Introduction to Smart Grid

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Lecture - 37
Design of Smart Grid and Practical Smart Grid Case Study- I

Welcome you all for the NPTEL online course on Smart Grid. And, today we will be discussing mainly on the execution of all the concept that we have learnt throughout the course, how it can be implemented on a hardware platform with help of an existing test bit.

Now, the concern here when we like to exercise any concept like your energy management, whether it is with grid or islanded mode of operation, whether the system is at peak operation or off peak operation. As well as all this HIL hardware in loop experimentation both in control strategy as well as in power mode can be analyzed in detail.

Now, all the listeners my personal request here, what I am going to present in today's discussion is belongs to our laboratory where we have created a very smart grid laboratory. And, all my simulations results are based on the outcome of the existing lab, which is currently functional at Indian Institute of Technology, Roorkee.

Now, we will be focusing on design of smart grid and practical smart grid case studies. So, first of all see how the smart grid has been developed. And, then we will take all the simulation studies into a real time simulation with hardware setup and analyze those results.

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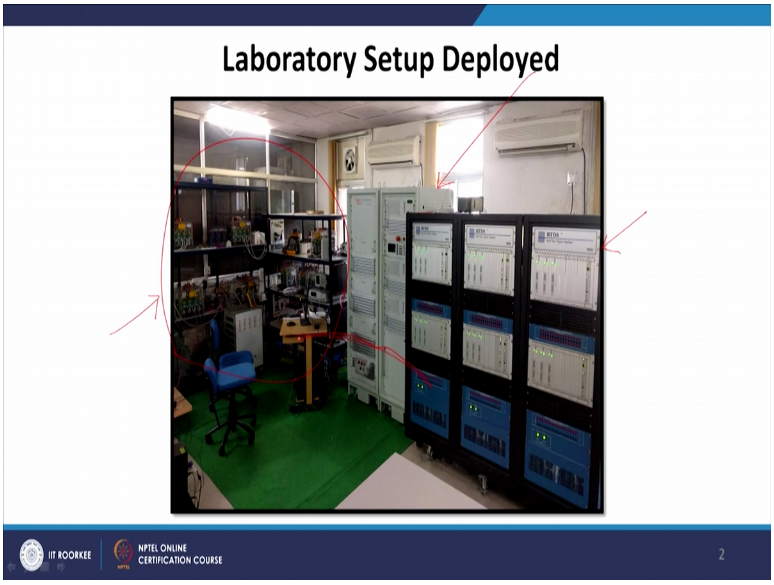

Now, this is how actually the lab look like so, I mean you can just see that is. So, this is mainly the RTDS of 6 rack and we can say this is the power amplifier, and then we have the smart grid hardware test bench. Now, all the 3 that is RTDS power amplifier and the test bed on smart grid being connected and simulated simultaneously. Now, let us understand what are the devices currently available in the laboratory smart grid laboratory?

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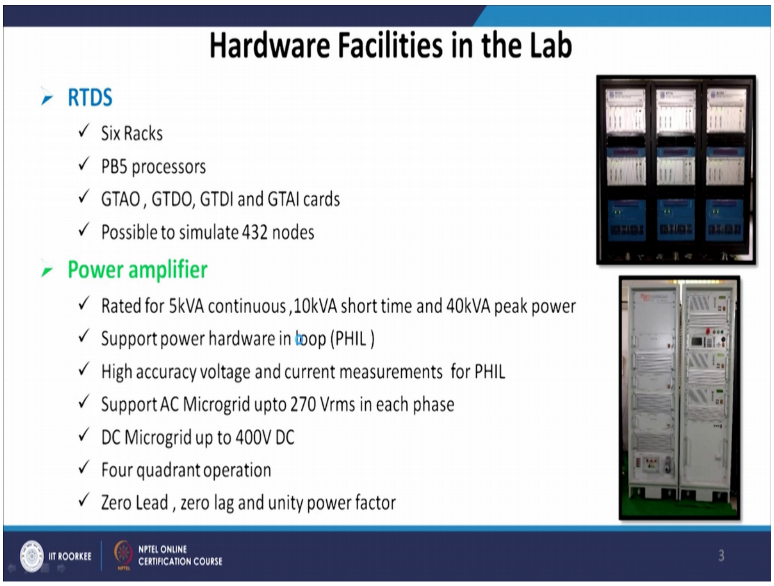

So, the hardware facilities available in our smart grid lab we do have a RTDS, which is of 6 racks, PB 5 processor, GTAO based, GTDO based, GTDI and GTAI card based RTDS. And, the very important part the RTDS can simulate a system which is a maximum of 400 and 32 nodes.

