Introduction to Smart Grid
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Lecture - 32
Simulation and Case Study of DC Microgrid

Welcome you all for today's NPTEL online course on Smart Grid, and today's lecture we will be discussing on Simulation and Case study of DC Microgrid. In our previous lecture, we have focused on Simulation and Analysis of AC Microgrid, and we have seen that AC microgrid operated in to different mode of operation both grid connected and isolated. We have chosen seven different cases that may commonly appear in a day to day life and those cases have been analyzed in the presence of distributed energy resources, and we allowed the load to change from one magnitude to the other and the simulation results have been presented briefly.

Today, we will focus on DC microgrid. About DC microgrid 1 thing is very interesting; we have seen the merits of DC microgrid and the importance of going for DC microgrid, just to avoid multiple conversion levels; that is from AC DC AC or DC AC AC. So, to do avoid multiple conversions, we prefer to go for DC microgrid. But being said that DC microgrid can be connected along with grid or operate along with the grid or it can also operate without a number or isolated mode of operation. But, commonly DC grids is an isolated mode become very popular, because it is easily achievable and in when you have a grid most probably we may not preferred to have a DC grid, we can have a hybrid AC DC grid but only DC grid having a grid AC grid in place may not be very commonly seen today.

So, in this lecture today, we will focus on DC grid simulation and analysis when it is operated in an isolated mode; that means, an independent grid catered with a DC bus or a DC voltage. But it may so happen, we may have multiple DC grids and they may exchange or support each other or complement each other or communicate each other for an better operation of multiple DC grids.

So, today's lecture is mainly focused on simulation and analysis of a single DC grid or it could be multiple micro grids; multiple microgrid simulation in the platform of DC or in independent DC microgrid simulation can be analyzed. Moving to Isolated DC microgrid operation, there are two major operational issues.

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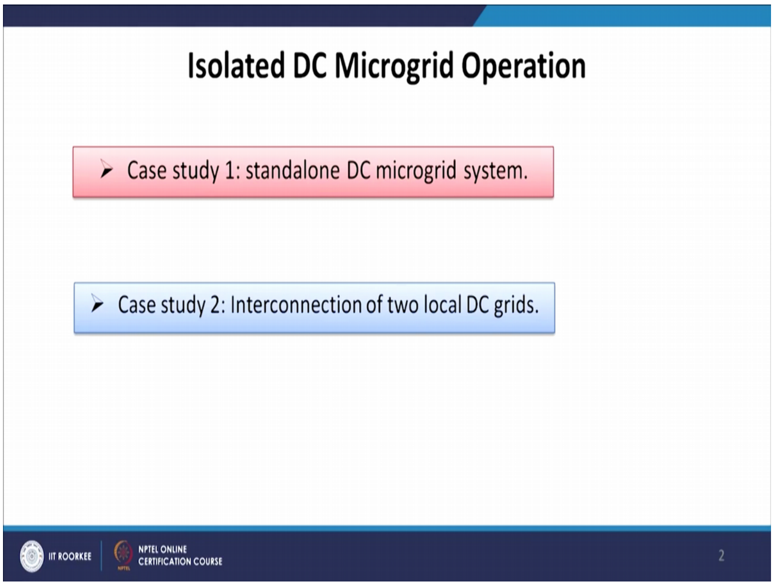

One is Case 1; where, standalone DC microgrid system which is very common feasible adoptable and realizable.

Now, moving to case study 2; where Interconnection of two local DC girds means in a remote there are two remote villages, they both have actually DC microgrid in place. But they like to operate together, because they do not have any grid support at all.

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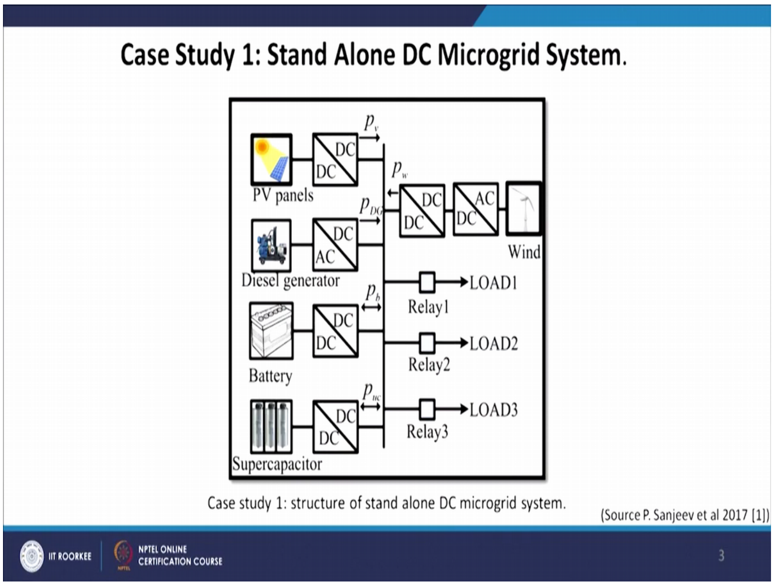

Now standalone DC microgrid; I mean this we have already seen. This structure of my DC microgrid, where we have P v panels and we can see that we have P v panels and we do have actually diesel generators, battery, super capacitors and also perhaps wind connected to my system by AC DC DC DC conversions and we have three different type of loads; where some of them are very critical and some of them could be non critical.

