Introduction to Smart Grid

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Lecture - 36
Energy Management

Welcome you all to the NPTEL online course on Smart Grid. And, today we will focus on a topic titled energy management. If, you remember my previous lectures on demand side management as well as demand response, where we have discussed in depth how my load curve can be made flatten by taking advantage of the presence of smart grid. Perhaps I can control the energy scenario of my smart grid such that the load curve experience by the utility can be made flatten.

And, then further we have entered to another topic called demand response where, the consumers participate in that activity and share their message through aggregator to the utility further.

So, that the aggregator demands or take observation from the consumer, if we are willing to participate in demand response activity and accordingly the aggregator design the new load curve which is more economical or efficient. Now, with this fundamental theoretical concept, now we are moving towards a DC micro grid energy management scenario. Where a demand response activity can be executed within the DC micro grid to support the grid, whether it is a peak load condition or is it at op peak load condition or sometime the grid is not there.

So, dear friends, now it is time for all of us to understand. If, the micro grid is connected to my distribution system and hence to the utility, but if the utility is really struggling with the peak requirement of the consumers, at large at system level, then the DC micro grid can perhaps adjust it is energy scenario such that instead of drawing maximum power from the grid, it can reduce it is maximum power from the grid.

If, it is at off peak it will try to get as maximum as possible from the grid, but making sure the peak is not shifted to another hour. And, the third one when the grid is not available it will redesign it is demand response activity in such a manner by curtailing some of the non important loads so, that the energy can be balanced.

Let us move step by step how this energy management can be achieved within a DC micro grid. So, that, the system can operates efficiently with the grid during peak condition, during off peak condition and also for the worst scenario, when the grid is not present. Now, first of all why there is lot of challenge for demand response, demand management, energy management why we are so, conservative? The present impact for conventional generation stressed the carbon free energy scenario or the generation around the globe, we are going for energy without making lot of carbon.

Renewable generation is at the top interest of most of the country due to increase in per capita energy consumption and deficiency of fossil fuel. Now, what happens because the per capita consumption is keep on increasing and hence we need to meet the expectations of consumers. And, it is very difficult for me to you know establish a huge power plant like super thermal or hydro within 2 3 years' time, and hence the quicker solution could be put lot of renewable into the system.

So, that will meet 2 of my things one is green energy and the second quickly you can meet the expectations or the per capita requirement of the consumers.

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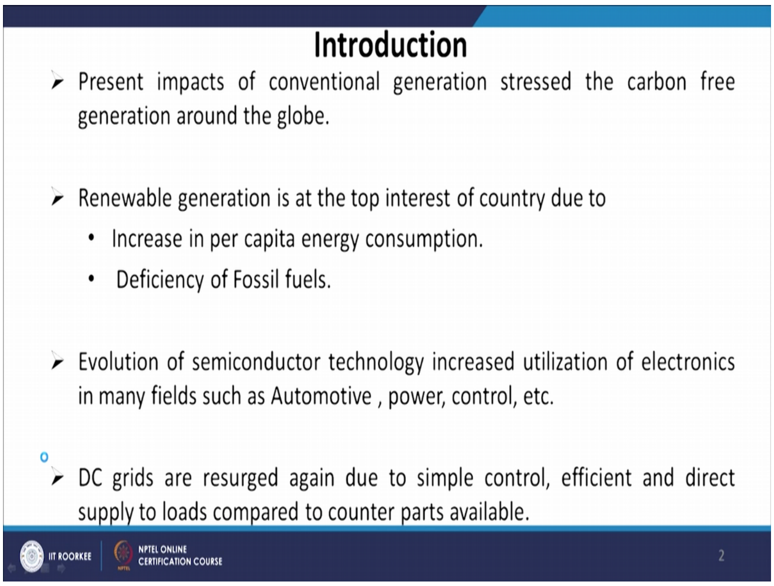

Now, evolution of semiconductor technology increased utilization of electronics in many fields such as automotive power control etcetera, that also forced me to go for such kind of DC grids and DC grids are resurged again due to simple control efficient and direct supply to the load compared to the counter parts available. So, in general what we are arguing here a smart grid is a must renewable energy is must and certainly a DC microgrid will be a better option. Now, we have seen the couple of times with the architecture of a DC microgrid.

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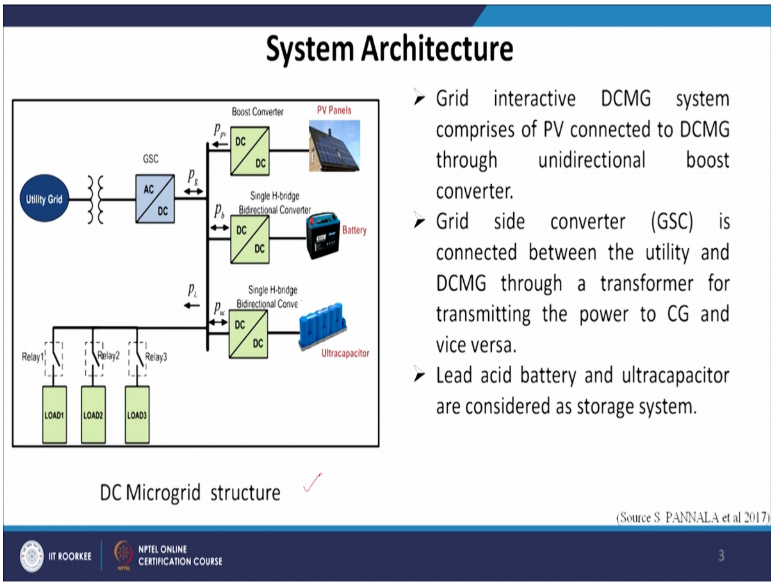

And, this is a very simple DC microgrid architecture I am not going to take lot of time here. Because, we all aware we have a single grid connected from the utility side which is a DC grid then we have DC loads and DC generations.

