Introduction to Smart Grid

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Lecture – 31
Simulation and Case Study of AC Microgrid

Welcome you all for today's lecture on Smart Grid and we will be focusing mainly on simulation of AC microgrid. In the past, we have seen that AC microgrid as well as DC microgrid along with hybrid AC; DC microgrid are being theoretically analyzed, different mode of operation including grid connected and isolated mode have been discussed in detail. And today we will try to focus on the simulation aspect of AC micro grid; now whatever we analyze in theory that need to be simulated to obtain feasibility when we take those AC microgrid to the field. And before we demonstrate in field or create a test bet it is necessary for us to simulate in real time platform.

Now, when we focus on simulation of AC microgrid; we will also consider different cases that commonly AC micro grid may face; both in grid connected as well as in isolated mode. And even with grid connected as well as in isolated mode different environmental condition may force my renewable generation not to operate its MPPT.

The load may fluctuate from minimum to maximum, the battery soc state of charge may vary and because looking into all developing countries in mind the AC microgrid commonly need to accommodate diesel generator to balance or to meet the load during supply interruption. So, today now we will focus on a AC micro grid which will have my renewable generation such as P V battery storage diesel generator and load.

So, this is a very small AC micro grid, but being very practical micro grid which can be analyzed and simulated in detail today; with different operating conditions under grid connected and isolated mode of operation. First of all what we understand by micro grid modeling and simulation?

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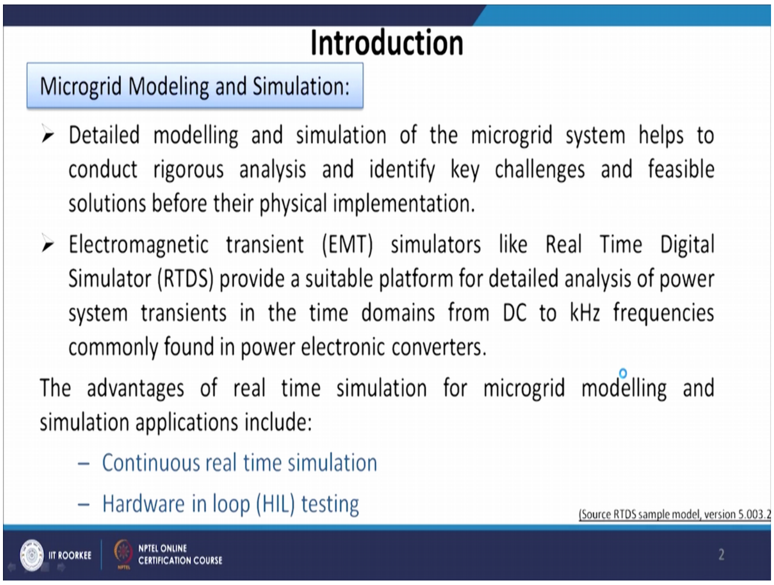

Detailed modeling and simulation of the micro grid system helps to conduct rigorous analysis and identify key challenges and feasible solution before their physical implementation. Now let us say we do some sort of study for example, we do have 1 unit of load and 0.5 unit of P V and 0.5 unit of let us say diesel generator and 0.5 unit of battery. But when the load is keep on changing or my P V injection to the grid is keep on changing; we really do not know what are the transient conditions the system may face and whether it is really settle down to a steady state after few milliseconds or not.

Now, the before we do that it is necessary for all of us to understand the model basic concept and also the simulate it in a proper platform so that it can be deployed or demonstrated in field or within a lab through test map. Now moving to the platform through which we can simulate electromagnetic transient which is also called EMT simulators like real time digital simulators RTDS or other simulator like OPLRT provide a suitable platform for detailed analysis of power system transients in the time domain from DC to kilohertz frequencies commonly found in power electronic converters.

The main advantages of real time simulation for microgrid modeling and simulation application includes continuous real time simulation as well as hardware in loop testing. So, whatever the system we design those systems need to be simulated as well as we need to test through HIL hardware in loop testing.

So, that we can confidently claim now this model or this setup can be deployed in field now what is continuous real time simulation?

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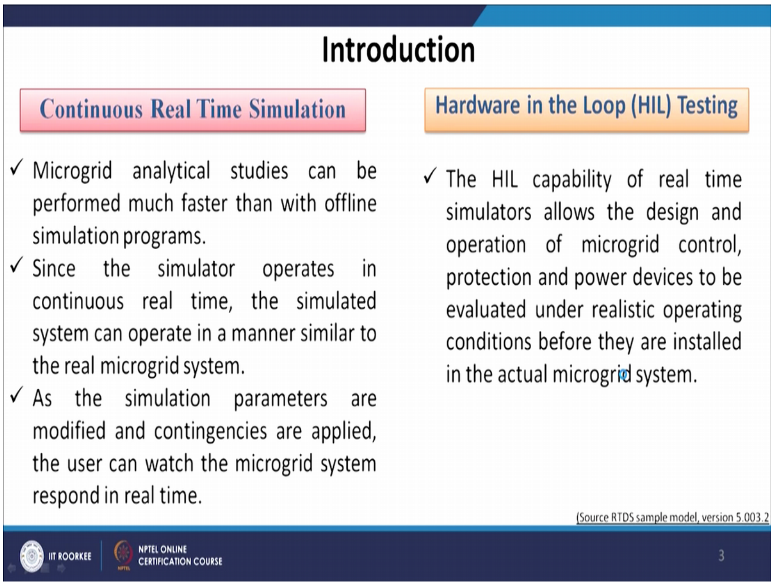

Micro grid analytical studies can be performed much faster than with offline simulation program. So, you go for continuous time simulation then the simulation could be made faster. Since the simulator operates in continues real time; the simulator system can operate in a manner similar to the real micro grid system by making your simulation under real time simulation platform, we can perhaps mimic the situation to a real time.