Then, we have second important device to our laboratory which is power amplifier and the rating which is 5 kVA continuous, it can perhaps the capacity of the amplifier can be increase to 10 kVA for a short time, and it can go as high as 40 kilovolt ampere for a few short duration of peak hours.

Now, this amplifier which is support power hardware in loop experimentation that is PHIL, it is a high accuracy voltage and current measurement for power hardware loop simulation. It supports the ac microgrid up to 200 and 70 volts RMS, in each phase ok. And, though we do not operate beyond 250 volt at a given time, but it has the capacity when the phase voltage goes as high as 200 and 70 still it can be made operational. Now, the DC microgrid if you like to connect this amplifier then it can accommodate up to 400 volt DC.

Now, it has the capacity to operate in all 4 quadrant and then finally, it has the ability to handle 0 lead 0 lag and unity power factor operations. Now, we do have sources energy sources the first one is PV emulator.

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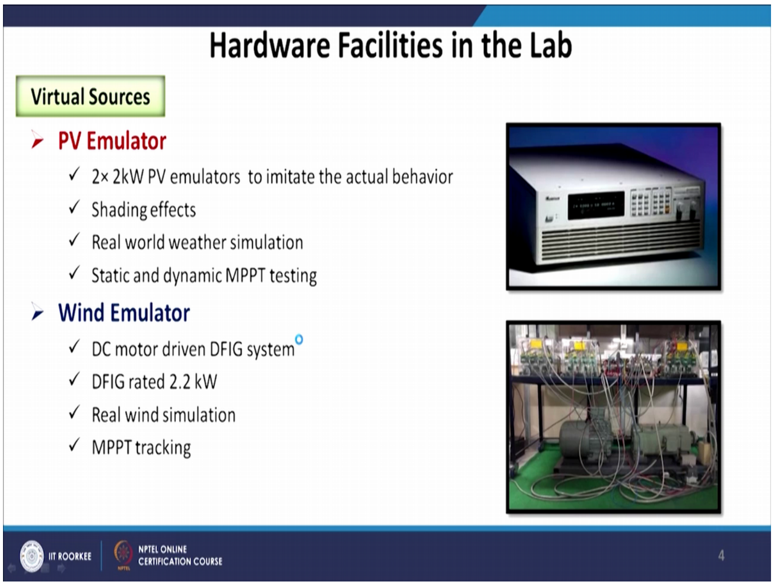

Which, will mimic your solar PV and we have connected 2 2 kilowatt PV emulator to imitate the actual behavior of APB solar, it has the capacity to accommodate the shedding effect, real world whether simulation is possible, static and dynamic MPPT testing also can be performed with the simulator.

So, this is a whole I can say 4 kilowatt of emulator in place. Now, we do have a wind emulator which can again mimic your wind renewables. And, it is based on DFIG, and DFIG rated 2.2 kilowatt capacity, and it can simulate real wind simulation is possible and we can track MPPT thus good news. So, as a whole if you see the PV which is a 4 kilowatt and wind of 2.2 at this moment, it has been connected to the test bed. Now, then we have also connected real PV roof top of one kilowatt and we also do have a diesel generator of 3 KVA capacity single phase and push button type.