Now, grid interactive DC microgrid system compromise of P V connected to DC microgrid through unidirectional boost converters. Grid side converter GSC is connected between the utility and DC microgrid through a transformer for transmitting the power to conventional grid and vice versa. Lead acid battery and ultracapacitors are considered as a storage system. Loads are categorized into 2 types a one is my essential load and the other one is non-essential load. Now, the control schemes this a very standard control schemes which is in place.

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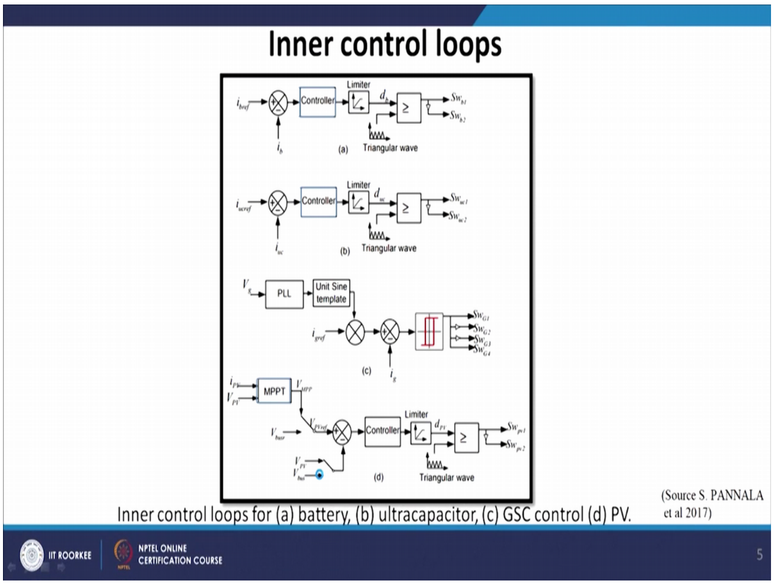

And, perhaps we can go for the inner control loops for battery ultracapacitor GSC control and PVS.

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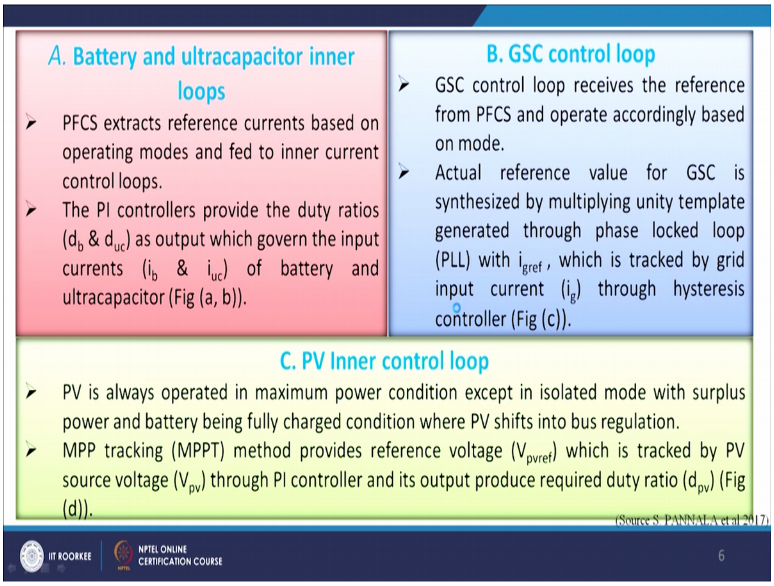

Now, battery and ultracapacitor inner loops.

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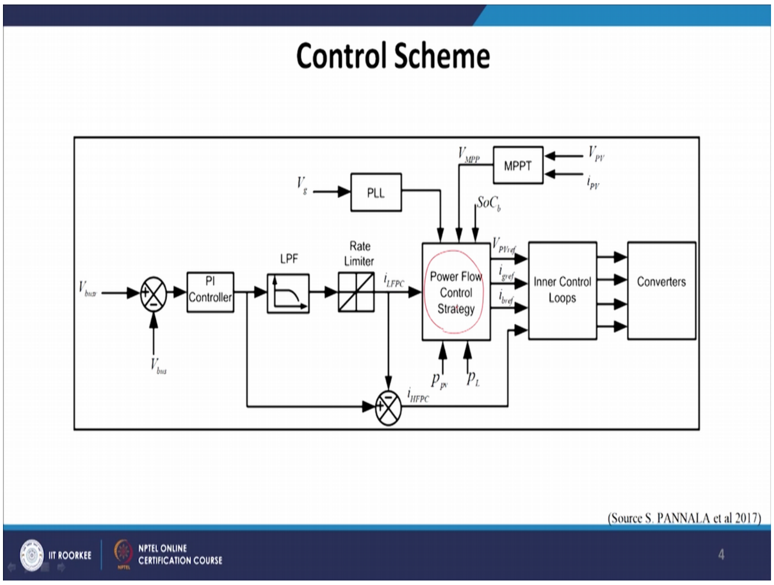

Now, the PFCS that is power flow control strategy we could see the power flow control strategy, where it extract the reference current based on operating modes and fed to inner current control loops. The pi controllers provide the duty ratio as output, which governs the input current a battery as well as ultracapacitor. Now, in case of GSC control loops the GSC control loop receives the reference from PFCS and operate accordingly based on it is mode.