As the simulation parameters are modified and contingences are applied; the user can watch the micro grid system respond in real time. For example, if my renewable is now going out of the system or it has or the battery started discharging suddenly or the load may increase and all those changes or contingences can be properly observed through real time simulation.

Now, when we move to hardware in loop testing the HIL capability of real time simulators allow the design and operation of micro grid control protection and power devices to be evaluated under realistic operating conditions; before they are installed in actual micro grid system.

Now in case of HIL, we can perform different operating conditions and we like to see whether my system is still consistent with those different scenarios and if it is validated through my HIL testing; then I can very confident enough to take this protocol or the prototype to the field. Now first of all consider a simple case study on AC micro grid.

Now, try to understand when we talk about AC microgrid; we will have hundred different types of loads and the tens of different type of generations that can be accommodated within a AC micro grid, but we have chosen a very simple system on AC microgrid for the benefit of the listeners to understand the basics of AC microgrid simulation.

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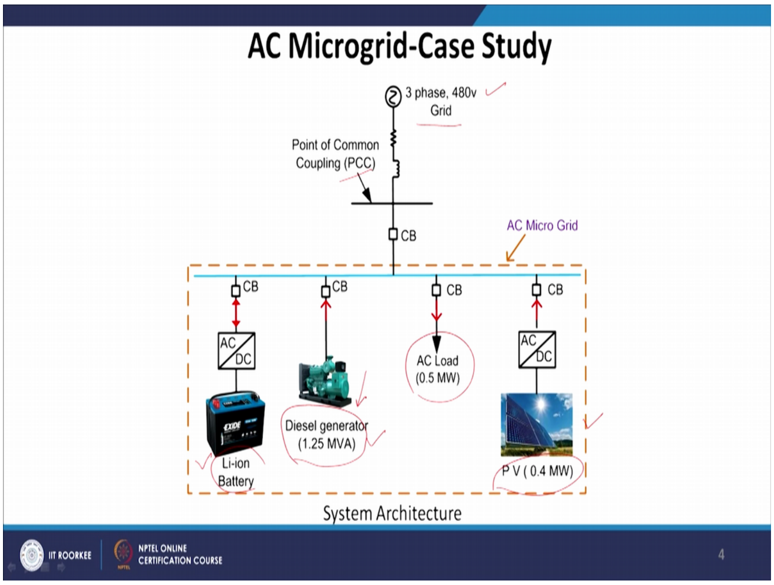

Now in this case we are chosen a very simple 3 phase system and the voltage is 480 volt it could vary from continent to continent. And then imagine this is my PCC point of common coupling and through circuit breaker we imagine that there are 4; 3 4 connectors 4 circuit breakers accommodate 3 different generators and 1 load

Now, we do have a battery and then we have a diesel generator then we have P V and we have a load. So, this system is not necessary to be of this rating always, but as a case study we have chosen load will be of 0.5 megawatt and the P V which is capable of delivering 0.4 megawatt and the diesel generator which is of 1.25 MVA maximum rating and the battery which could be either between a 0.5 megawatt maximum.

Now, this is considering this basic system architecture; the main emphasis to incorporate diesel generator into microgrid to see that what kind of challenges this developing countries are going to face. Because if you look at Indian contest I think all the commercial building of this country do have a diesel generator in place like malls, commercial buildings, educational institutions.

So, whenever they do have a diesel generator; it is important for me to understand AC micro grid in the presence of diesel generator. So, this is a unique way of analyzing AC microgrid where we have P V we have load, we have battery and we have diesel generator. So, the ideal condition would be like you keep on operating your P V with its MPPT and then keep on catering your loads, excess energy can go to battery ok.

And when the P V is down then we can take the energy from the grid and if that is also not possible, then we can go ahead with the diesel generator; when the grid is not supporting you operate in a isolated mode. Now, there are two mode of operations as we all know one is grid connected mode and the other one is isolated mode.

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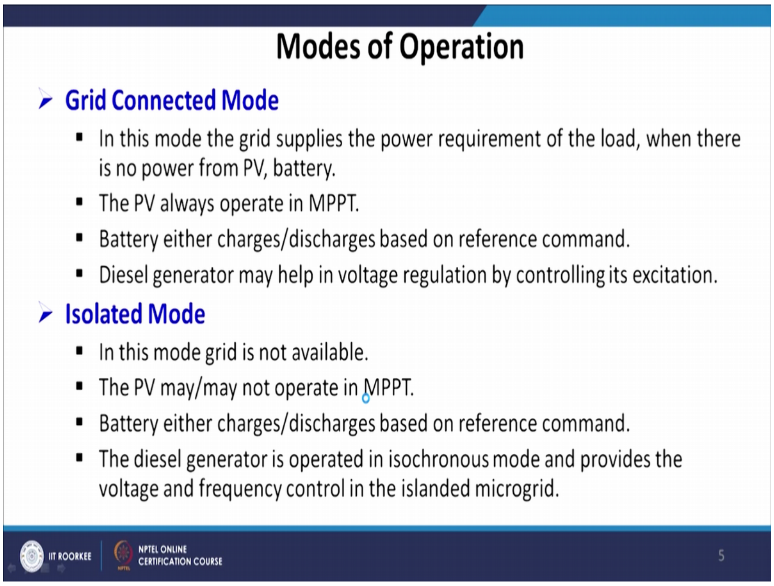

Now, in case of grid connected mode; the grid supplies the power requirement of the load where there is no power from P V and battery. The load is always been taken care by the grid even there is no battery or no P V. The P V always operate at its MPPT; battery either charged or discharged based on reference command received, diesel generator importantly help in voltage regulation by controlling its excitation.

