Power Electronics with Wide Bandgap Devices
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Lecture-35

WBG Applications-Renewable Energy Sources

Hello, welcome to the course on power electronics with wide band gap devices. Today I am going to discuss about another application of wide band gap devices which is in renewable energy source applications. So, in the last lecture I have discussed about integrated motor drives, their challenges and how use of wide band gap devices can be beneficial for that application. Now, when we consider renewable energy sources, the first thing comes to our mind is solar pv or the wind right.

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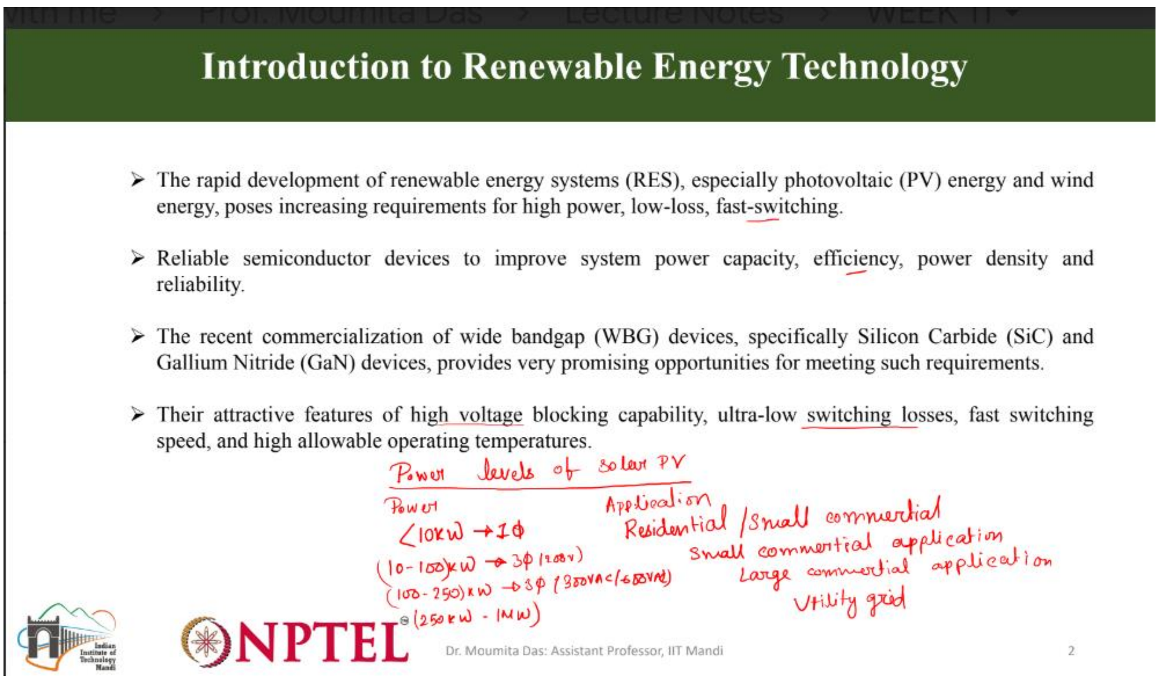

Now, when we consider solar PV or wind obviously the one of the important thing of this applications are it is expected to have a high power density system, high efficiency, low power loss these are the properties are kind of needed from the power converter right. So, as you can see this rapid development of renewable energy systems Especially photovoltaic energy and wind energy possess increased requirement of high power, low loss and fast switching.

Now if we use silicon devices obviously there are limitations with respect to the wide bandgap devices. This fast switching part obviously will be restricted when it will go for high power level. Now this high power level so generally what are the power level kind of expected for this wide bandgap devices applications or the renewable energy sources use. So, what kind of power level we are focusing on? So, if I consider for solar PV let's say just take an example of solar PV any solar PV based system.

So, like there are different power categories right. So, now so power levels if I try to classify. If the power, so let's classify the power and the applications where we need this kind of power level. So the minimum power level which can be focused on other than like single solar PV which is connected to light applications and all. So mostly like power level we need to consider if it is less than 10 kilowatt.

Right, it can be anything between 0 to 10 kilowatts, 500 watts, 1 kilowatt, 1.5 like that it can be anything. So generally this is in use for like mainly household applications, right. And it can also be used for small commercial application, not large commercial applications, right. Mainly it is focusing on residential kind of applications or small commercial.

Now, this power level can be more than 10 kilowatts. Now, another important thing is that when we are considering 10 kilowatt, then what is happening? It is basically connected to single phase inverter. So, single phase inverter kind of application, single phase or the split phase inverter kind of application. So, they are this kind of solar PV will be connected. Now, if the power level is between 10 to 100 kilowatt.

kilowatts. Power level can be in this particular range, right. So, here also, so basically here it is mainly focusing on small commercial application, not residential, mainly small commercial application. So, it is considering 3 phase inverter connection which is having 208 volts in that particular level. Right, now the power level can be 100 to 250 kilowatts.