Actual reference value for GSC is synthesized by multiplying unity template generated through phase locked loop that is PLL with i gref, which is tracked by grid input current i g through hysteresis controller. Now, the P V inner control loop P V is always operated at it is maximum power condition, except in isolated mode with surplus power and battery being fully charged conditions where P V shifts into bus regulation. That means, all the time we want our P V to operate it is MPPT until unless the battery is fully charged or maybe the grid is not available etcetera.

MPP that is MPPT method provides reference voltage V P ref, which is tracked by the P V source voltage V P V through pi controller and it is output produce required due to ratio d P V. Now, the power flow control strategy what are the main features.

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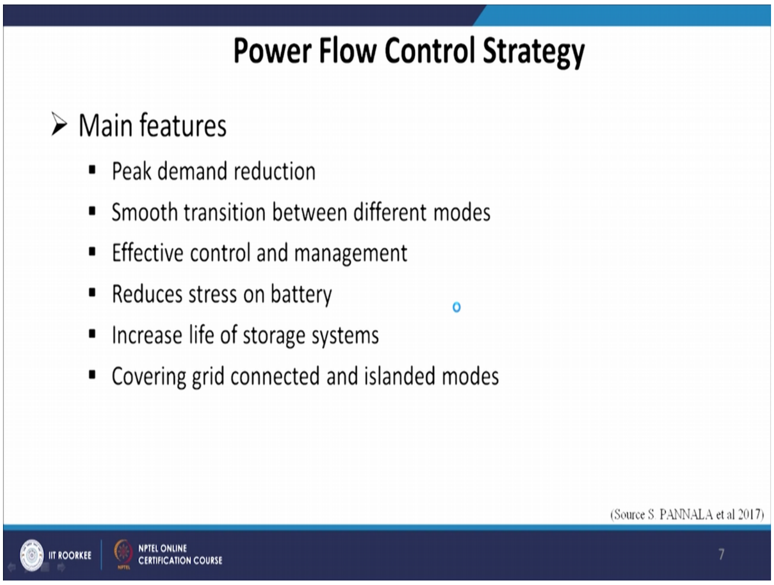

First of all using power flow control strategy we can reduce the peak demand, smooth transition between different mode of operation, effective control and management, reduces stress on the battery, because it is a smooth transition, increase in life of the storage systems, because you allow the storage to charge as well as discharge depending upon it is SoC level.

Covering grid connected and islanded mode; that means your system is can operate whether the grid is there even it operates without the grid. Unity power factor feeding to an drawing from conventional grid means the very important fight when the grid, I mean you feed power and you draw power from the conventional grid only through DC microgrid along with unity power factor only.

Now, let us see the power flow control strategy, which has been proposed in this talk today let us start from this point.

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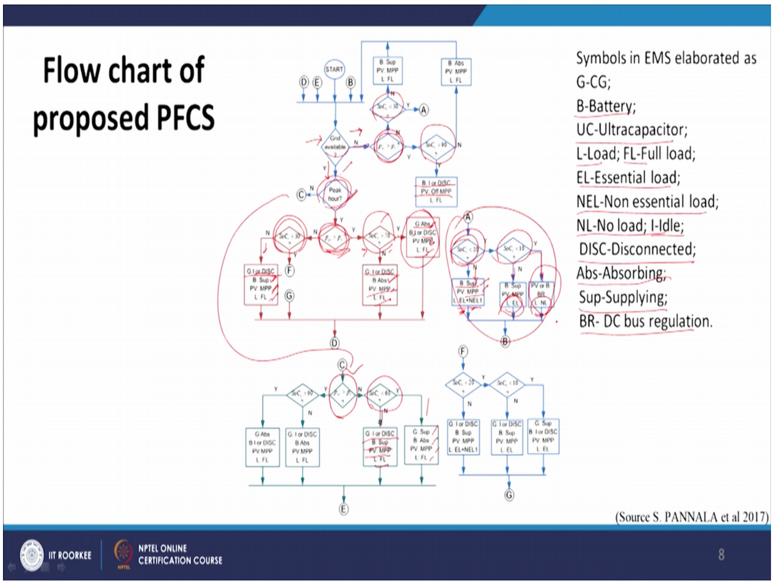

This is my grid and the grid there are 2 scenarios the grid maybe available to me and sometimes the grid may not be available to me.

Now, let us see if the grid is available then I move this way if the grid is not available then I will follow the other low grid grid is not available means islanded operation if the grid is available then it is either peak or off peak. So, when the grid is available to me check whether it is peak hour, if it is peak hour then we will check the P from P from the generation, a generation real power generation from the P V. Whether the P V is more than the P load or not I do repeat check whether the grid is available if the grid is available check whether it is peak hour or not, if it is peak hour then you can check whether the power from the P V is more than p load or not.