So, diesel generator play a very important role for your voltage and frequency regulation. Now in case of isolated mode; in this mode the grid is not at all available to us and the P V may or may not operate at MPPT. The main challenge here if your load is low and if you operate with MPPT grid is not there; so you cannot basically evacuate your energy excess energy available to you and hence we normally do not allow the P V to operate with the MPPT during of peak conditions when it is at isolated mode.

Battery either charge and discharge based on the reference command; the diesel generator is operated in synchronous mode and provide the voltage and frequency control in the islanded grid. So, very importantly because the voltage regulation can be achieved by the diesel generator, when it is connected to my main grid, but when it is isolated then both voltage and frequency regulation is possible through the diesel generator which is available to me within my AC microgrid and it is disconnected from the main system.

Now let us look into each and every component of the AC micro grid first of all the P V and battery they are inverted control based.

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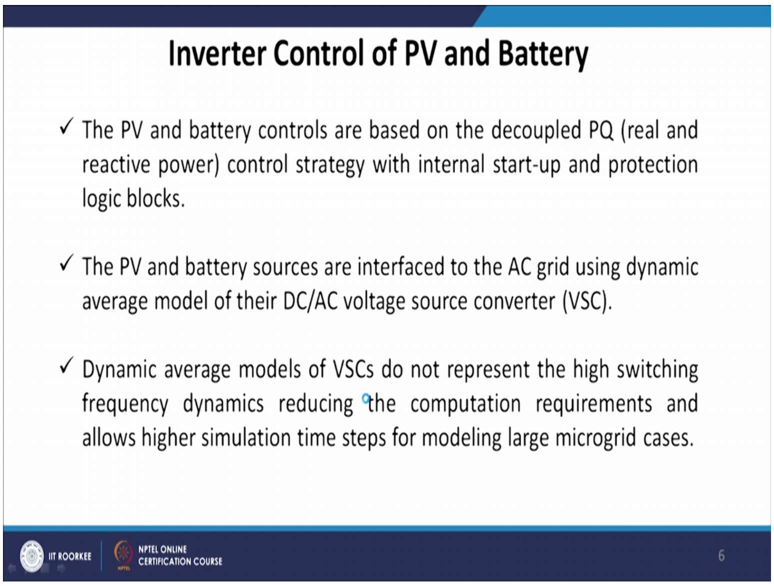

The P V and battery controls are based on the decoupled PQ that is real and reactive, control strategy with internal startup and protection logic blocks.

The P V and battery sources are interface to the AC grid using dynamic average model of their DC AC voltage source converter that is VSC. Dynamic average models of VSC do not represent the high switching frequency dynamics reducing the computation requirements and allows higher simulation time steps for modeling large micro grid cases.

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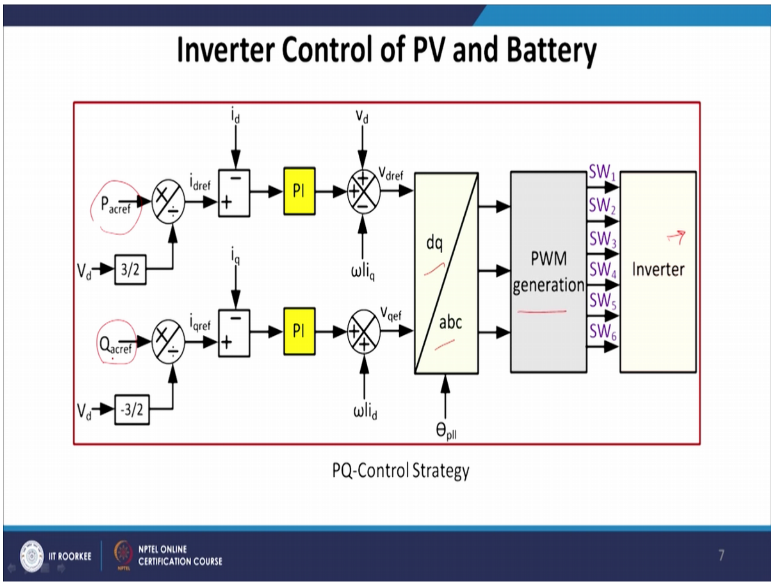

Now, this is the PQ control strategy we can clearly see the blocks and this is my final outcome for inverter and we have PWM generations d q and abc and we can see that reference power for real as well as for reactive.

