Economic Operation and Control of Power System

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Lecture – 38

Hello and good morning everyone. Welcome you all for the NPTEL online course on the Economic operation and control of Power System. We are continuing with our real time case study on reactive power dispatch and coordination among multiple voltage regulating devices. In the previous class we have also learnt, we have taken a small system it is IEEE 33 bus distribution system, it is IEEE 33 bus distribution system. This is a radial system and this is also balanced system. Usually practical distribution system is unbalanced.

So, for study purpose this is a balanced system as per IEEE standards that we have taken this system. So, there are certain loads each bus has a AC load, each bus has a load in it, there is a load in at each bus and one can get the data of 33 bus distribution system through internet. So, we have not displayed the data. So, each bus carries some load and at certain buses you can see here we have considered a load which is different from a IEEE 33 bus distribution system.

So, we can call this as a modified IEEE 33 bus distribution system, slightly modified and also we have considered DFIG of 1.1 megawatt DSTATCOM and DC microgrid which consists of DC load, battery and a PV as well. So, which is connected to the bus number 5 via the inverter. So, OLTC as I already discussed is part of the system which helps to maintain the voltage profile at of bus bus number 1. Basically it tries to sense the bus number 1 voltage you can see here Vm1 it is sensing and then when the voltage of this specific bus is they will keep some dead band sort of thing there is a dead band.

So, if the voltage let us say the dead band is 0.005 per unit or something like this and there is some dead band. So, if the voltage should from 1 per unit if the voltage deviates 1 plus dead band or 1 minus dead band then only the OLTC will consider thus that as a time for action and this voltage deviation which is a dead band voltage should be existing for certain duration also. So, there is some time delay time or whatever you can consider some time. So, some time should this deviation should exist for some duration minimum duration then OLTC would consider and then based on the voltage deviation is positive or negative it would change its stop tap upwards or downwards I have already spoken plus or minus 16 taps change in the voltage which each tap each step change or each tap change is 0.00625 per unit we have already discussed this. Now the idea is in a decentralized fashion device is operated under coordinate voltage regime without communication without communication refers to decentralized operation. That means, now there is a voltage regulating devices present here the DSTATCOM is one such voltage regulating device DSTATCOM is one voltage regulating device and the DFIG's converters can also help to maintain the voltage of this specific bus bus number 22 and then bus number 5 voltage profile can also be monitored and tried and help we can help to control this bus number 5 voltage through the inverter. So, basically inverter associated with the DC microgrid basically we have three buses which are on direct control from the voltage monitoring device bus number 1 bus number 22 and bus number 5, but since it is a radial network and they are all interconnected even if you try to maintain the voltage profile of one specific bus it will have an impact on other buses also. So, as I already told in the beginning also that the bus number 18 would suffer with the minimum voltage because radial network.

So, can we somehow manage this voltage regulating devices even without communication because when communication is placed there are multiple challenges also will come along with the communication. That means, there will be communication delay there could be cyber attacks there could be you know communication failure also. So, multiple challenges are placed. So, and cost also will increase. So, we are saying in a decentralized fashion without communication among any of these voltage regulating devices can we able to manage the voltage profile bet, but can in a better manner among compared to the without coordination scheme without coordination or existing scheme.

And also in a way we are trying to improve the overall reactive power reserve in the system. So, voltage stability is decided based on the ability of the system to offer reactive power reserve reactive power during the emergency situation basically that decides how much stable the voltage the system is about. So, owing to any severe faults or any temporary faults whatever. So, these are the objectives. Now, let us try to understand how we have worked out.

So, first of all we have designed or we have considered three operating scenarios of the system. One is called as a steady state. This is steady state and second we considered as a dynamic state and third we have termed as a transient state. The steady state is decided based on any state is decided based on two things. One is the voltage profile voltage profile, second thing is the reactive power injection from the fast acting converters as expected during that specific state.