Now, when the power is more than the p load then you check whether the state of charge or the battery is greater than 70 percent or not. If, it is 70 percent then you come to this point where you operated full load and P V also you allow it MPPP, but do not charge your battery the storage is no more required, but if it is not charged if it is not charge then you operate the grid and the battery still absent the PVS it MPP operation and load is at full load, I do repeat if the storage is more than 70 percent for you and it is at peak hours and then and the P V is also greater than PL.

So, then certainly it is my role to support my grid. So, I can perhaps give that excess energy available to me to the grid, because grid is struggling with peak hours and I can support it, but if it is not the P V is not enough to meet the load and if the battery is also at less than 30 percent. So, that case if it is not 30 percent then the grid at will be disconnected or it can be connected, but the battery will be supporting my super capacitor and the P V can operate at MPP and load can also operated full load.

Before, we proceed let us quickly understand the acronyms B for Battery, U C for Ultracapacitor, L for Load and FL for Full Load, EL for Essential Load, NEL for Non-Essential Load, NL for No Load, I means Idle; that means, when I say I or this means it could be idle or disconnected. Abs means it is the battery is observing and the ok, abs means it is observing Sup means it is supplying and BR means, which is DC bus regulation.

Now, just quickly I will just go back once again. Now, check whether that grid is available or not if it is available check whether it is at peak hour. If it is at peak hour then check whether the P V output from the back solar is more than the load or not. If, it is yes check the SoC condition if it is 70 percent, then you make your grid observe all the energy which is excess available to you, because the P V is more than PL and the storage is also full. So, the grid can observe the power from my DC grid the main grid can observe power from the main grid.

And, the second one whether you can you know connected to this whether you disconnect it or keep it ideal it is one of the options available to us and then the P V can be at MPP and load can be at full load. Similarly, if it is not there then what we can show, that if it is not show the SoC is not more than 70 then we can allow your battery to observe. And, that the grid could be ideal or it could be disconnected and the P V at MPP and load will be at full load only because locally you have to manage at any cost.

Now, if the P V is not greater than PL it is not more than PL and then you check whether your SoC is less than if it is 30 and if it is no then the grid could be ideal or disconnected and the battery has to supply, because your generation is low to meet your own grid and the battery has to supply and the P V will be at MPP no doubt and load could be at full load.

Now, let us say that it is not at peak hour if it is not at peak hour that is off peak. So, certainly I can take my energy from the grid. And, then I move from this point to this point. So, here I check whether my P V is greater than my load or not and if it is not and the SoC is less than 60, then I make sure the grid will be ideal or disconnected and the battery will be supplying and the P V will be at MPP and load will be at full load.

Now, if it is less than sixty then the grid will be supplying battery will be observing P V will be at MPP and load will be at full load. So, first of all you have to meet your own load and then you can support, but the condition here if the grid is at peak point then you try to discharge your batteries and allow you grid to observe and the grid is at off peak then you do not allow your grid to observe perhaps you take from the grid, grid is supplying power to my DC grid if the battery is not fully charged. So, this algorithm you know repetitively will help you all the scenario, how do you manage your grid? So, that, the overall load of the system can be maintained.

Now, one more important when let us say if the grid is not available, which is the islanded grid is not available to me and then you check whether the P V is greater than PL grid is not there, but P V is more; that means, you have more generation from your load and grid is not there. So, what you will do with that.

So, if it is yes and then you check my battery if it is also fully charged then the battery will be ideal or disconnected and P V will be off MPP. Now, if the grid is not available and you have excess energy and the battery is also full charged. So, then I have to derate my P V which is will not allow my P V to operate at MPP I have to lower down my P V capacity to make the energy balance within this.

Now, if it is not if the P V is not greater than PL and the SoC is also less than 30 and then I come down to this scenario because the battery is low and then SoC is less than 20, then I if it is not then I allow my battery to supply P V at MPP and I will have one essential load and one non-essential load, and if the battery still less than 10 percent and then I will just go for only non-essential loads and if it is not less than 9 then I will greater my essential load.

So, the conclusion here if the SoC is less than 20 under off grid the grid is not connected and if my if it is not less than 20 then certainly the battery can supply P V at MPP and I can cater my essential load and non-essential load, but if it is less than 10 then I will certainly take care of my essential load only ok.

And, if it is less than 10 then there is no load that I can cater means I do not have grid and my P V is also not greater than P load and my battery is also do not have my energy. So, then finally, I have to keep on curtailing the non-essential loads and finally, I will come to a condition whether is no load of the grid is not there, my microgrid is also not able to meet the basic loads.

So, this is the whole scenario of the control strategy, which has been incorporated now there are different operational modes.