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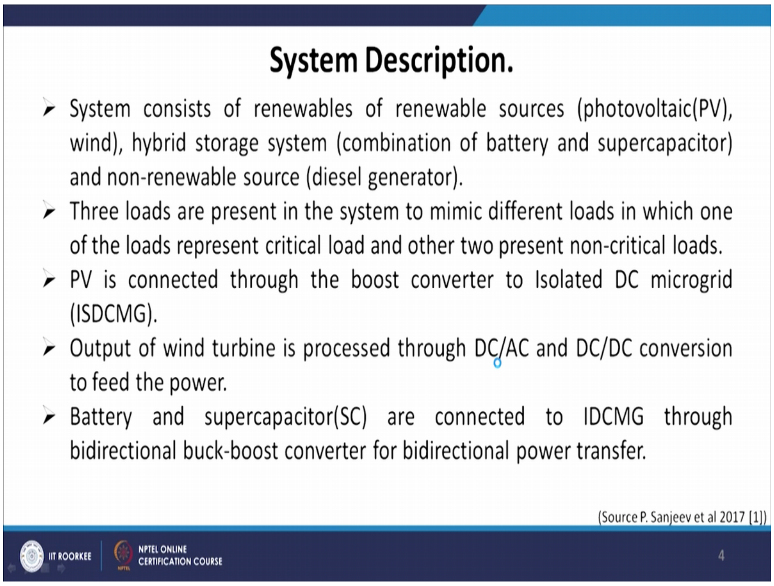

So, this is the basic architecture of DC microgrid is being considered for further analysis the System Description. System consisting of renewable energy sources that is could be P v or wind; hybrid storage systems that is a combination of battery and super capacitor; and non-renewable energy sources such as diesel generator. If you like to electrify a rural remote area through DC grid, we can certainly encourage the presence of P v as well as wind along with battery and super capacitor in place.

Further, we can have a diesel generator looking into evening hours load catering. If the renewable energy source is not enough to meet my load; then certainly the diesel generator can come to active participation. Three loads are considered in the simulation where two of them are considered to be non critical and one of them considered to be critical. Means, under no circumstances one load can be taken out or compromised whereas, two non critical loads can be compromised if my renewable energy sources and diesel generator is not able to meet those.

Now, P v is connected through the boost convertor to isolated DC microgrid. Output of the wind turbine is processed through DC AC DC DC conversion to feed power. Battery and super capacitors are connected to isolated DC microgrid through bidirectional back boost converter for di bidirectional power flow, because they can be charged or they can be discharge. Diesel generator is interface to my isolated DC microgrid through the controlled rectifier. Now, this is one of the control algorithm which has been developed for DC microgrid system.

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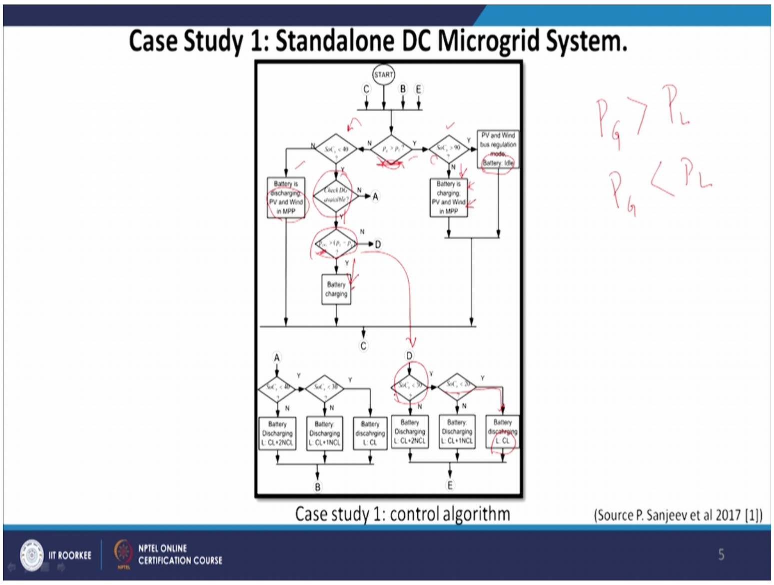

Now, let us go carefully step by step. Now let us say my load which is P L and the generation which is P G. Now the generation may be more than my load or some time the P generation may be less than my P load. So, how do I optimally utilize my resources available to me to operate my DC microgrid, when my generation is more than P L or the load or when my generation is less than P L?

Certainly, we need to store when the generation is excess and you have to discharge your battery when the generation is minimum, but let us depending upon the state of charge conditions of the battery. Now if the P generation is greater than P L if it is true; that means, and if the battery is at SoC which is 90 percent and if it is not charge up to 90 percent then, I can charge my battery and allow my P v and wind to operate at its MPPT.