So, now when it is going to 100 to 250 kilowatts, then also it is connected to 3 phase inverter. But the power, so power level is much higher. So, the voltage level of this particular inverter will be either 300 V ac or the 600v ac. So, it will be for large commercial applications.

Right. Now, again the power level can be more than that. It can be 250 kilowatts to 1 megawatt. It is connected to same three phase kind of connection which is having voltage level of 300VAC or the 600VAC. This is basically focusing on the connection with the utility grid, the grid connection. So, these are the different power level.

As we go for high power level, this first switching limitation will come using silicon devices, right. And also losses will increase at high power level. So, that is why it is important to look for the semiconductor devices. which will have properties like wide band gap devices. So, this will help the system to operate at high frequency right.

So, this will improve the system power capacity. So, basically power density will improve, efficiency will improve and then reliability also will improve right. So, that is why the wide band gap devices will be suitable for renewable energy source applications. Now this recent commercialization of the silicon carbide and GaN devices has promising opportunities for meeting all the requirement in renewable energy applications. So, the features which wide band gap devices are having that high voltage blocking capability of silicon carbide devices, ultra low switching losses.

So, this is very important to operate any like system at high frequency. Then fast switching speed, high allowable operating temperature. So, all this thing enables these devices to use for high power renewable energy source applications. But this is not the only advantages which we are considering renewable energy sources. These are the some advantages another thing I will discuss.

So, the like there is like also there are also challenges for using wide band gap devices in renewable energy applications. So, what are the challenges?

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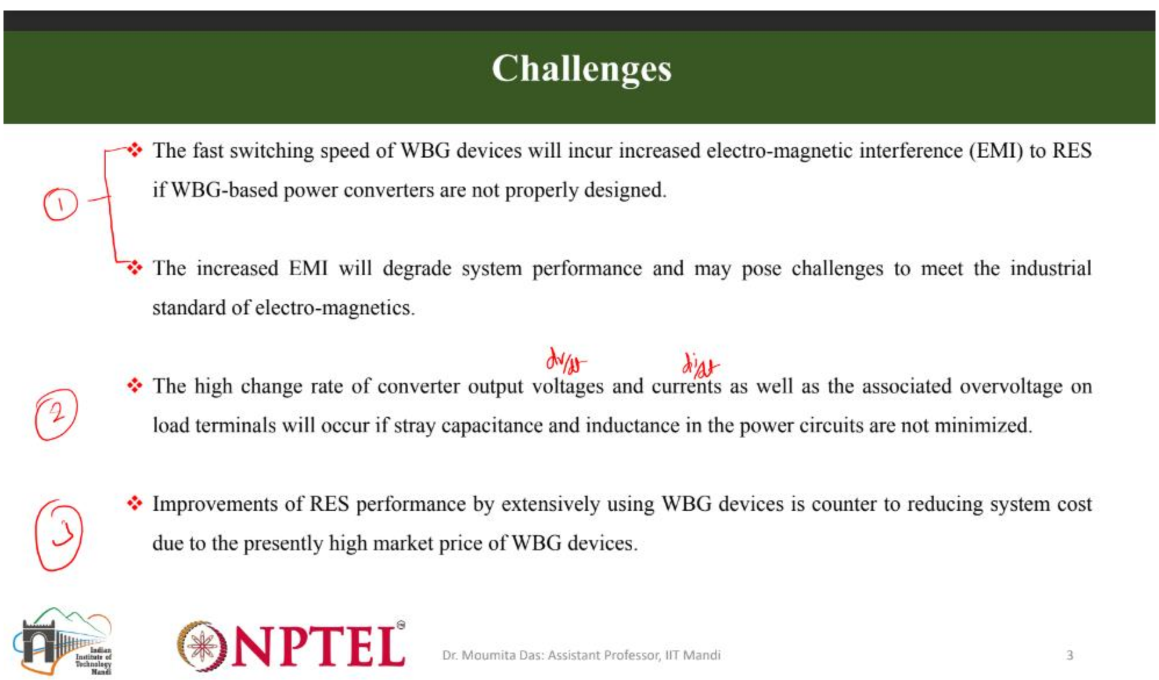

So, when we consider this application the first switching speed. will cause the problem of electromagnetic interference, right. So, if this renewable energy sources are not designed properly, anyway like renewable energy sources when it is connected to utility grid. So, the connection itself can cause the problem of EMI.

Because you know the renewable energy sources it will be connected in a place from there the converter in order to connect it there will be some distance which need to be like that distance related problem need to be shot out out by using the filter. So, like if any like noises which arise due to the long wear correction and all this thing. Again like That is at low frequency operation by when we consider silicon devices. Now, if we consider wide band gap devices, we will be going for higher frequency. Then this kind of problem related to electromagnetic interference that will increase.