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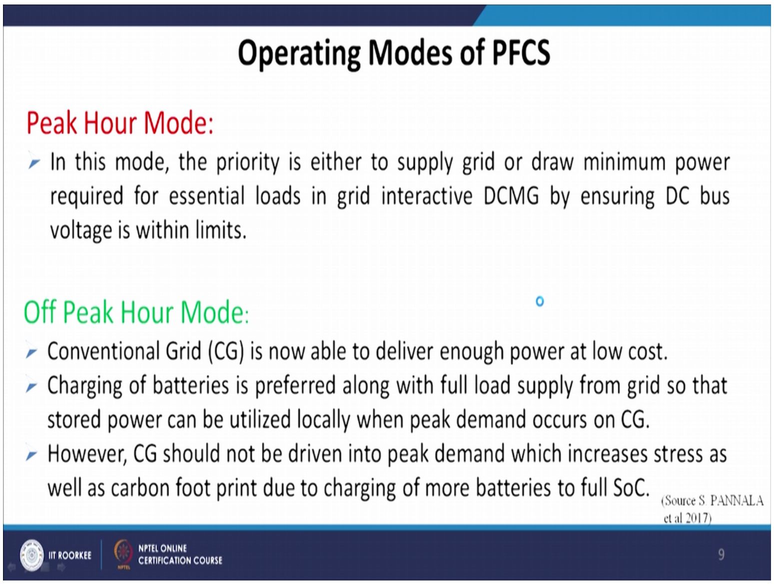

If, you look into the peak hour mode in this mode the priority is either to supply the grid or draw minimum power required for essential loads in grid interactive DC microgrid by ensuring DC bus voltage within it is limit. Now, in case of off peak hours conventional grid is now able to deliver enough power at low cost charging of battery is preferred along with full load supply from the grid. So, that the store power can be utilized locally when there is peak; that means, if the system is it off peak we can take power from the grid charge your battery and that can be discharge during the peak hour experienced of the main grid. So, the local load can be managed by it is storage scheme instead of taking energy from the main grid.

However, the conventional grid should not be driven into a peak means if you charge value of battery during off peak; it means through happen that the grid may experience a peak hour. So, that should be avoided. So, you had a peak and you have a off peak you keep on charging your storage. So, that off peak hour goes to a another peak which is not desirable. Now, in case of isolated mode of operation this mode comes into picture.

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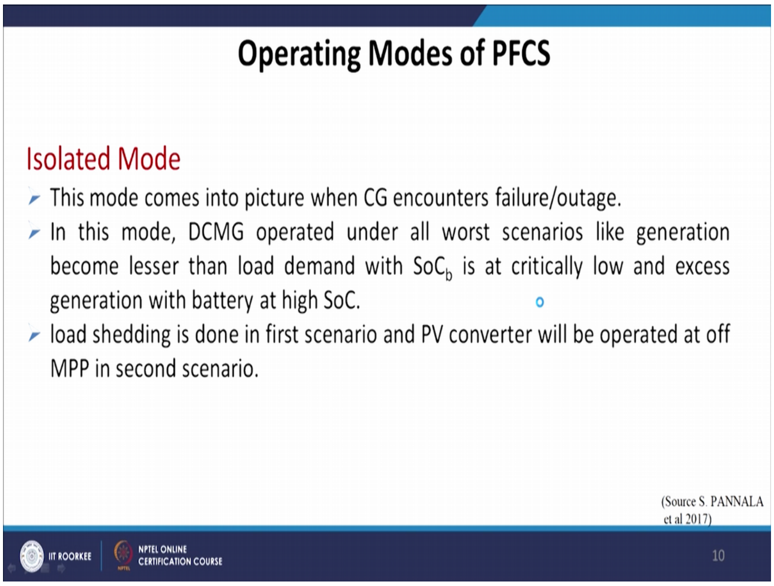

When the conventional grid encounters failure or outage in this mode, DC microgrid operated under all worst scenario like generation become lesser then the load demand with SoC is at critically low and excess generation with battery at high ~~soes~~SoCs.

Load shedding is done in the first scenario and P V converters will be operated at off MPP in the second scenario; that means, if you your battery is fully charged grid is not there P V is more than load, then you have to go for a off MPP scenario to balance your energy . Now, there are couple of simulation scenarios ah. So, we have taken a small DC microgrid. So, simulation is carried out and grid interactive DC microgrid system.

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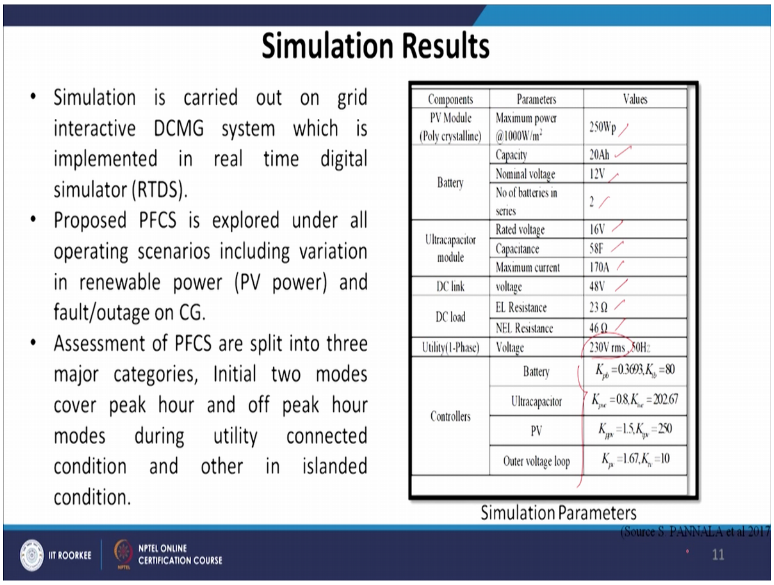

Which is implemented in real time digital simulator that is RTDS and the system is quite small. So, the P V module is the 200 and 50 watt power.