So, it is not a standard definition as such for our easy understanding and for maintaining the better reactive power reserve. So, we have considered these three states. So, during steady state the voltage profile will be within the range of 0.92. The voltage is greater than voltage is greater than 0.9 per unit because it is a steady state. Voltage is greater than 0.9 per unit and reactive power required is less than 40 percentage. That means, there is a small deviation in the voltage profile due to small switching of the loads reactive power loads. Whereas, the dynamic state is the same voltage profile voltage is greater than 0.9 per unit whereas, the reactive power injection expected from the fast acting converters is 40 percent more than 40 percentage of their available capacity. So, why this is there? The difference is there because there is some heavy load switching maybe the induction motor coming up due to which there is a significantly higher number of reactive power demand from the system. And there is something called as transient state. This is the emergency state where the voltage profile due to some fault falls down below 0.9 per unit and this is a emergency scenario.

So, you want all your reactive power injection devices especially the fast acting converters to exercise maximum their capacity during this state transient state. And one more thing is during dynamic state though the reactive power injection expected from the fast acting converters is greater than 40 percentage we hard limit it. That means, we will not try to you know meet out the expectation we hard limit it to 40 percentage. So that we can have some bare minimum reactive power capability reserve for the transient state because fault can happen any time we do not know. So, we should have some reactive power reserve.

So, this is the definition that we had considered. Now, we have proposed a coordinated voltage control scheme which is a decentralized scheme as I already told and we have compared with the existing scheme. Now, I will just go through you with the existing scheme before we had proposed this coordinate voltage control scheme to help you understand what was the state at that time. See the existing scheme first of all it would determine which state the system belongs to based on the voltage profile. Now, if the voltage is within the range of 0.9 to 1.1 per unit is steady state or dynamic state and then we will check whether the voltage is 1 per unit or not. If the voltage is 1 per unit certainly there is no action expected from the fast acting converters and they can sit ideal. So, they have considered is reactive power injection for all these fast acting converters which is a STATCOM grid side converter pertaining to the DFIG wind system and DC microgrid converters, inverters are 0 right. But if and then if not the case that means if the voltage is not 1 per unit that means it is deviated then the this existing control scheme will check whether the reactive power injection expect is less than 40 percentage or greater than 40 percentage. That means we are determining whether it is a steady state or dynamic state basically.

So, if it is a steady state then all the fast acting converters are allowed to play a master role. Here master role means they are allowed to freely inject reactive power without any boundaries. They can freely play, they can freely pitch in to execute the reactive power injection. Whereas if it is the reactive power injection greater than 40 percentage then it would be hard limited to 40 percentage. That means even though it the demand is more than 40 percentage we are not injecting more than 40 percentage of its capacity.

So, and what about the OLTC? OLTC would do it action as I already indicated it would sense the voltage and then if the voltage deviation is beyond the dead band and for minimum duration of some time the deviation exists then it would tap change the tap accordingly. Now this is the action and during the transient state OLTC cannot act. Henceforth we consider OLTC to be in slave mode. During steady state or dynamic state OLTC all the fast acting converters everybody is every player is acting in a master role. During the transient state OLTC cannot perform only because the voltage is less than 0.9 per unit and we have already discussed that the range of operation of OLTC is within the range of 0.9 to 1.1 per unit. Because the taps change taps are designed pressurize 16 taps to operate it during this voltage deviation. Now OLTC cannot act at all and this fast acting converters they would be allowed to inject reactive power as per their capacity.

But still DC microgrid converter is considered to be slave here because it is been isolated from the system because there is a fault and the system is isolated. Whereas the D-state com and wind grid converter they are operating in a master role. They are injecting reactive power up to 100 percent of its capacity. But the problem with this scheme is during especially during steady state and dynamic state you see here OLTC which is a sluggish device and fast acting converters are also they are fast in response everybody is operating in a master role. So even a small amount of reactive power injection from this fast acting converters may stop the OLTC to complete its action.