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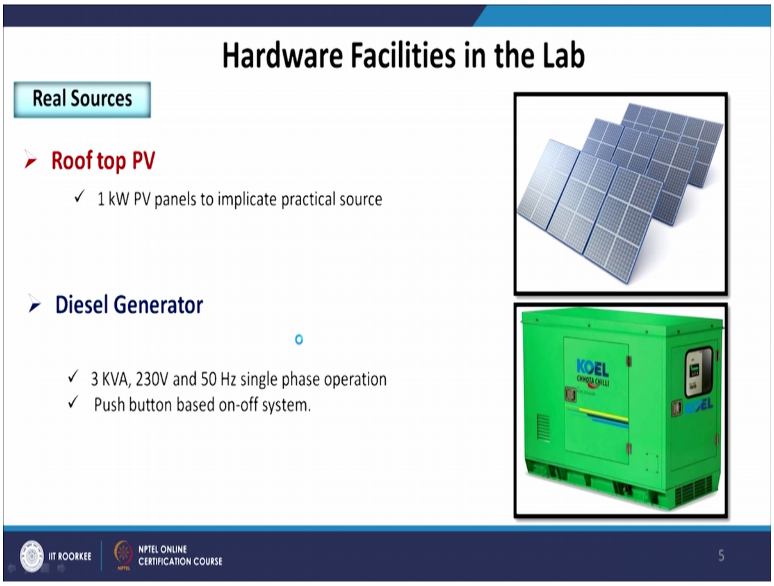

So, if you see the sources is as high as actually 4 kilowatt of PV and 2.2 for wind. And, 1 4 rooftop and 3 4 diesel so, close to 10 kilowatt source has been connected to the test bed. So, I can say it is a interesting setup which is very nicely handle 10 kilowatt capacity.

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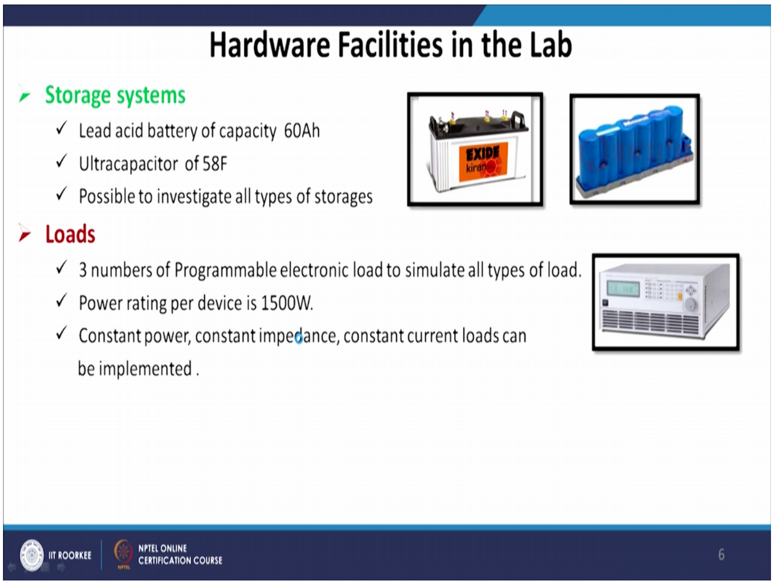

Now, we also do have storage sources and lead acid battery of capacity, 60 ampere hour and then we have ultracapacitor of 58 farad and we can possibly investigate all type of storages. And, we do connect approximately the given time maybe if, 6 to 8 kilowatt of or the KVA of storage that can be connected to my test bed at any given time through battery.

So, is a whole we can certainly test test bed of 15 to 20 kilowatt capacity. Now, then coming back to loads we very interesting recently acquired a programmable load, I mean it is basically 3 single phase loads. And, the power rating of each device is close to 1.5 kilowatt. So, total of 4.5 kilowatt load and it can very interestingly operated all 3 constant power, constant impedance, and constant current load, that can be implemented.

And, then going back to converters we do have this converters reused for integration of sources as well as storage. And, we have both DC DC and AC DC type converters and we do have the converters, which has the capability of both bidirectional and unidirectional capability inbuilt.

Now, what is hardware in loop HIL experimentation, you must have heard about HIL experimentation of smart grid, you develop a concept, you simulate something. And, then you try to assure confirm your analysis or concept or validate it through in HIL experimentation.