In the capacity is 20 ampere hour for the battery and nominal voltage is 12 volt and we have 2 batteries ultracapacitors 16 volt 58 farad 170 ampere. And the DC link voltage was 48 volts and the DC load which was 23 ohm and the nel resistance, which is the 46 ohm and the voltage utility voltage consider to be 230 V rms at 50 hertz. And then these are the control parameters being chosen for battery ultracapacitor P V and outer voltage loop.

Now, the proposed PFCS is explored under all operating scenarios including variation in renewable power and fault outage in the conventional grid. Assessment of PFCS are split into 3 major categories, initial 2 modes cover peak hours and off peak hour mode and during utility connected conditions whether other will be in islanded conditions. So, we take utility connected peak and off peak and then you have islanded conditions where the grid is not present.

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Ah. This a very simple scenario so, we have taken different cases at t 1, t 2 t 3 t 4 t 5, and this scenario is mainly for your t 1 and specific and this is for t 5.

And, you could see that the SoC characteristic this is irradiation and you can see the SoC characteristics, which is keep on changing and the voltage of the bus, which is at 48 (Refer Time: 23:14) 48 this is for information and the current which is the P V current which is dropping at t 2 with different cases in the current, now the battery which is increasing and further decreasing means it is started charging and then discharging. And whereas, this ultracapacitor current small variation, then we look at the load we had a load earlier in the load is keep on reducing.

So, essentially when the load is keep on dropping you could see the different scenarios from the P V as well as from the a batteries and this is my voltage. So, the grid and the current of the grid and these are all close scenarios of both t 1 and t 5 and they are the zoomed characteristics, at t 1 and at t 5 means the initial time and the ending time.

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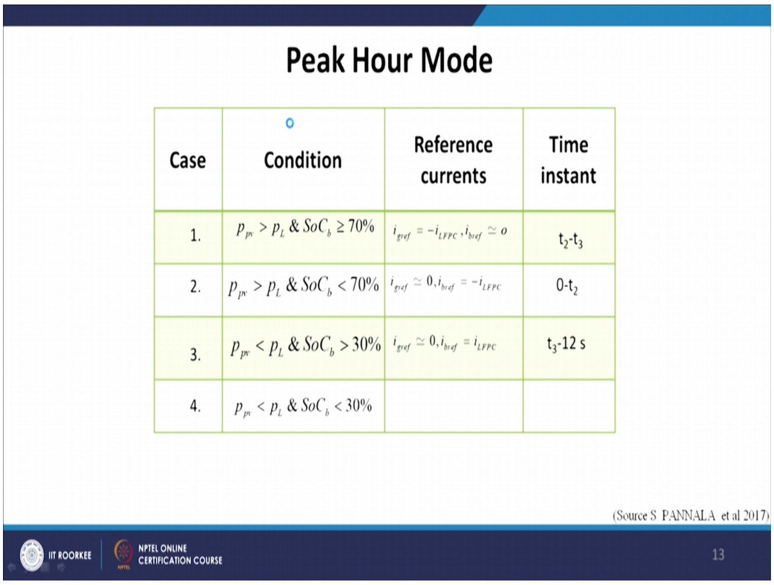

Case	Condition	Reference currents	Time instant
1.	$p_{pv} > p_L \ \& \ SoC_b \geq 70\%$	$i_{gref} = -i_{LFPC}, i_{bref} \simeq o$	t_2-t_3
2.	$p_{pv} > p_L \ \& \ SoC_b < 70\%$	$i_{gref} \simeq 0, i_{bref} = -i_{LFPC}$	0-t_2
3.	$p_{pv} < p_L \ \& \ SoC_b > 30\%$	$i_{gref} \simeq 0, i_{bref} = i_{LFPC}$	t_3-12 s
4.	$p_{pv} < p_L \ \& \ SoC_b < 30\%$		

Now, during the peak hour mode we have consider different conditions and based on operation case one where we say P V is greater than p L and SoC is greater than 70, and second case we say p v is greater than p L and the SoC is less than 70, we consider the case 3 where p v is greater than less than p L p v is less than p L and SoC is greater than 30 and then we had the forth condition, where p v is less than p L and SoC is less than 30.

So, we have taken in brief 2 major scenarios my p v output is more than load or less than load and the battery condition whether it is more than 70 or less than 70 or more than 30 or less than 30. So, those scenarios have been captured and the energy management has been performed during peak hour.