Concentrate, if the generation is more than load I do have excess energy; check whether my battery has been charged up to 90 percent or not if it is not been charged up to 90 percent and if my generation is more, then I can allow my battery to charge as well as keep on generating do not reduce the generation from PV and wind. Allow them to operate at a MPPT mode. Now, if it is already being charged up to 90 percent then PV and wind bus will go to regulation mode and the battery will be ideal; we will not charge further.

But if P generation is not greater than P L means if the P generation is less means you will follow this step check whether the battery which has been having the SoC less than 40 percent; if it is not discharged below 40 percent, then the battery can discharge to meet my shortage of generation and allow my P v and wind to operate it MPPT certainly. But if it is already been discharged below 40, then I have no option my generation is low and my battery which is already been discharged below 40.

So, the third option available to me could be check with the available of diesel generator and if the diesel generator is available to me then the PDG can meet my difference between load and generation. So, whatever the gap between load and generation can be taken out from my diesel generator. Now if it is excess diesel generator is still excess; then I can allow my battery to charge and if not, then I will come for to this point.

Now here, I will see to that if the battery which has the state of charge is less than 30 percent, then I will charge my if it is less than 30 percent, then I will go further it is less than 20 percent and if it is yes. Then, I can go for battery discharging and single critical load can be met. I do repeat if my diesel generator has we having excess energy which is more than the difference between the load and the generation. Then, if it is greater; then I can charge my battery if it is not greater, then I have to take some energy because the diesel generator is not able to meet my load generation different.

So, that case I have to see whether my SoC state of the battery and if it is less than 30 percent. So, then it is not a good state to discharge. So, then if it is SoC is less than if it is not less than 30 percent, then I can discharge. Critical load and non critical loads are in operation, but if it is less than 20 percent, and if it is not less than 20 percent then I can go to one non critical and one critical load and battery can discharge. But if it is less than 20 percent, then I will only switch on my critical load and start discharging my battery.

So, please understand the algorithm is such where we try to understand what is the switch are situation of the system, if my generation is more than load; then I can start charging my storage. But if it is less; but before charging the battery, if the generation is more, I have to see the state of my battery. If the state of battery which is fully charged, then certainly I have to make my battery ideal and do not operate my P v or wind at its MPP, but if the P generation is more than P L load and the battery which is not been fully charge. Then, certainly I can charge it.

But if the P G is less than my load, then what is the option I have to check whether the SoC of the battery. If the SoC of the battery is not less than 40 percent, then I can certainly discharge my battery to meet my load; but it is already 40 percent less, then I cannot take my shortage of energy from my battery. So, I have to switch on my diesel generator. Now once the diesel generator is on; if the diesel generator is able to meet the gap, then the excess diesel generator energy available to me can be used for battery charging.

But if it is not so, then I have to see to the state of charge my battery. I have to keep on discharging to meet my loads and slowly because the battery is getting discharged, the diesel generator is not having the excess energy to meet the difference. So, that case I have to curtail my loads. So, first of all I have to curtail one non critical load and then, the second non critical load and the critical load can never be curtailed.

So, that case from 40 percent to 30 percent even after 20 percent even slightly below 20 percent, I can discharge my battery to protect my critical load.

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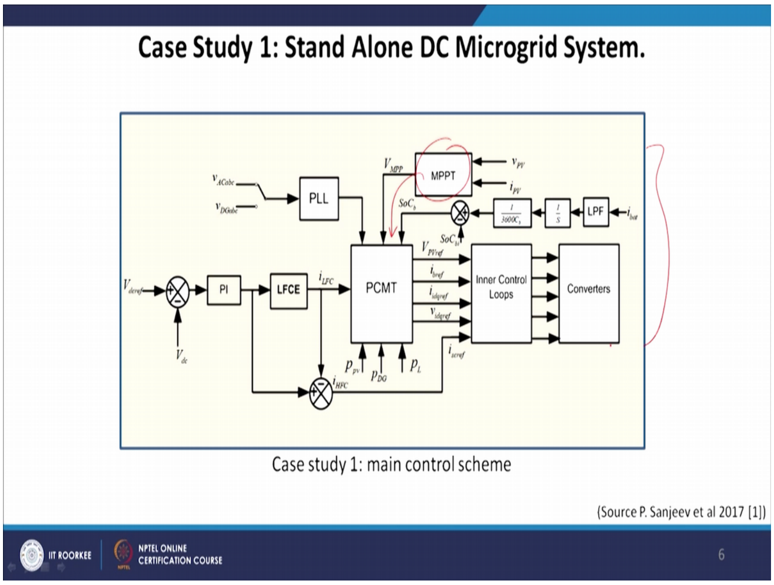

Now the Stand Alone DC Microgrid System; where the main control system being adopted where you see it is at MPPT operation and this basic structure represent the control algorithm for the control scheme for standalone DC microgrid.