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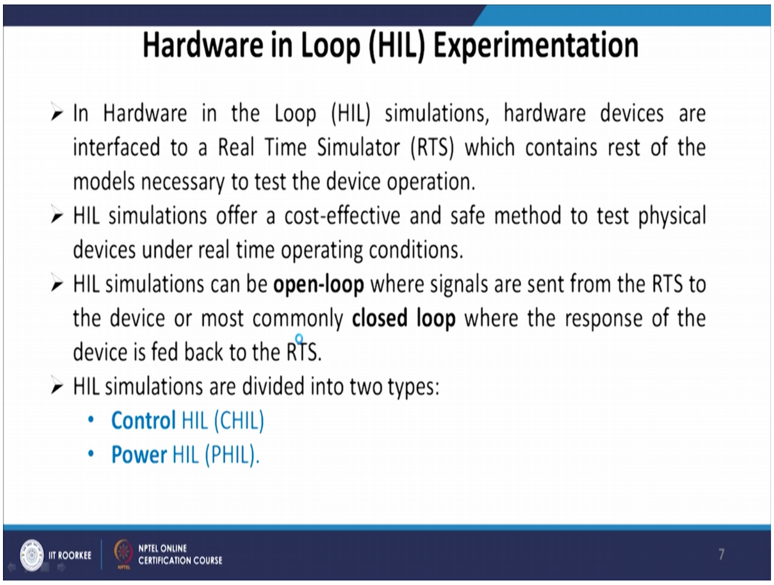

And, in hardware in loop HIL simulation hardware devices are interfaced in a real time simulator that is RTS, which contain rest of the model necessary to test the device operation. So, through HIL we basically connect the hardware devices to your simulator and most of the components are available within the simulator and few hardware devices that can be interfaced with your simulator.

Now, HIL simulation hardware in loop simulation offer a very cost effective and safe method to test physical devices under real time operating conditions. HIL simulations are of 2 types one is so, called closed type closed loop type and the other one is known as open loop type. And, in case of open loop type it is very interesting that where the signals are sent from the RTS to the device or most commonly whereas, in case of closed loop the response of the device is fed back to my RTS.

So, we do have 2 types of HIL; one is closed loop and the other one is open loop. In case of open loop hardware in simulation during open loop, where signals are sent from the real time simulator to the device so, we have a simulator. So, signals are sent from the simulator to the physical device whereas, in case of closed loop the response that has been received from the device can be given back to the RTS. Now, there are 2 types of HIL we one is known as control hardware in loop and the other one is known as power hardware in loop.

CHIL, Control Hardware In Loop simulation PHIL power hardware in loop simulation.

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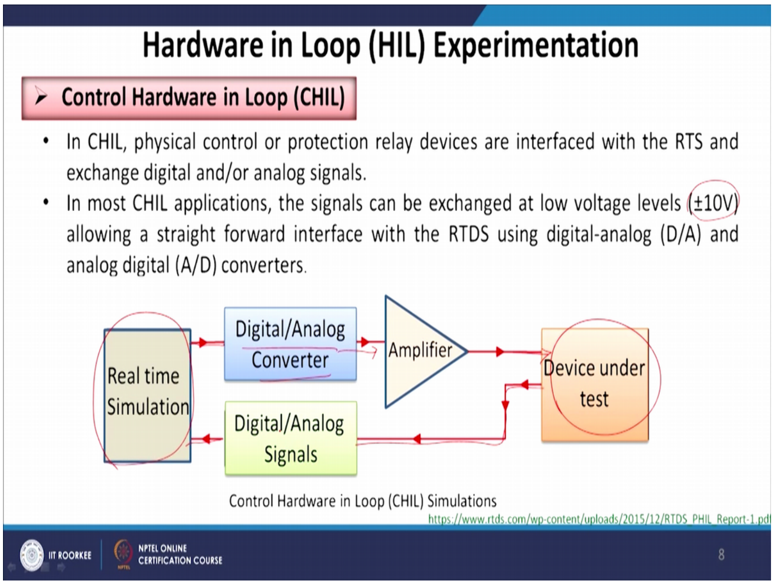

Now in case of CHIL physical control or protection relay devices are interfaced with the RTS and exchange digital and or analog signals. So, there is signals are exchanged, but no power. If you see the CHIL application the signals can be exchanged at low voltage level around plus or minus 10 volts, allowing a straight forward interface with the RTDS using digital to analog and analog to digital converters.