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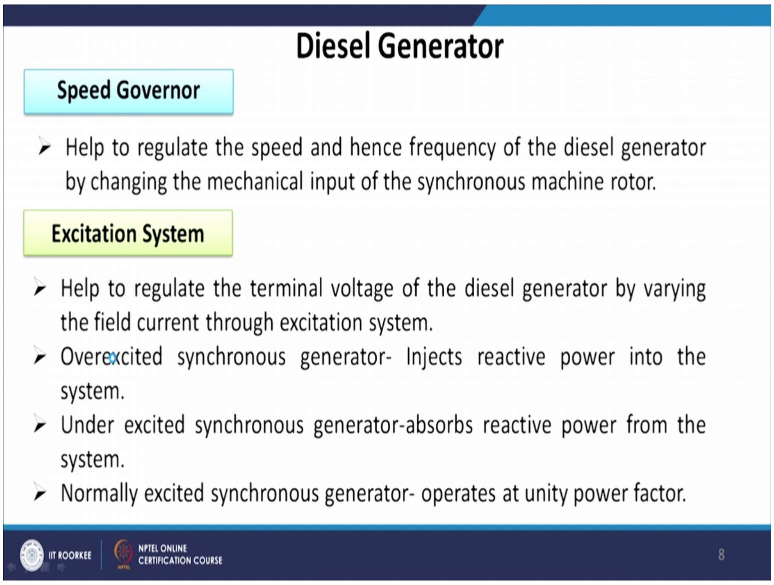

Now moving to diesel generator; the speed and governor help to regulate the speed and hence frequency of the diesel generator by changing the mechanical input of the synchronous machine rotor.

Whereas, the excitation system helps to regulate the terminal voltage of the diesel generator by varying the field current through excitation systems; over excited synchronous generator inject reactive power into the system, when it is under excited it observes reactive power from the system. And normally excited synchronous generator operate at unity power factor.

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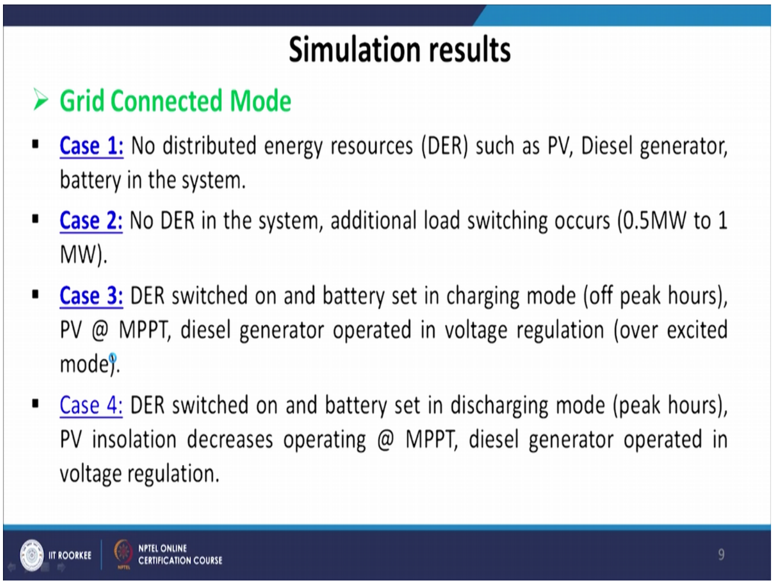

Now, before we move to different simulation studies let us make different cases that the system may come across there could be thousands of different scenarios, but we have precisely chosen few case cases those are very common and frequently seen in day today life of operation. Now, grid connected mode we will consider first the case 1 where we will not have any distributed energy resources such as P V diesel generator battery in the system only the load will be catered by the micro grid without any DER.

Now, moving to the case 2; where we will consider there is no distributed energy sources means there is no diesel generator, there is no P V and there is no battery, but only load, but that load may suddenly changed from considered 0.5 megawatt to 1 megawatt means what will happen if the load changed from x to y or 0.5 to 1 megawatt, when there is no DER within micro grid in operational state.

The third is very important distributed energy resources are switched on and battery in its charging mode. Means we assume that the load is it of its peak; the load is little minimum and the battery can be charged and all the DERs are operating in operational conditions and the P V is mainly allowed to operate with its MPPT and diesel generator operated for voltage regulation that is for over excited mode.

And now we will move to the next case where we consider the load is reasonably high that is at peak hour. And the DER is switched on and the battery start discharging to meet the increase in load and P V may not be operating at its MPPT. Means the DER is on the battery start discharging and P V perhaps reduce its generation means not operating with its MPPT. Load increased, battery discharged, P V generation reduced very interesting scenario where the diesel generator operate for in a voltage regulation mode.

Now, what could be the scenario that may occur during a isolated mode?

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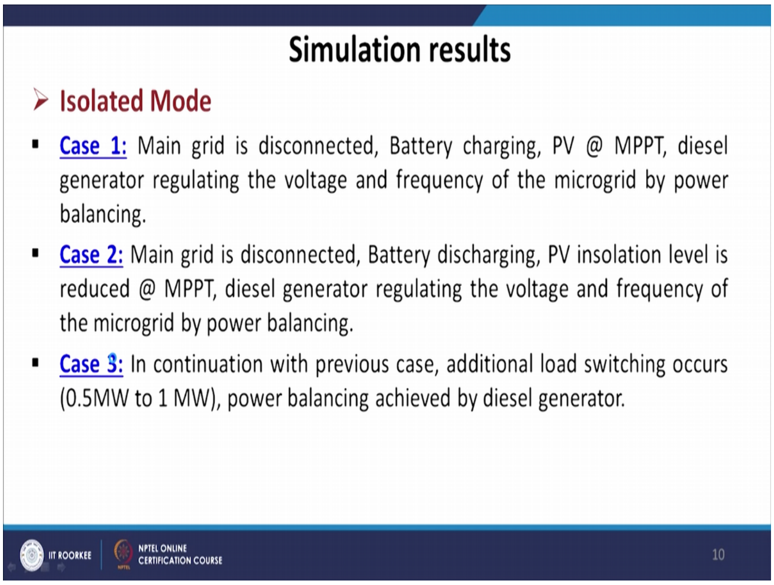

Now, in case of isolated mode let us consider the case 1, where the main grid is disconnected. Now battery is getting charged and my P V is operating at MPPT; diesel generator regulates both voltage and frequency by power balancing. Now we can have one more case, where the main grid is disconnected, battery is discharging, P V is not operating at its MPPT or reduced from MPPT and diesel generator regulate voltage and frequency of the micro grid by power balancing.