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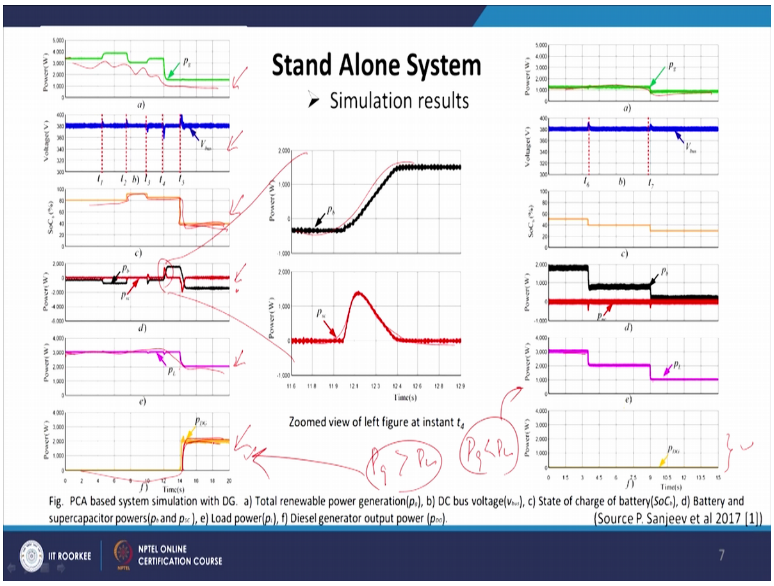

Now, in case of a standalone system; now, let us focus on a very interesting simulation where the first characteristic represent your renewable power generation and the second one represent your DC bus voltage and this is the state of charge my battery, and this is the power of my battery and super capacitor, then this is the load power how the load is being taken care and this is my diesel generator output.

Now, we can see the power renewable power generation which is keep on varying over a period of time and the voltage which is almost study excluding few transients and very interestingly, we can see that the state of charge of battery which is keep on varying from 80 percent to 90 to 80 and then 40 etcetera. And then finally, we can say the characteristic of battery and super capacitor, the power and this is how the load is keep on changing and the diesel generator characteristic.

Now, one very interesting thing I like to tell you here, when the state of charge of the battery is at low, I we can clearly see the diesel generator is operating with its maximum capacity because certainly it is active, because the battery is not able to meet the load and if this characteristic has been assumed, to this picture when we can see how my super capacitor and battery they behave during transients.

And this is one more characteristic where the power is varying and the voltages the SoC of the battery, battery and super capacitor, power characteristic, load power and my diesel generator. So, in one case the diesel generator is not at all active because the it is not required for my diesel generator to be switched on; where is in other case at 14 second the diesel generator came to action perhaps because the load is slightly low, we can see the load is at 2 and here the load is reduced; whereas, the load is reduced; so one scenario, where the load is reduced.

So, we can see this scenario where the load is at 3 and the generation is at 1. We have seen another case, where the load is at 1 and the generation at its 3.5. So, one case; where P generation is greater than P load. We have simulated and the other case where P generation is less than P L.

So, it is certainly clear, when your generation is more than load then the diesel generator may not be brought into the system operational conditions; whereas, the generation is less from the renewables the DG come to play. But the characteristics depends on how your battery status and how they have been designed.

So, we can clearly see only when the battery falls below a particular SoC, then the DG come to active operation. Now we will consider the isolated mode of DC microgrid; but instead of 1 DC microgrid, now we will concentrate on 2 DC micro grids and interconnection of these two local DC micro grids. The first of all why do we need to have integration or interconnection or complementation between 2 DC microgrid?

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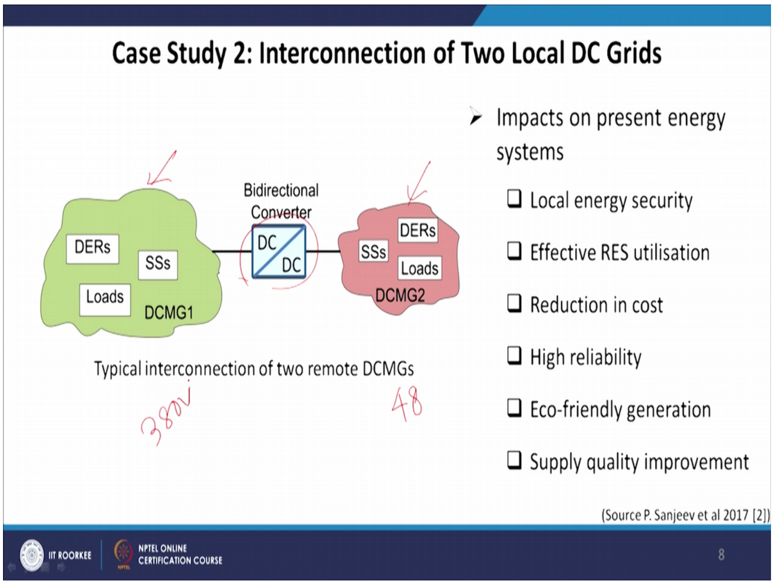

Now, this is how we have a DC microgrid 1 of a village 1, let us say and this is another DC microgrid of another rural area or remote area and this 2 have been connected where DC DC convertor, but one thing is very clear both the DC micro grids are not necessarily operating at the same voltage level.