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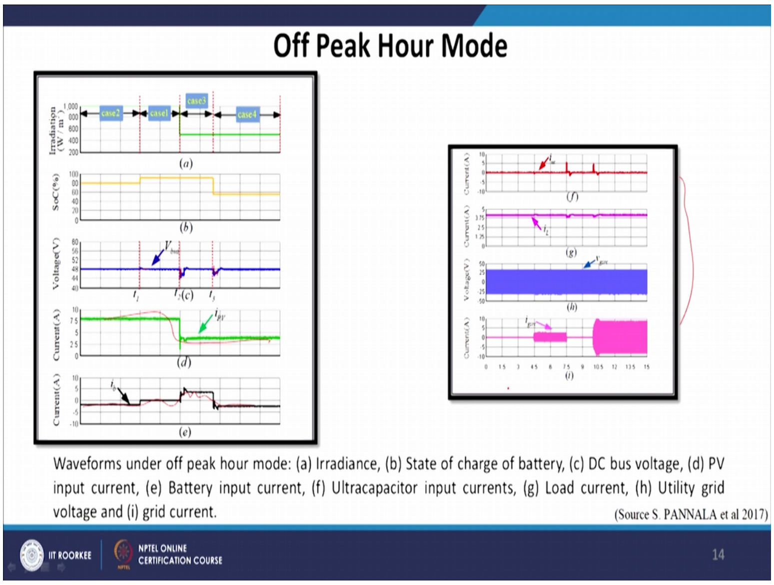

So, when you move to the off peak hours we can see the scenarios where, we could see the bus voltage bus, which is very close to 48 excluding couple of variations this is my P V current and this is my battery current variations. And, these are the zoomed structures for your ultracapacitor current load current and almost the same 1 2 3 4 5 6 7 8 9 characteristics, but here we have separated out the last 4.

Now, during off peak powers also we have considered a few cases. The case one where the P V is greater than P L and the SoC is greater than 90 percent, the case 2 where P V is greater than P L and the SoC is less than 90 and case 3 where the P V is less than P L, but the SoC is greater than 60 percent, and P V is less than P L where the SoC is less than 60 percent.

So, you may be surprising why 90 60 70 30 have been considered. So, they are based on the existing expertise, but they can certainly vary depending upon the size of the battery and give a loading conditions.

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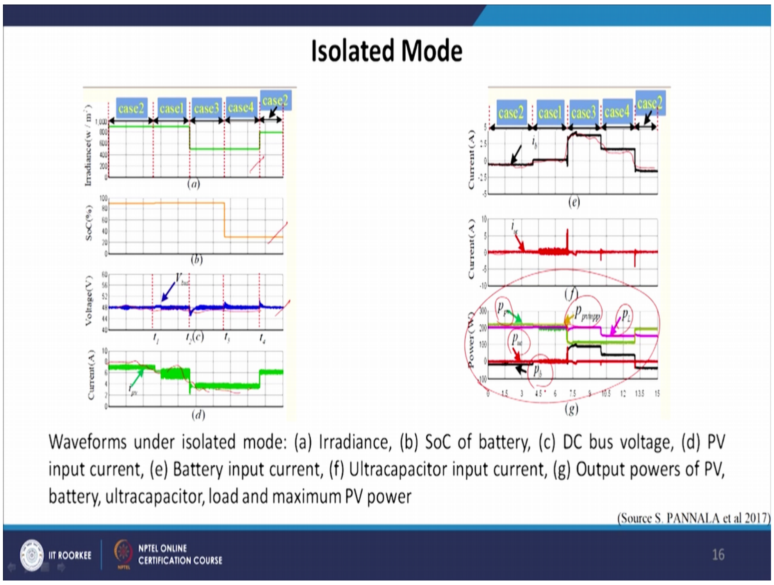

Isolated mode when we move to isolated mode and we can see that this is my load scenario and then this is a SoC scenario, and b bus which is again with minor variation and you can see the current for the P V which is varying and then this is this is my battery current characteristic. And finally, my ultracapacitor and this is a superimposed characteristics where the power from the P V and power during MPP and the load current ultracapacitor power and power from the battery all have been simultaneously a captured.

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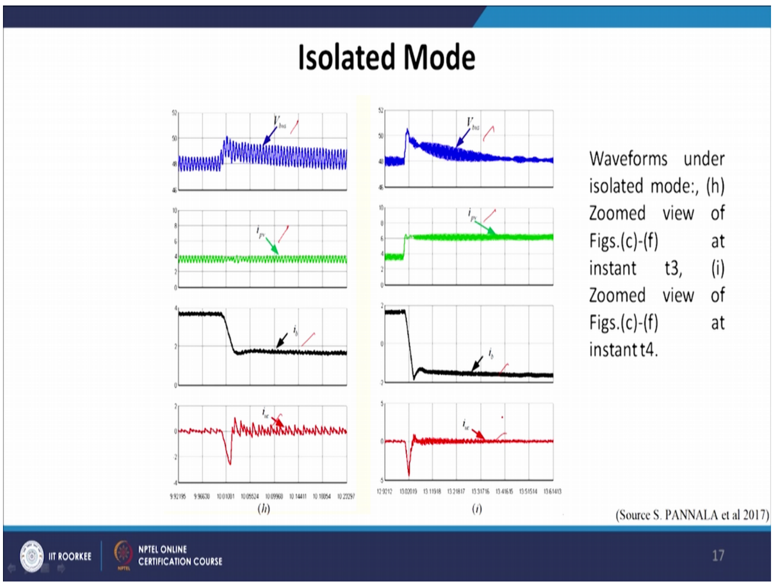

Now, they are the actually voltage characteristic slightly zoomed then i pv i battery I ultracapacitor v bus i pv i battery and i ultracapacitors. So, as a whole if you see the energy management scenario the control strategies very smooth, and we are able to balance the available energy along with my storage energy available to meet out the existing loads. Even both grid connected and without grid during both peak and off peak hours when the grid is existing. So, we try to manage the energy in such a manner. So, the peak and off peak scenario of the grid existence duration will be met successfully-.