So, if you see this is my RTDS all the real time simulator, then we convert the output from d to a and that analog information will go to my amplifier and then to my device, which is under test. Now, the outcome of the device now can go back from analog to digital conversion feedback to RTDS.

So, this kind of setup is certainly a closed loop and it is control hardware in loop simulation with closed loop representation.

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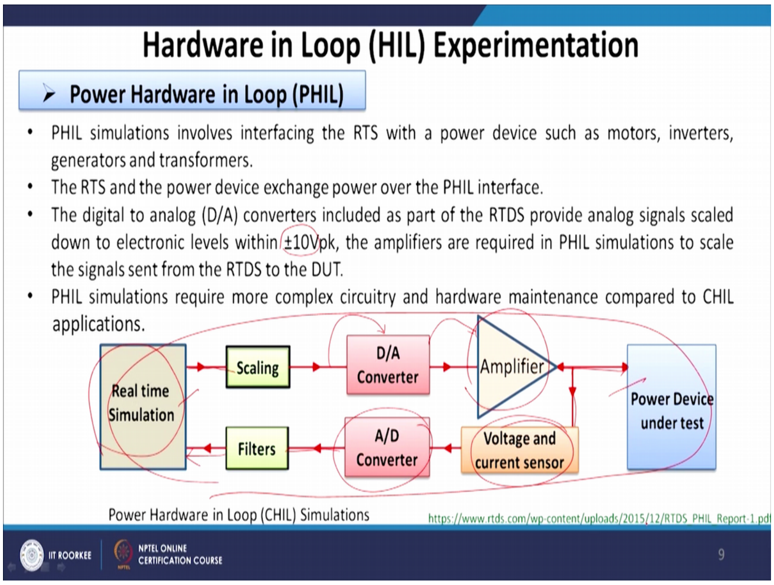

In case of Power Hardware In Loop simulation PHIL simulation involves interfacing the simulator that is RTDS with a power device such as a motor, inverter, generator, and transformer. And, the real time simulator and the power disk device exchange power over the PHIL interface.

So, the simulator and the device do exchange power, which was not there in case of your control hardware in loop simulation, but in case of power hardware in loop simulation the devices could be either motor, transformer, inverter, you know converters and there is a power exchange takes place or between your device and the simulator.

Now, the digital to analog DA converter includes as part of the RTDS provides analog signal scale down to electronic level within plus or minus 10 volts, and the amplifier are required in PHIL simulation to scale the signal sent from the RTDS to the dut unit or your device unit. Now, please try to understand in case of PHIL we did we do need to have an amplifier and that amplifiers perhaps scale up your signal received from your simulator and give the amplifier signal to the device. Now, in case of PHIL simulation which requires complex circuitry and hardware maintenance compared to control hardware in loop simulation.

Now, this is the closed loop setup of your PHIL, we can see this is my RTDS and we have scaled and then D to A converter and then through amplifier it is being given to my device which is the under test. And, further at feedback we can have voltage and current sensors in place and then A to D conversion and through filter, we can give that output to my simulators. So, this is a closed loop where the amplifier to interface both your RTDS and the device and the device could be your test bed too.

Now, there are different case studies we have considered for discussion for this NPTEL course, where we will talk many case studies one by one how it has been validated through hardware setup. In previous lectures we have discussed about simulations and today we really talk about how they have been validated through a hardware test bed or a platform through both CHIL and PHIL experimentations.