One is operating at let us say 40 eight volts and the other may operate at 380 volts. So, the important challenge here when you have 2 DC micro grids operating at different voltages can there be interconnected and can they complement to each other that is what the important analysis we will like to focus here. What are the impact on the present energy system when you have integrated more than 1 DC microgrid or you know more than 1 DC microgrid or being operated together. The energy security will increase for example, 1 DC microgrid do have condition where the generation is more than load and we have seen the other case where the generation is less than load.

Now, when the generation is less than load, we have seen the diesel generator has to be brought actively once my battery not able to meet the loads load increase. Now if you have 2 system in one case you have excess energy and the other case you have shortage of energy. Now instead of bringing the DG in the other system where the generation is less from renewable; perhaps I can take the excess renewable energy available in the other microgrid to meet my energy shortage in the other microgrid.

So, perhaps it is one of the wonderful opportunity for the DC micro grids to operate incorporation and complement or support to each other. First of all we can achieve Local energy security, Effective Renewable Energy Sources utilization, Reduction in cost, High reliability, Echo-friendly generation and Supply quality improvement can be achieved.

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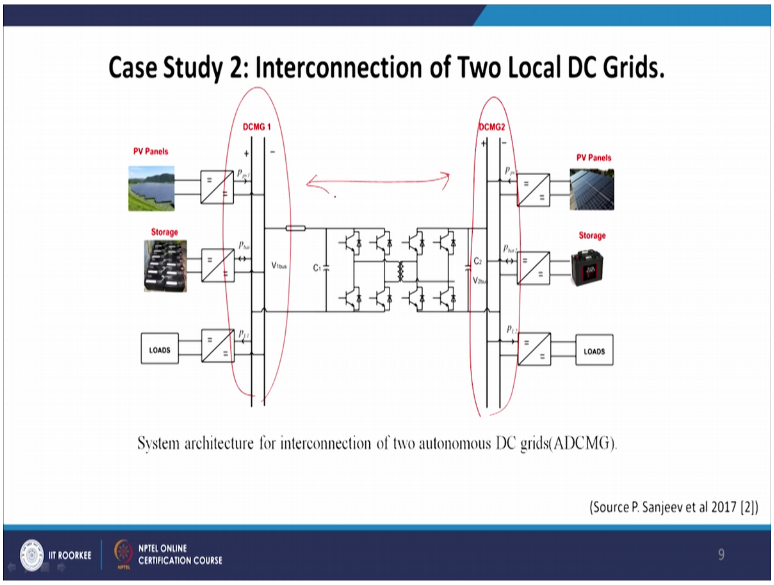

Now, this is how actually the structures of we have this is DC microgrid 1 and this is my DC microgrid 2 and they two are inter connected and they two are interconnected.

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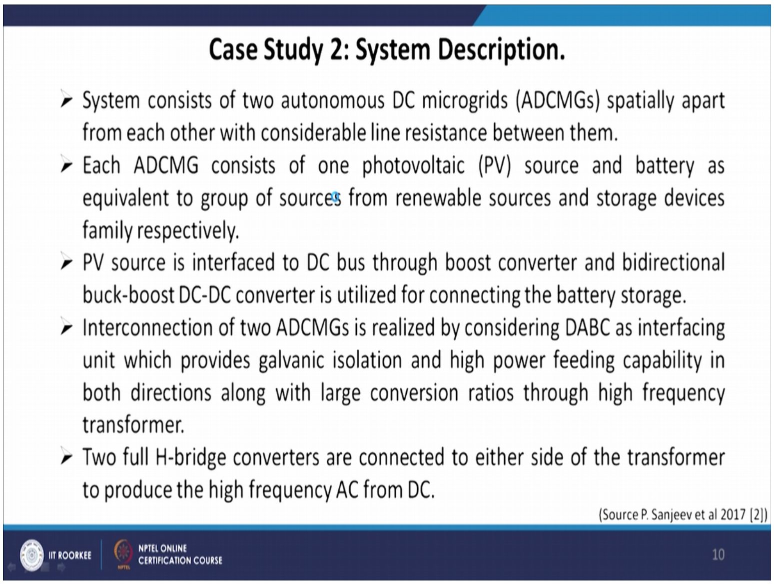

System consisting of two autonomous DC microgrid especially apart from each other with considerable line resistance between them means we have 2 DC micro grids separated reasonable cable length between this two.

Each DC microgrid consist of one photovoltaic source, battery as equivalent to group of source from renewable sources and storage devices etcetera. P v sources is interface to DC bus through boost converter and bidirectional buck-boost DC-DC converter is utilized for connecting the battery storage.

Interconnection of 2 DC micro grids is realized by considering DABC as interfacing unit which provides galvanic isolation and high power feeding capability in both direction along with large conversion ratio through high frequency transformers. Two full H-bridge converters are connected to either side of the transformer to produce the high frequency AC from DC.