Now, in case of isolated mode we have considered like p v whether it is greater than p L when the SoC is greater than 90, and then we have case number 2 where p v is greater than p L and the SoC is great less than less than 95 percent.

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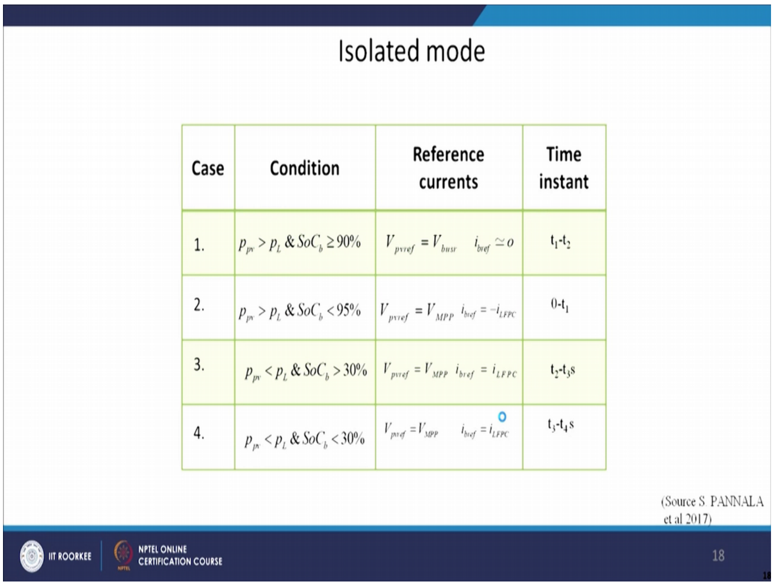

Case	Condition	Reference currents	Time instant
1.	$p_{pv} > p_L \ \& \ SoC_b \geq 90\%$	$V_{pvref} = V_{busr} \quad i_{bref} \simeq o$	t_1-t_2
2.	$p_{pv} > p_L \ \& \ SoC_b < 95\%$	$V_{pvref} = V_{MPP} \quad i_{bref} = -i_{LFPC}$	0-t_1
3.	$p_{pv} < p_L \ \& \ SoC_b > 30\%$	$V_{pvref} = V_{MPP} \quad i_{bref} = i_{LFPC}$	t_2-t_3s
4.	$p_{pv} < p_L \ \& \ SoC_b < 30\%$	$V_{pvref} = V_{MPP} \quad i_{bref} = i_{LFPC}$	t_3-t_4s

Then, we have case number 3 where p v is less than p L and the SoC is greater than 30 percent, and then we have p v less than p L and the SoC is less than 30 percent. So, once again different scenarios have been discussed.

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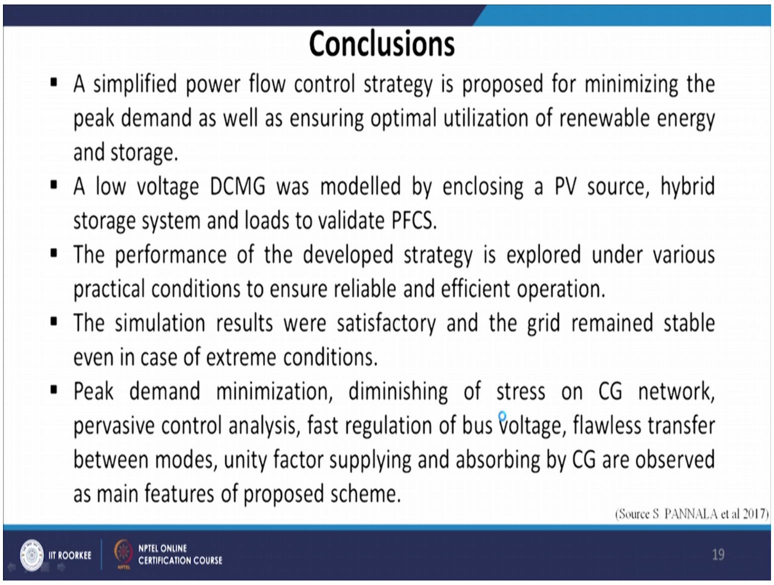

So, to conclude a simplified power flow control strategy is proposed for minimizing the peak demand as well as ensuring optimal utilization of renewable energy and storage. So, what has been concluded?. Now, whether you have grid when you have the grid it may be available, it may not be available under both the circumstances my microgrid has to balance is energy.

By optimally utilizing it is own resources from the P V and the storage which is available to now a low voltage DC microgrid was model by enclosing a P V source hybrid storage system and load to validate the concept of PFCS. Now, the performance of the developed strategies explored under various practical conditions to ensure reliable and efficient operation of a DC microgrid.

The simulation results were satisfactory and the grid remain stable even in case of extreme conditions. The grid was stable even under extreme conditions. Peak demand minimization diminishing of stress on the conventional grid network, pervasive control analysis fast regulation of bus voltage flawless transfer between modes, unity power factor supplying, and absorbing by the conventional grid are observed as the main feature of this case study.

Thank you.