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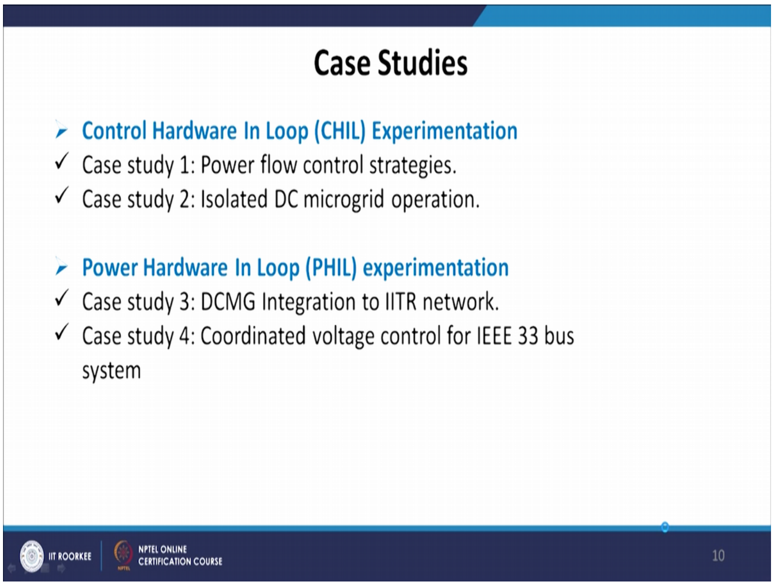

Now, first of all power flow control strategies, that is your case study one we will be discussing, then we will talk about case study 2 where isolated DC microgrid operation and then we will take care of PHIL we will consider a case study 3, that is DC microgrid integration to IIT Roorkee distribution system. And, case number 4 coordinated voltage control for I triple E 33 bus system. So, these are the 4 case studies we will be focusing in detail in during today's lecture.

Now, when we see the power flow control strategies, in the initial stage, I think in the previous lecture also you might have seen the DC microgrid architecture.

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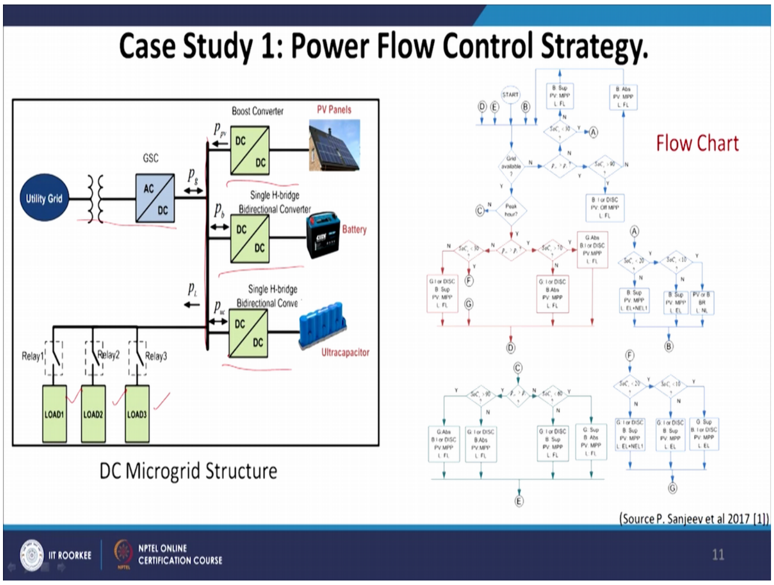

This is my utility grid and we had GSC and this is my DC bus, we have loads connected and my PV battery and ultracapacitor in place we have also discuss the flowchart in our previous lecture.

So, depending upon the grid situation we can control your devices within the DC grid. So, that the maximum stress on the utility can be avoided by optimally operating your storage devices to meet out the loads. So, by sensing different soc points one can easily allow, it is battery whether to charge or discharge and similarly the PV and other connected devices such as supercapacitors.