Now the third case, we can in continues with the previous cases that we have analyzed the P V may operate with a MPPT or without MPPT; under those circumstances the load will be allowed to increase from 0.5 mega watt to 1 mega watt and power balancing is done by diesel generator.

So, we would like to see with two different case 1 and case 2 if the load is changed suddenly from 0.5 megawatt to 1 megawatt; how does the system is going to behave? Now start with the simulation results all the listeners; I now need your attention very close attention. Because the simulation results are being presented here I may be able to discuss within I mean 15 to 20 minutes the next 7 cases, but it requires lot of involvement and maybe an outcome of more than a month or 2 of hard work this simulation results are available. So, I request all of you to please concentrate and understand very carefully.

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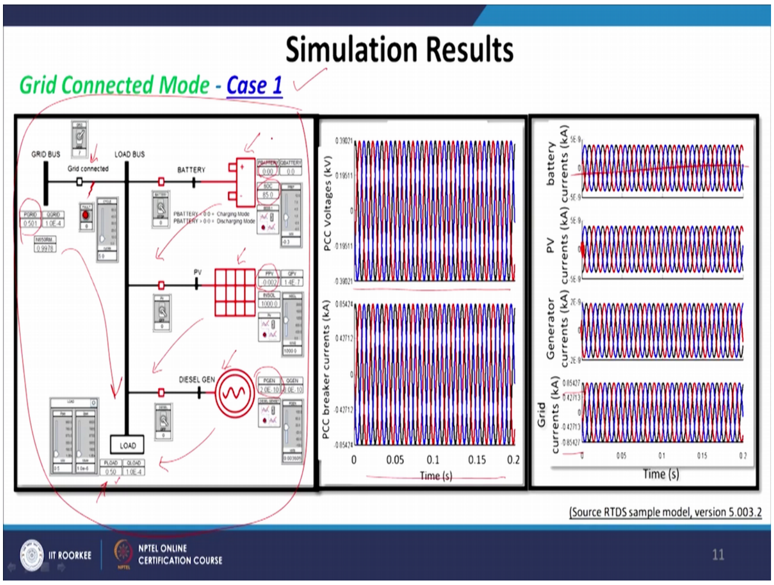

Now, the moment we talk about grid connected mode that is case 1; the case 1 is the special at situation where it is the AC microgrid is connected to my grid, but the DER distributed energy resources are not active and the load which is a 0.5 megawatt is being catered by the grid.

So, during simulation you can clearly see the red line shows that the battery is not operational. You can also see that the battery charging or discharging magnitude shows 0.0 means the battery is stand still, but the soc is considered to be at 85 percent means the battery has energy, but it is not doing anything no activity. Now next come back to your P V; the P V which is also disconnected; so, we can clearly see the energy outcome is very close to 0.

Similarly, the diesel generator which is also not operating and you can say negligible P regeneration of the diesel generator, but perhaps the load you can see that 0.5 megawatt of real power required by the load and the grid has been connected grid has been connected. So, if you measure you can clearly see that 0.501 real power which is as close as 0.5 is being available to me from the grid.

Because nor the battery, nor the P V, nor the diesel generator provides any energy to meet my load requirements. And now moving to the PCC; the point of common coupling voltages we can clearly see the voltage characteristics and also we can see the breaker current characteristic seems to be very stable. And interestingly we can see the battery which is though it has a signal, but it is very close to 0 reference ok.

So, there is nothing happening really and the P V which is again varying or oscillating very close to 0; similarly my generator, but the grid you can very clearly see the grid current is significantly higher and oscillates close to 0.85 kilo ampere is being drawn to meet the load. So, this is how; so what I wanted to inform you here you can perhaps simulate AC microgrid with different operational conditions and current voltage at each and every bus and line can be observed.

Now let us move to the second case where the case number 2 is that it is grid connected; my AC microgrid is connected to grid and no energy coming out of my distributed energy resources, but the load has now being increased to 1 megawatt instead of 0.5 mega watt. So, there is a sudden transient from 0.5 to 1 and we like to see how the system behaves at this stage.