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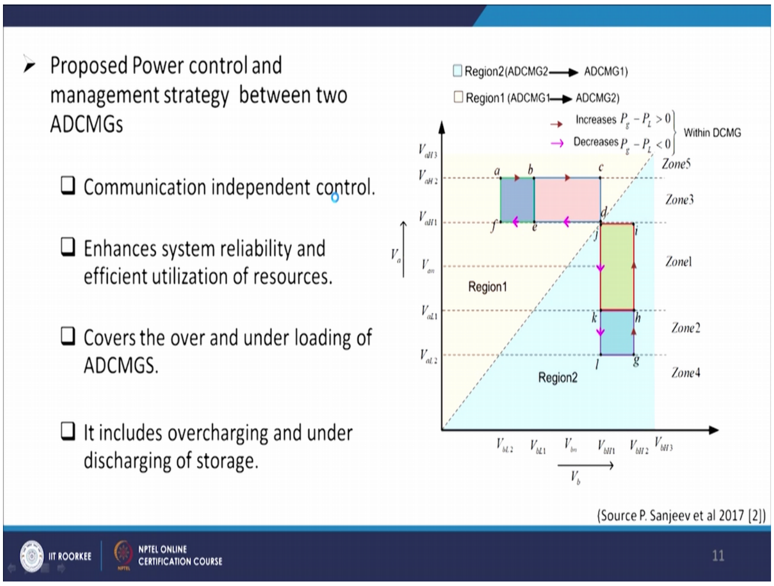

Now, this is of the proposed control power control management strategy between autonomous DC micro grids. We proposed the communication independent control. It had an enhanced the system reliability and efficient utilization of resources. Covers the over and under loading of autonomous DC micro grids. It includes overcharging and under discharging of storages.

Now, we can see this strategy region 1, where the autonomous DC microgrid 1 is feeding energy to autonomous DC microgrid 2 and the reason 2 is being used when the autonomous DC microgrid 2 is feeding energy to my autonomous DC microgrid 1.

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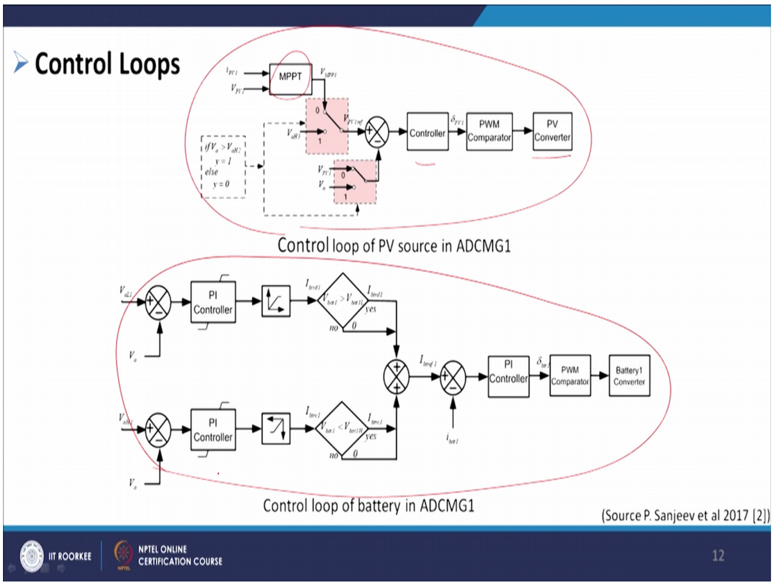

Now, this is control loop of the battery of my autonomous DC microgrid 1. We can see MPPT operation, we have two controller. And finally 2 P v controlled P v convertor. So, this is this control strategy for my P v and we can have this control strategy for my battery.

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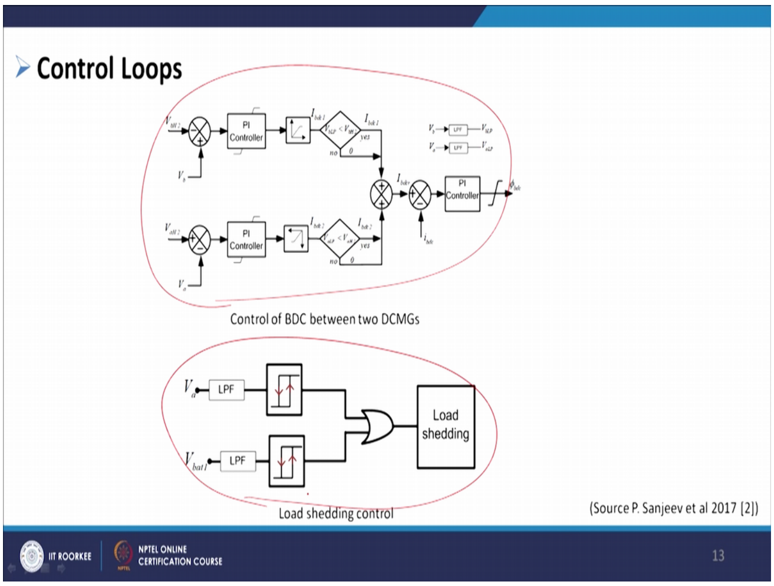

Now, moving to control loops of DC microgrid, basic structure and then, we have a load shedding control because here we have seen that if required the loads which are not critical need to be set or disconnected. Now this there are 2 microgrids have been considered here and we will see the rating those have been considering before simulation.