So that means we are not able to utilize OLTC to the best of its ability. So what we are trying to say is let us propose some CVC scheme which can help to operate OLTC which can allow OLTC to freely exercise then we can ask this fast acting converter to act if it is required. So what the changes we have done? First of all everything looks same only thing we have inserted is this part. First of all we will check if there is a change in voltage and if there is if there is a steady state or dynamic state where once we determine it is a steady state or dynamic state. First of all we will check whether the voltage is is equal to is less than or equal to 1.1 per unit or point greater than 0.9 per unit and then we will see we will issue a delay period, delay time before the operation of the fast acting converters. So once this delay time is passed then only the OLTC is allowed to act then only this fast acting converters are allowed to act. During the delay period that means we are giving a pass before the operation of this fast acting converters. So that we are giving some extra time for OLTC to complete its action then if at all if there is a voltage change and still if there is a reactive power required then the fast acting converters are allowed to act and rest remains the same.Now the question is how much delay to give? How much delay to give? So there is a small delay which is expected I mean let us say if we there are two possibilities if we give too much of delay then it is not good from the system point of view. If we give if we do not give any delay then there is no difference between the existing scheme and the proposed scheme which will not have any improvement in the reactive power region. Voltage profile will not be also improved. So how much delay to be inserted that is a very critical thing here. But there is no communication also between any of the buses that makes challenge even more complicated.

Because if there is no communication I do not know whether the OLTC has completed its action or not. So how much delay is too much? How much delay is too minimum, too less? Now to sort out this issue we have come up with some idea. So before that I will just help you go through the different stages. First stage is identifying the operating conditions of the grid. Steady state, dynamic state or transient state will just sense the voltage pertaining to that specific bus.

So with PT or whatever then you get the voltage information. Determine which bus I mean we are in which stage, steady state, dynamic or transient state. Checking the availability of the device and assigning the master or slave role. It is required to first check for the availability of the device for particular operating condition before assigning any role for it, right. OLTC and DC microgrid are present during steady state and dynamic state because DC microgrid will be disconnected during fault and OLTC cannot act because it is designed to operate during 0.9 to 1.5. So whereas wind grid side converter and DSTATCOM, they are available during all states. So it is natural to consider that though wind grid side converter and DSTATCOM can be considered master throughout all the situations, all the states, we do not want to do that because we want to improve the reactive power reserve. So now third stage is the very critical stage. That means introducing the time delay in operation. An intentional time delay is inserted for all the fast acting devices like wind grid side converter, DC microgrid converter and DSTATCOM.

For all the fast acting converters and intentional time delays introduced. This ensures that the slow acting OLTC would complete its action after which the fast acting devices are allowed to operate. The minimum delay time is calculated for each and every bus where the fast acting converters are connected. If the waiting period is less than this delay time, then OLTC might not complete its action. You understand? This is a very minimum time delay.

How to understand this? How to calculate this? So we have come up with this expression.

$$t_d = \frac{(|1 - v_{busx}(pu)|) * t_{OLTC}}{v_{OLTC}}$$

So what it indicates? The delay time for that specific bus and this delay time for the converters also varies. It is not fixed. Now that is depending upon that bus voltage, difference between one per unit, the nominal voltage and the actual bus voltage where that fast acting converter is placed and time of operation of OLTC and voltage is per V OLTC is per unit change in voltage due to single tap change of OLTC which is 0.00625 per unit. This is a constant. So how we have come is, the understanding is we have assumed a fictitious OLTC to present to be present at each and every bus where the fast acting converters are present. We have assumed there is a fictitious OLTC. OLTC is not present physically. We have assumed instead of this fast acting converter, let us assume the OLTC is present there. If OLTC is present, it would certainly take some time to complete its action because we know what is the voltage profile at that specific bus.

To that voltage how much time the OLTC will act? That we can able to understand. That is what is this TD. Because time of operation of OLTC is fixed, that is known for one change, one step change in tap, how much time it would take, that is known. And what is the change in voltage is also known.

So for one, one let us say I am telling, for 0.00625 per unit change in voltage, so and so time is required. This time is known to us. And if that is the case, for V it is a voltage profile of that specific bus. So V bus x per unit, for this is the change in voltage, how much is the time required? So that is nothing but 1 this into T OLTC by V OLTC. Now that means this is a fictitious OLTC operating time.

Now by giving this as a time delay, the real OLTC which is present in bus number 1 will certainly complete this action because it is a radial network. It is a radial network, the bus where we have considered is bus number 5 and bus number 22. Since it is a radial network, the bus voltage at this buses will be less than the bus voltage which is where the actual voltage is present, which is bus number 1. So if we at least take this time delay, it will be naturally understood that the physical OLTC would have completed its action sitting at bus number 1.