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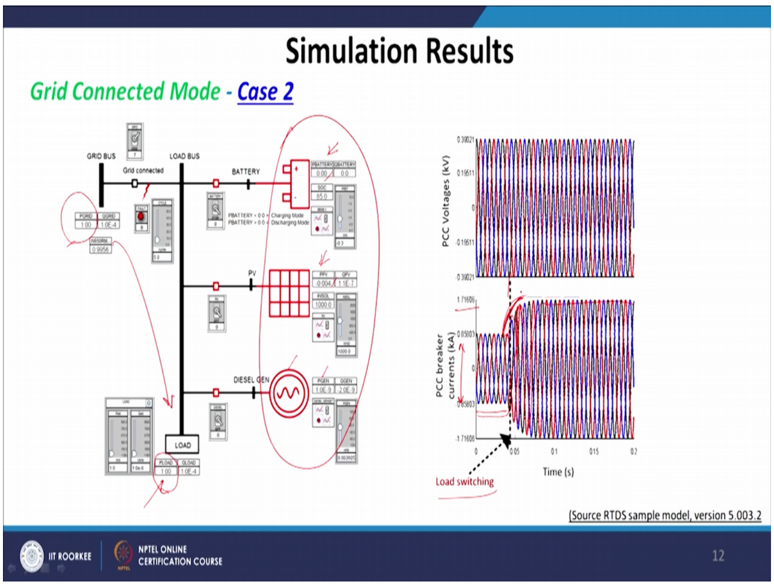

Again once again; I can say that the battery is non operational, you can see this is 0; even the P V is at 0 operational and the diesel generator is also not producing any real power, but the load very importantly to you can see which is now increased from 0.5 to 1.0

megawatt. And we can also see from the grid the energy that is so, the power coming from the grid is same as my load.

So, the directly the load is being fed by my grid and this 3 P V diesel generator and battery becomes stand still. Now looking at the simulation this is my loads switching are took place at 0.05 second. So, we were operating similar to the previous case I think you can see the variation which was as exactly same my previous slide that I have shown to you. And that this response was for 0.5 mega watt of load and now load has suddenly been increased to 1 megawatt.

So, we can see the load has been switched from 0.5 to 1 and the characteristic started oscillating and finally, settled to 1.71 kilo ampere instead of 0.85 kilo ampere, but the system is still stable. So, this transient is very important for us to observe how would the load is being switched from 0.5 to 1 megawatt and how does the current behave from a 0.5 mega watt load to 1 megawatt load.

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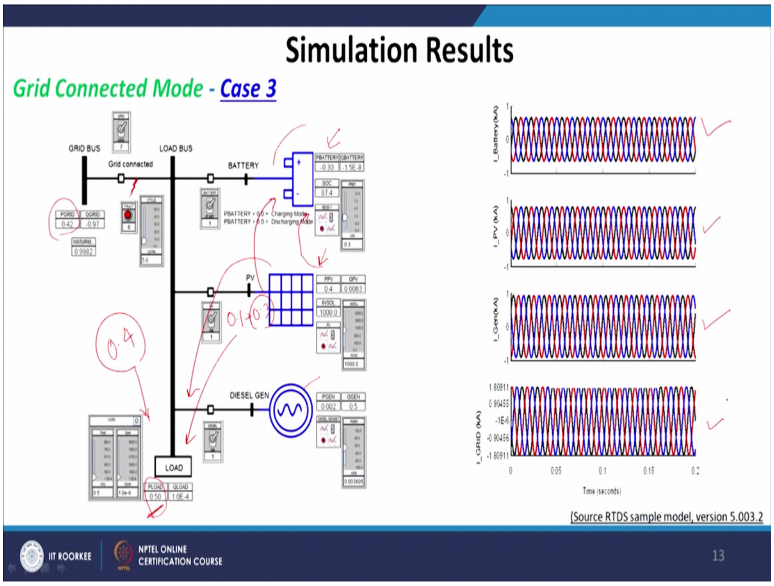

Now, let us move to the case 3 which is slightly interesting where the load is at 0.5, but you can see now the battery because we considered the first one is opaque means the battery is basically I mean charging. So, you could see the battery is receiving a 0.3 mega watt of energy or power and the P V which is operating at its MPPT and giving you a 0.4 per unit; we can consider or it is megawatt and the diesel generator which is perhaps working for its voltage regulation.

Now, if you clearly see the grid is now, giving the supply of approximately 0.42 or let us say 0.4. And we can see that the load is at 0.5; so 0.1 unit of energy that is coming from the P V and rest 0.3 is used for my charging. So, it is something like I can say for the 0.5 type of load, 0.4 is coming from my main grid and 0.4 is the output of my solar which is 0.1 is coming for my load and plus 0.3 which is going towards my charging.

So, now, what is happening here we have P V operating at its MPPT giving me 0.4 units the load is at 0.5 units and the grid is providing 0.4 and the rest excess 0.3 is being used for my battery charging. Now, these are the characteristic of current characteristic of the battery; the P V current characteristics, generator current characteristics and the grid current characteristics.

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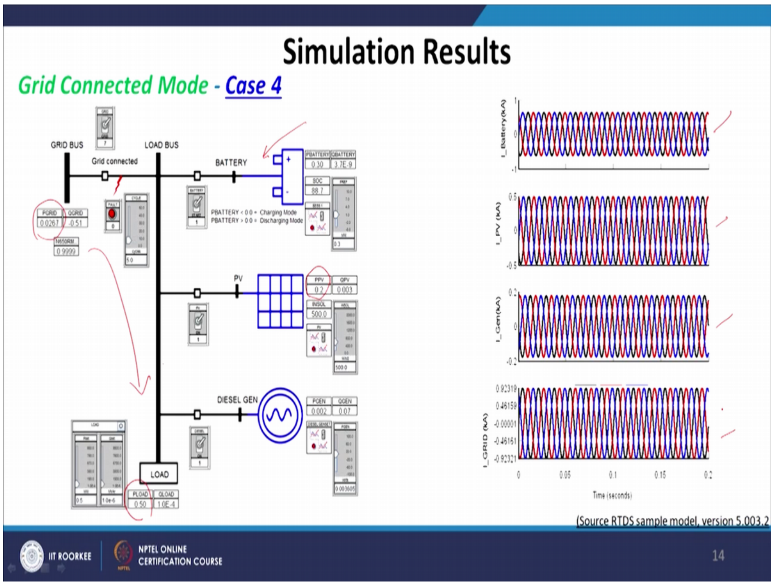

Now we will move to the case 4 where we will allow my P V not to operate it MPPT. So, you can clearly instead of 0.4 now it is giving you 0.2 units of energy and the battery do discharge 0.3 instead of charging.