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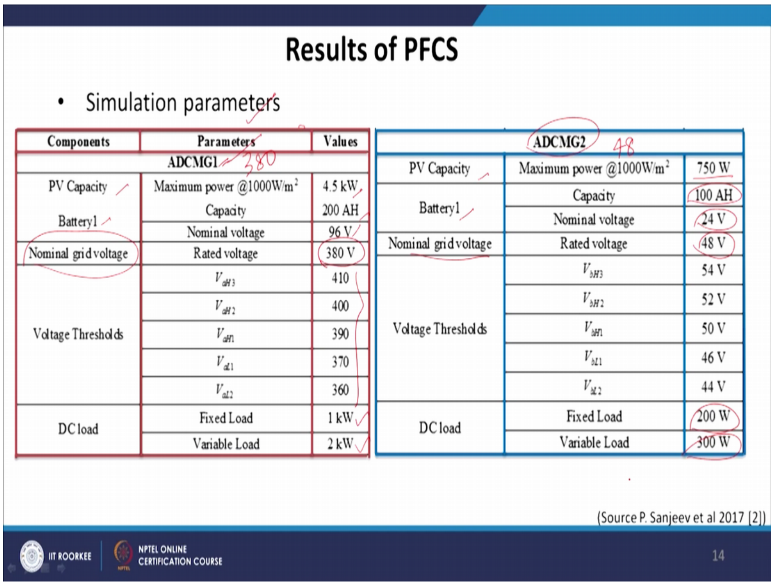

First of all let us consider the autonomous DC microgrid 1; where we consider the P v capacity of 4.5 kilowatt; then, the battery which is of capacity 200 ampere per hour and the nominal voltage which is at 96 volt for this 2.

And very importantly, the nominal grid voltage considered to be 380 for my 380 for my DC microgrid 1 and voltage thresholds have been assumed and the fixed load which is 1 kilowatt which cannot be varied and we have a variable load of 2 kilowatt; so, 1 kilowatt of fixed load and 2 kilowatt of variable load. Now, moving to autonomous DC microgrid 2, where the P v capacity which is of 750 watt the battery which is of 100 ampere hour operating normal nominal voltage at 24 volts and the rated nominal grid voltage assumed to be 48.

So we do have three, one autonomous DC microgrid 1 operated 380 volt; autonomous DC microgrid 2 operate at 48 volts and the DC loads which is 200 watt fixed and 300 watt variable. So, indirectly we do have a largest system operating at large voltage rating that is 380 volts we have a very small microgrid DC microgrid operate at low voltage at 48.

So, now we want to interconnect this two.

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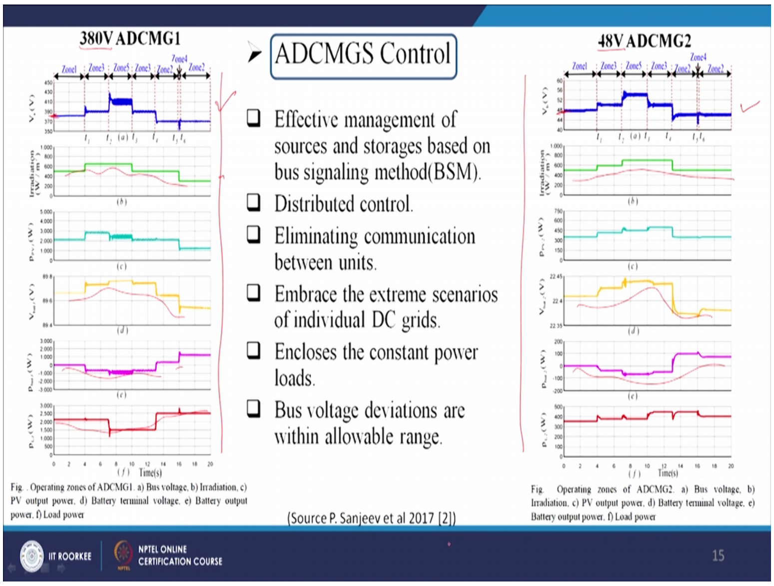

Now, when we focus on autonomous DC microgrid control, it is mainly effective management of source and storage based on bus signaling method. It has distributed control. Very importantly, it eliminates the communication between the buses. Embers the extreme scenery of individual DC grids and close the constant power loads, bus voltage division are within allowable range.

Now, this is my operation of my autonomous DC microgrid 1 and this is my autonomous DC microgrid 2; operate at 40 eight volts and operated 380 volts. We can clearly see this is my bus voltage which is very close to 380 and this is very close to 48 volts. And we can also see the irritation which is varying and in case of microgrid 2, it is also varying; whereas, the P v power output which is more or less close to 2 per unit.

And here, it is close to 350 or 325 watts. Now then, moving to battery terminal voltage which is varying, we could see the similar scenarios. Then, battery output power; battery output power and then with this is my load power which is varying from 2 and goes up to 2.5 and here it is varying from a 350 to close to 400. So, as you have seen in case of my microgrid 1, the load is close to 3 kilowatt. So, this is what it is very close to 3 and this is at 400 to 300 watts. So, it is operating very close to 300 watts.