So this is what we have done actually. Taking the advantage of radial in the network, so now this is just a execution of whatever I have told in RTDS platform. So there are different blocks in implementation. First of all we calculate the change in the error in voltage at specific bus and this is the delay time that need to be executed. And then we have reset the clock. That means if there is a change in voltage, the clock will begin to ensure that we wait for such time.

There is a clock we have inserted. So once this clock is done, then we will sense the voltage. Let us say this is bus number 5 execution. There is a reference voltage 1 per unit and there is actual voltage. So the change in error is passed on to the AC voltage, it is a PI controller. So this output of PI controller, that means this loop will activate only we pass on this delay time, only we pass on this delay time.

And then if it is, the delay is passed and still there is a change in, there is an error present, then what happens? Then there is a reactive power command which is issued. And then block C would ensure that it will generate a modulation M, modulation M which varies from 0 to 1, modulation index, we call it as MI, right? So and then based on this we will generate the switching pulses and pass on to the particular inverter. So that is what we have done. So basically the essence is the voltage control loop would be into action once the delay period is passed on. And these are the control loops for PV, DC to DC converters and MPPT, battery and other things.

So that is not required. So what is the result? You see here, this is important to observe. So we have compared with the existing scheme which I have already discussed where they consider steady state and dynamic state, during steady state and dynamic state all the voltage regulating devices to be playing a master role, OLTC and fast acting converters. Whereas in our case we are not allowing fast acting converters to play a master role. And then there is a without CVC scheme.

That means half a sadly everybody is acting. There is no intellectual control which is monitoring any of these devices. You place everything, all the voltage regulating devices, they are acting on their own. So we have compared them. The blue colour one is proposed, red is existing, black is without, black colour one. You see here the advantage is in the blue colour one, you see here there is a delay time.

We are not injecting any reactive power. Whereas the existing CVC scheme, this is a hard limit, 40%. So it is, it sense there is a dynamic state sort of thing. It senses and reaches 40%, it is hard limited. Whereas without scheme, it keeps on injecting reactive power, black one.

So there is no boundary for it. So because of which you can see here, there is an increased reactive power reserve. You can see here there is a black means without and there is a red means existing. There is an additional reactive power reserve which is being preserved in the case of proposed CVC scheme as compared to the existing and without. And because we have preserved the additional reactive power reserve and we are optimally utilizing the OLTC, you can see that the overall voltage profile in the system also is improved. The blue colour one you can see here, there is a change in, there is an improvement in the voltage profile of the, all the buses, it is IEEE 33 bus distribution system.

In all the buses there is an improved voltage profile. And during transient state, that means we have considered a temporary fault for a duration of 150 millisecond. We could see that because now we are pumping more reactive power into the system during transient. You can see here, this is for DSTATCOM and this is a wind grid side converter. You can see here the proposed scheme, they are starting from 0.

2 MVAR whereas existing and without scheme they are starting from 0.4 or something. That means we have around 0.2 buffer, 200 KVA of buffer already there. So that additional reactive power will help to reduce the post-fault voltage recovery time. That means once the fault is cleared, now the system would bring back the voltage back to the 0.9 per unit. Now the fast acting converters are also supporting by injecting additional reactive power reserve. But in the case of proposed scheme, it is even better compared to without and existing. So that means we can reach 0.9 per unit from the fallen voltage up to 0.5 per unit quicker compared to the existing and without. That means we are trying to recover the system voltage profile from the abnormal situation to the normal situation much quicker compared to the without or existing scheme. So this is the advantage. So during steady state and dynamic state, voltage profile is improved. During transient state, the post-fault voltage recovery time is reduced. So and then we have validated, I discussed about power hardware loop experimentation in detail.

So what we have done is the DC microgrid part, initially everything was present in the simulation. Then we removed this DC microgrid from the simulation RTDS and we have developed a hardware microgrid, DC microgrid to validate the results of simulation. And then the power amplifier was present and then we validate the results.

You can see here these are all PHL results. These are all PHIL results. This is in match with the real time simulation, simulation results. And then we further improvised this our own proposed scheme. That is what we call it as improvised novel coordinated voltage control scheme. The improvisation and we compare with our own proposed previous scheme.

Anyway proposed scheme was proven to be better than existing and without. Now there is no point improving against again with existing and without. So we have just compared with improvised that is even better scheme compared to the previous scheme. What we have done is here, there are two changes that we have brought in. The time dealer concept remains the same.