So, we could see that 0.3 and 0.2 that is 0.5 unit of energy or power is available to me at the grid to meet my load and hence I am drawing no power from the main grid. So, it is something like where you do not operate it its MPPT; so, the P V generation reduced, but the battery started discharging and hence you are not taking any energy from the main grid 0.3 from battery, 0.2 from P V is able to cater my load of 0.5 units at any given time.

And you can perhaps also see the battery current characteristic, P V current characteristic, generator current characteristics and the grid current characteristics the system is absolutely stable.

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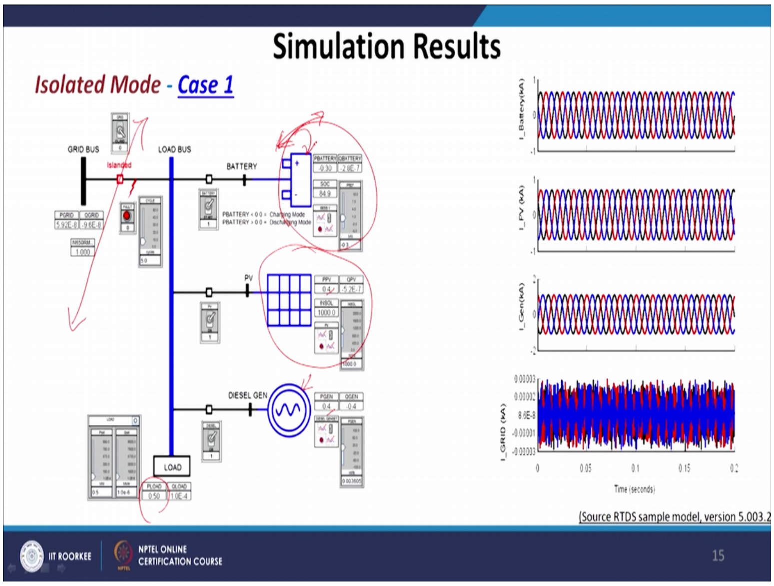

Now, let us move to the isolated mode its very interesting. Now in case of isolated mode, now the battery which is the discharging 0.3 and the P V which is operating at its MPPT that is 0.4 and the diesel generator because the grid is islanded or disconnected now the diesel is actively participating in supporting the real power as well as reactive power both.

So, now, we do have actually 0.4, 0.4; 0.8 unit of power is coming from your generator as well as P V at MPPT and the load is at 0.5. And so 0.3 excess energy is being charged by the battery; so now what is happening you allow your P V to operate its MPPT; you allowed your digit to generate some power. So, 0.4 units coming from your P, 0.4 units coming from your diesel generator the load is 0.5.

So, you have excess of 0.3 units and your grid is not connected; so you cannot give it back or neither reduce your diesel generator. So, that case you allow your battery to charge, so this 0.3 excess energy is being taken by the battery, so that the battery start charging because you have excess energy.

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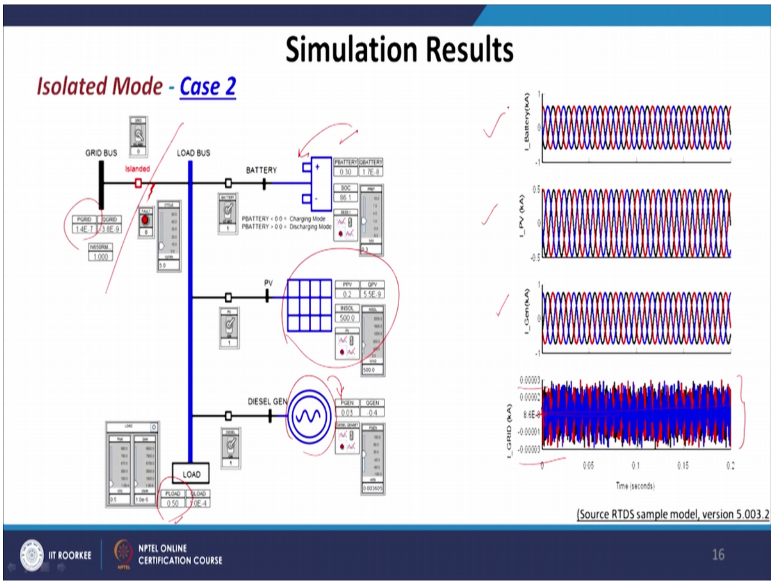

Now let us move to the case number 2 where if you allow your battery to discharge instead of charging and the same load is being maintained and the same load is being maintained. So, if you give 0.3 from the battery then we need a extra 0.2 because the load is 0.5 and the battery is now giving me 0.3; so, I am sort of actually 0.2 units and that 0.2 unit can come from my P, which is not operating at its MPPT.

So, now my P V is giving me 0.2; load is 0.5, the shortest 0.3 can be taken from my battery directly and forcing my diesel generator not to generate any power at all and certainly the grid is disconnected so the grid power is also coming to my AC microgrid is negligible.