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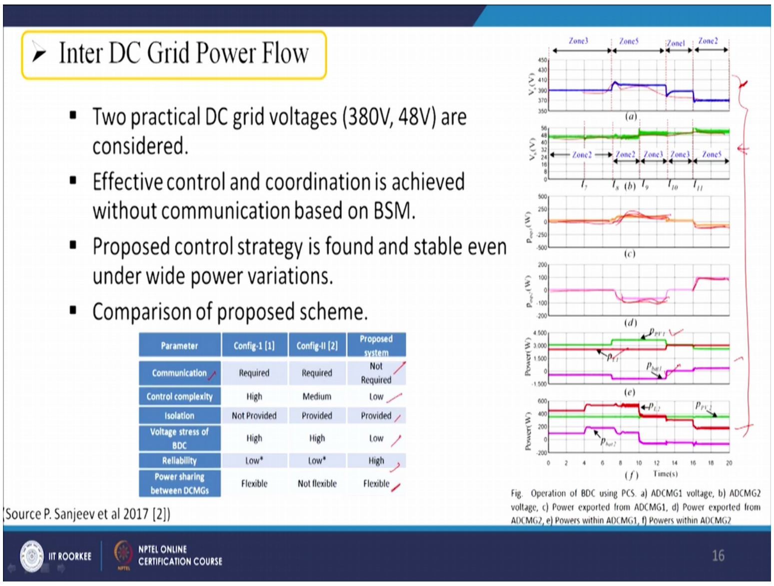

Now, inter DC grid power flow 2 practical DC grid voltages 1 is at 350 380 volts and the other is at 48 volt are considered. Effective control and coordination is achieved without communication based on BSM. Proposed control strategies found and stable even under wide power variation comparison of propose scheme and it is been seen that the communication which is not required.

Control complexity is very low. Isolation provided voltage stress of the BDC is very low; reliability is extremely high and the power sharing between DC microgrid is flexible means excess power can brought from DC microgrid 2 to 1. And we can also exchange power from microgrid 1 to microgrid 2. So, here now we are putting both the DC microgrid simultaneously.

Now, we can clearly see that this is showing the voltage of my microgrid 1 which is a around 380, but its varying and this is for my microgrid 2 which is around 48 and then, we can see that the power exported from my microgrid 1, there is almost slightly exported and you can say this fellow is observing the microgrid 2 and when is importing now the microgrid 2 is exporting.

So, we can see this is kind of mirror image as and when there is they both are operating at 0, suddenly if there is a requirement then the a DC microgrid 2 is receiving power and excess from the microgrid 1 and when it is excess from microgrid 2 being observed by microgrid 1. And finally, we can say power within the microgrid 1 as well as power within the microgrid 2, we can see the load characteristic, we can see the P v characteristic and we can see the battery perhaps characteristics.

So, we can see within the microgrids, the power output of the battery load and the P v can be seen; as well as there is a power exchange between these two grids are possible without violating much of the voltage requirements at 380 and 48 volts. So, this is a extremely challenging task and it effect can be achievable; then the system reliability will certainly go up because you need not brought or bring your diesel generator unwontedly if there is a excess power available to you the nearest DC micro grid.

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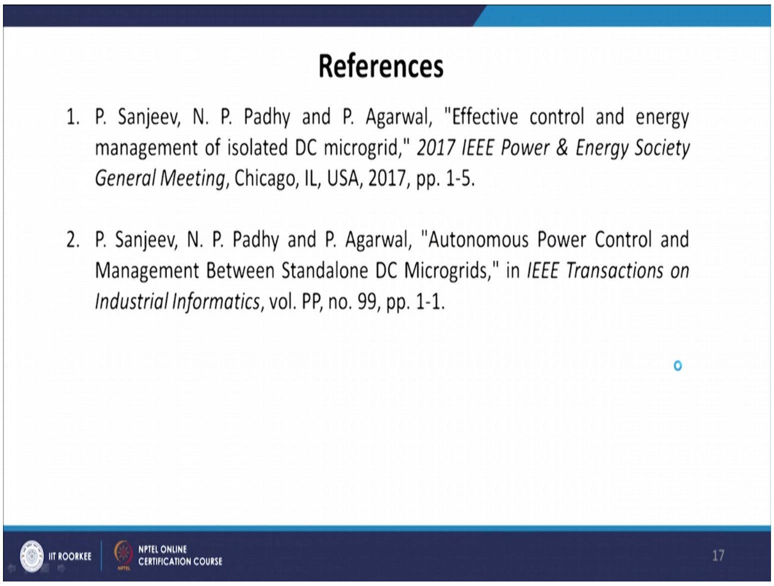

And all the present presentation are mainly out of this two; IEEE transitions as well as one General Meeting article and with this, we will like to conclude that the DC microgrid is an important task, simulation is achievable; but very importantly it is being focused here how the DC microgrid in an isolated mode can operate. And we also extended this analysis to a multiple microgrid operating at two different voltages, and capable of exchanging their power to benefit each other.

Thank you very much.