo volts, 230, 226 and 227 more than 220 kV. So, it is a transmission level, right. x by r ratio is very far greater than 10 or 20 let us assume, x by ratio it could be 10 or 20 greater than 10 or 20 and there is some typical line flow which is happening in terms of megawatt and time we have. So, this is the operating scenario. Now, let us consider a case where if line 3 to 5 is taken out of service due to a permanent transmission line fault.

So, what is happening here is line 3 to 5 that means there is a bus which is present at there is a line which is present between bus number 3 and bus number 5 that means this bus this specific line. Due to some reason now there is a fault and this line is been taken out from the system. It was carrying some active and reactive power. Now, this power has to flow to bus number 5 via bus number 6 and now this line is gone now there is a path present here actually, there is a path still present.

Now, this line will have to carry the remaining power. So, what is happening? The flow on line 3 to 6 has increased to 54.9 megawatt. It has increased now 3 to 6 that means these lines. There is a line between bus number 3 and 6 and there is a increase in power flow which is happening.

I will show you that. Earlier you can see here this is 43.8 megawatt and 60.7 MVA are now that will increase now. I will show you here. You can see here there is increase in flow 54.9 and 64.6. There is a increase in active and reactive power flow because one line is gone. You can see here it is 0 megawatt and 0 MVAR that means this is not carrying any power. Most of the other transmission lines experience a change in reactive power flow. Not only that other lines you can look into the pictures, other lines also there is small change in the active and reactive power flow.

The bus voltages at the load buses are impacted. The voltage magnitude at bus 5 is about 5 percentage below normal. You can see here that earlier at bus number 5, this is a load bus, the voltage was 226.7 kV. Now what is happening is due to line voltage, it has decreased to 219.3 kV. Why this is happening? You can see here there were two parallel lines present. There were two parallel paths between bus 3 to bus 5. Now let us simply consider this line impedance as x and x. Let us consider for time being same.

So, the line total impedance will be x by 2 because they are parallel. Now this impedance is gone. Now the overall impedance is just x that means it has doubled. Impedance is doubled but the power has to flow. The current is also increased that means there is a double in the effect of reactance impedance as well as that current also.

So, what is happening because of which IR drop or IX drop will increase. Because of increase in drop, there is a decrease in voltageat the receiving end. So, from bus 3 to bus 5 and this may lead to violation of the voltage limits. You understand the effect of line voltage on the limits. So, this is one typical example. Now another case, show the impact on the system when generating unit at bus 3 is taken off due to steam pipe.

There is some fault in the steam pipe and steam pipe generator 3 is gone due to some reason. The loss of generation is picked up completely by the slack bus generator or bus node 1. I will just show you that. So, this is the case. If there is a generator which was present, now this is not generating any power and because of which there is a at node 1 means this one.

Earlier this was generating some 108.5 megawatt and 29.8 MVAR. Now because this 60 is gone, 60 and 68 is gone, now this is shifted to this generator. That is why you can see here now this has increased to 175 and 16 point something like that. So, there is a change. You are intentionally giving command to this specific slack generator assuming this is a slack generator. You give this command and increase its generation such that you will meet out the expectation.

This is how you manage or you can also collectively divide among the different generators. There are two generators, you can share among them also. It is up to a individual to take a call, system operator to take a call This is what we have considered and next class also we will be discussing the continuation of the system security and then we will take up the further topics in the further sessions. So, with this I will conclude. Thank you very much.