One important case study we need to see here; the grid you can say which is almost 0 though it is we have zoomed the diagram for your better understanding; no current flow from the grid which is oscillating at 0 and the maximum scale is 0.00003 and minimum is 0.00003. And you can see the generator P V and battery operate extremely well within 1 per unit to minus 1 per unit.

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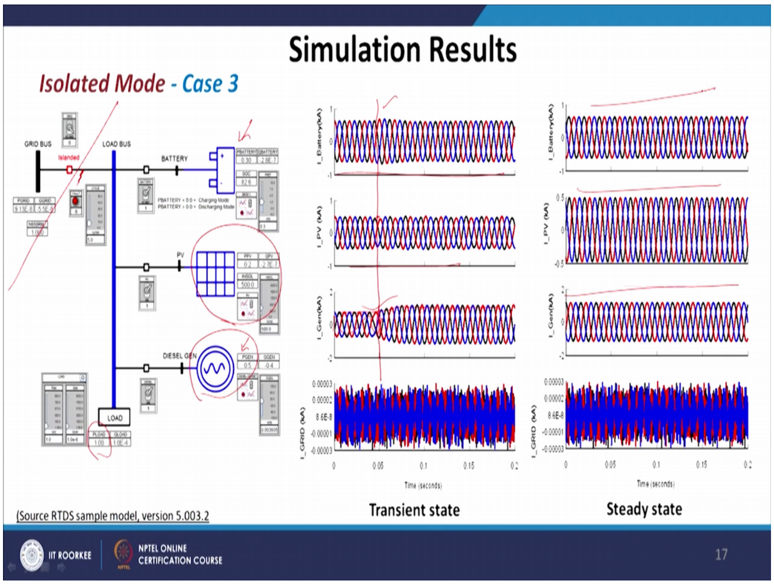

Now, the final one is the isolated mode of operation case 3; very interestingly I have already mentioned in past and now I am repeating the same sentence again. We allow the load to increase from 0.5 to 1 and the grid is disconnected and my P V is not operating at MPPT means I am getting 0.2 unit of power from my P V and the load is 1.

So, I need extremely a sort of power and those need to be maintained by both battery and P V sorry both battery and diesel generator. So, the diesel generator is now catering 0.5 and the battery is providing me 0.3; try to understand the P V is not operating its MPPT operating its less than MPPT assume to be 0.2 megawatt power is available to me.

The load now, increase from 0.5 to 1 and that 0.8 mega watt of energy requirement for the load can be brought from my generator and battery. So, we are getting 0.5 megawatt from the battery generator and 0.3 megawatt from the battery. So, the total load can easily be maintained even though the P V is operating not operating at its MPPT because the battery is now capable of discharging along with my diesel generator.

So, we can see that all 4; I mean that load is active from 0.5 to 1, the battery is active discharging 0.3, the P V is even though it is not available giving its best of 0.2 and the diesel generator is actively contributing to the major shortage of power and that is 0.5 megawatt. Now very important factor we need to see here for the now you can see the battery connectors moving this way P V.

And now we can see when the load is changed and you can see the generator; current is now shifted to a new denims. This is the important scale I want everyone to observe you can see the generation current actually increased, there is a deep in my P V and the battery anyway responding nicely and the grid which is at 0 ampere because it is completely isolated.

So, this is the transient state when the load increased from 0.1 to 0.5 to 1, but when we move to study state as in a system is absolutely a stable. So, this shows that even with a sudden load variation my AC microgrid is capable of handling those sudden change in loads. And once we do this simulation if you are convinced, now it is better or advisable for me to go for a test bet development or maybe real time deployment in the field.

And that is why the today's lecture is very important where we like to understand all the scenarios that may exist within AC micro grid. And given a scenario, given a condition we can easily simulate those scenarios and we can see the transient phenomena as well as the steady state phenomena and based on that we can execute this AC microgrid in field or we can develop test bets within the laboratory which may be certainly successful. We are ending with the following references those are being very rigorously used to prepare this presentation.

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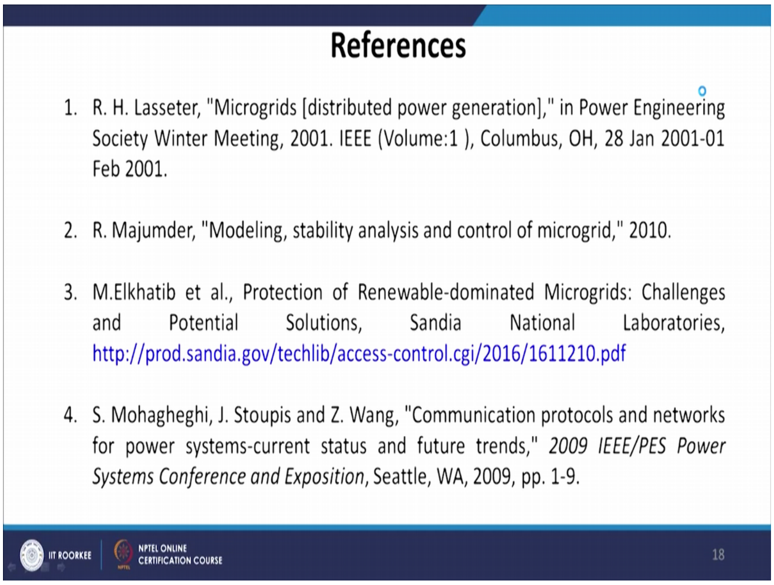

Thank you very much.