The two changes makes the results even better. The first change is during the previous scheme, our previous proposed scheme, the reactive power during the waiting period or the delay period was 0. They were not injecting reactive power, they were sitting idle. But during this in the case of INCVC scheme, what we have done is instead of making sit idle, we ask them to consume reactive power.

We have asked because the voltage is anywhere between the 0.9 to 1 per 1.1 per unit. So we are not going we are not taking system away from steady state or dynamic state. So this is the time where we can have more reactive power reserve. So that means we are taking advantage of 4 quadrant operation of the inverter. They can inject reactive power, they can also absorb reactive power. So anyway system is in steady state, can we have more reactive power reserve? So we have absorbed the reactive power from the system.

And second thing what we have done is now waiting period for all the voltage buses, instead of you know keeping all the bus voltage, keep on waiting you know waiting, instead of avoiding this waiting period, what we have done is see we have taken this OLTC operating time. This is how it looks like you know. You see the voltage deviation if it is too too high, if the deviation voltage you can see here, it starts from 0 or something to 10 percentage. This is in terms of percentage.

That means if the voltage deviation is very large, that means if the voltage is 0.9 per unit, then the OLTC will quickly act and I told you the time delay concept, there is a fixed operation of time delay something like that. Actually to be very honest the OLTC operation time is like sort of this characteristics. If the deviation is too less, then it would take more time to operate. So what we have done is we have put a bar here.

That means you can see here 5 from 1 to 5, that means 5 percentage change. Above this it takes more time to operate. So what we have done is from 0 to 5 percentage, that means if the voltage is between the range of 0.95 to 1.05 per unit. We are not introducing any time delay. Even though if you introduce time delay, it will not have much impact. And if the voltage is above 0.95 and beyond 1.05, then it makes sense because the time delay is quite large. I mean it takes this thing. So we have taken this as an advantage and that is also been considered here. So this is just an execution of the things. And the results you can see here. So as compared to our own previous scheme which is shown in this colour, this maroon colour I guess and this is a blue colour is the improvised novel scheme.

You can see here the reactive power, you can observe here there is a negative, is minus 1. That means during delay period this is consuming the proposed scheme. Whereas the exist then NCVC is just idle. So you can see here we have more reactive power reserve and because of which that means we are better utilizing OLTC and then there is a significant improvement in the voltage profile as compared to NCVC scheme and other schemes. And then transient resource also you can see here, we have more reactive power to offer in the case of improvised novel coordinated voltage control scheme because of which we can further reduce post fault voltage recovery time basically. So I just help you understand how we can implement in RTDS and carry out multiple research works, research objectives can be met by just implementing the model and executing it in RTDS.

So the other key thrust areas also which can be implemented and executed in RTDS like machine learning applications to solve power system problems, we can loss minimization, forecasting, etc. Here you can see in the same work we have not used artificial intelligence. So it can make, we can make it more optimum. Can we just use artificial intelligence to sense without having communication also what is the exact time delays.

It is not exact time delay calculation basically. So it is approximate or it is better but can we exactly find out what could be the time delay so that we can have more optimal operation with the help of artificial intelligence, collect the data, train the system and create so many scenarios can we have better results. So it is just one more area which where we have not explored till date. And renewable penetration challenges like fault ride-through inertia and EV integration challenges also. If there is electric vehicle presence in the distribution system, can electric vehicle can help to improve fault ride-through, can they also participate in this kind of CVC scheme, reactive power injection schemes.

So that is another thing. And demand side management, virtual inertia, health monitoring of the operators, BMS, resiliency is another very important upcoming research topics, virtual power plants that means if there is a fault and if there are multiple microgrids placed, they can also able to share power among themselves. So that you know if I let us say if there is a building, there is multiple homes present, due to some reason blackout, if the whole apartment is isolated from the system. So I can share I mean I have some solar plant, you also have some load. If there is a excess of power that I have, I can sell power to you.

It is like peer to peer energy trading and all that can also be done. Virtual power plants, concept, microgrid control, protection, stability, so many research areas. That is it with this we will conclude and we will take up a new topic in the next class. Thank you very much. Thank you.