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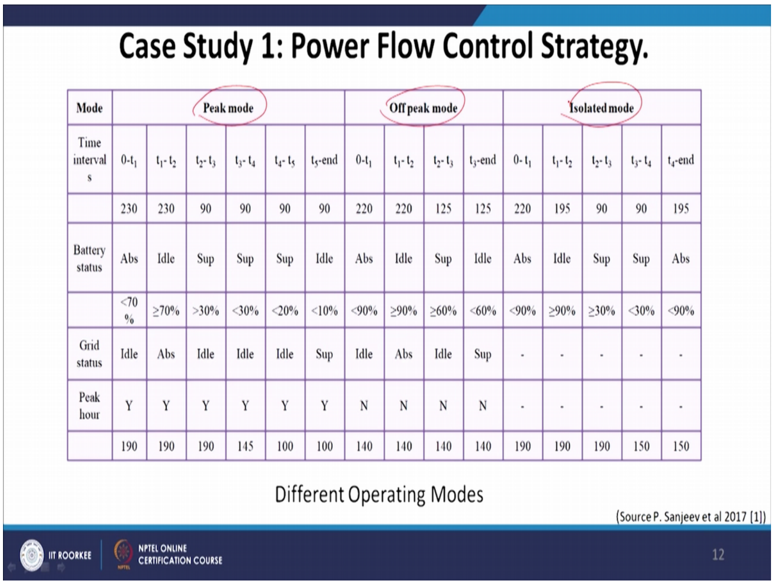

Mode	Peak mode						Off peak mode				Isolated mode				
Time intervals	$0\text{-}t_1$	$t_1\text{-}t_2$	$t_2\text{-}t_3$	$t_3\text{-}t_4$	$t_4\text{-}t_5$	t_5-end	$0\text{-}t_1$	$t_1\text{-}t_2$	$t_2\text{-}t_3$	t_3-end	$0\text{-}t_1$	$t_1\text{-}t_2$	$t_2\text{-}t_3$	$t_3\text{-}t_4$	t_4-end
	230	230	90	90	90	90	220	220	125	125	220	195	90	90	195
Battery status	Abs	Idle	Sup	Sup	Sup	Idle	Abs	Idle	Sup	Idle	Abs	Idle	Sup	Sup	Abs
	<70 %	≥70%	>30%	<30%	<20%	<10%	<90%	≥90%	≥60%	<60%	<90%	≥90%	≥30%	<30%	<90%
Grid status	Idle	Abs	Idle	Idle	Idle	Sup	Idle	Abs	Idle	Sup	-	-	-	-	-
Peak hour	Y	Y	Y	Y	Y	Y	N	N	N	N	-	-	-	-	-
	190	190	190	145	100	100	140	140	140	140	190	190	190	150	150

We have seen that there are different operating modes have been considered. So, one could be my peak mode of operation and the other one could be the off peak mode of operation. And, then finally, we can considered the isolated mode of operation, please try to understand. The main objective of having DCS microgrid or smart grid in place with my existing power system is to perhaps support or help the main grid to survive better, which was not possible earlier without smart grid.

So, here one of the main objective the system is always under stress means the utility is under stress because they do have different load characteristics. And, when it is at peak point then certainly the system is under stress, because they are not able to cater all the loads connected during that particular hour.

So, now we have couple of let us say couple of microgrids maybe 100 of microgrids maybe millions of microgrid in place across the country after 5 to 10 years. So, if those microgrids let us say had bit of energy stored in their batteries. So, instead of taking energy from the grid during peak hours, if they can survived themselves or some extent then the grid will be completely relieved. And, also during off peak hours when the system is not are stress.

So, then if my battery stress status can be checked and if the smart grid storage is already having huge storage, then it can manage it is load and if not then it can draw energy from the main grid to charge the battery storages.

Whereas going back to the third scenario if the grid is not present to me, then also I can get some sort of comfort to meet my critical loads without the grid. So, that case depending upon the storage capacity we will keep on catering the loads and if the battery discharges SOC is very low maybe below 30 percent of below 20 percent, we will slowly keep on disconnecting the non critical loads and if required finally, because the grid is not there even the critical loads may be compromised.

But, if you do a proper design certainly the critical loads can be protected with a hope that the grid a which is not available to you is not for a very long time, but if it is completely isolated remote area then you have to design your network such that given a period of time of your application, you must be able to manage your critical loads at any given time of the day. When, we come back for the next lecture we will talk few more applications on smart grid on hardware setup.

Thank you.