So, that is one of the main challenges to use this wide band gap devices for renewable energy source applications. Now as you know like the problem of EMI so obviously I mean this will degrade the performance of the overall system and also it will be difficult to meet the industrial requirement means like whatever specifications is given as per the standard so maybe after using filter also it will be difficult to attend that kind of requirement right. Now, this is one problem. The second is that the high change rate of the converter output voltage that means dv/dt and current that is di/dt. So, this is dv/dt and this is di/dt.

So, this dv/dt di/dt problems associated with over voltage on load terminals will occur if stray capacitance and inductance in the power circuit are not minimized. as i have already discussed in previous lectures so what are the effect of this parasitic capacitances and inductance and while designing pcbs how we can actually minimize them so those problem need to look after so if at high power level so these problems will become quite significant and then the problem of DV/DT and DI/DT will come and then it will be very difficult to use the wide bandgap devices for high frequency renewable energy applications. So, this improvement of this performance by extensively use wide bandgap devices is counter to reducing the system cost due to presently high market price of the wide band gap devices that already you know that cost of this devices is much higher than that of the silicon device but like the advantage of these devices with respect to reduction of the passive component cost and the like requirement of heat sink can be minimized so that overall system cost can be reduced down right so this is another disadvantage so mainly three disadvantage here not disadvantage basically challenges you can say so this we need to solve this three you can see here one is emi another is dv/dt di/dt already i have discussed with you how to solve this dv/dt di/dt related problem but that discussion was with respect to device now when we go for high power application high power means around 1 megawatt in that level right so then how to solve this dv/dt di/dt problem at that power level while the device is operating at high frequency that we need to explore and the third thing is the cost part that we cannot do anything but yes we can actually optimize size of the remaining component in the converter other than the device part so that overall cost can be reduced down right so these are the three challenges you can always see in this application.

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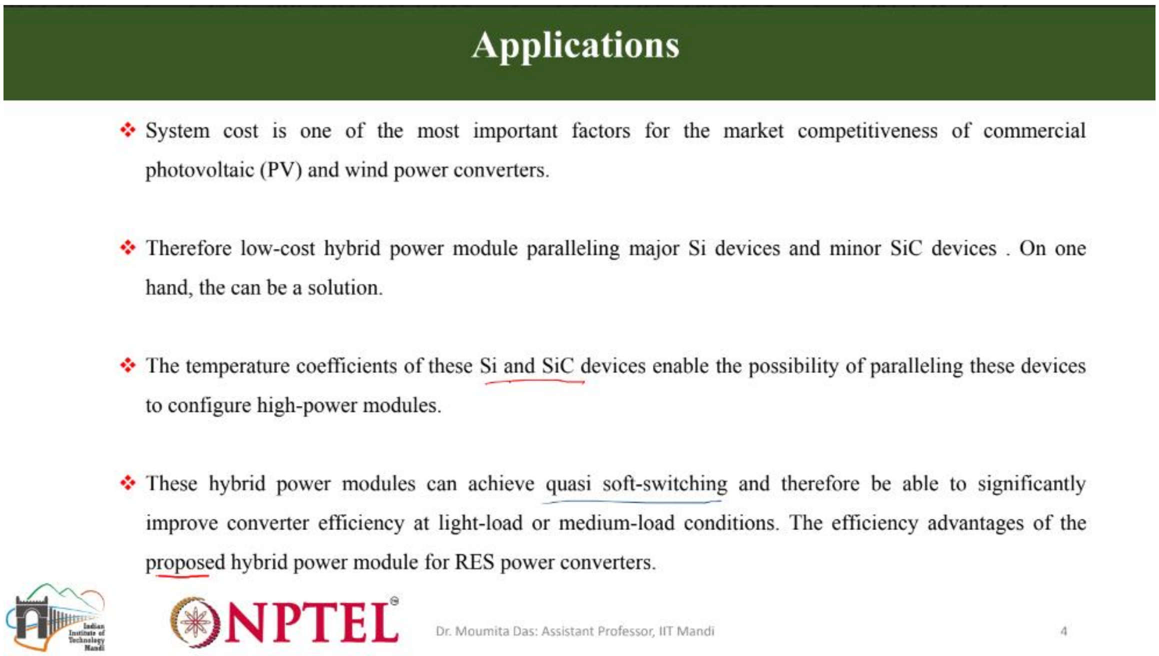

now application so system cost as you know it will be higher with respect to power converter then what can be done One possibility is that we can actually use hybrid kind of device instead of pure wide bandgap device or pure silicon device. I will discuss that in details how this hybrid device connection will be.so basically Place wherever the device need to be connected in the converter.

So there instead of using the pure wide band gap device 2, 3 devices can be connected in parallel. So out of 2, 3, one can be wide band gap device so that we can have advantages of wide band gap device and then remaining can be silicon devices. So that price will not be high. Right. So, this can be one of the solutions.

The temperature coefficient of the silicon-silicon carbide device enable the possibility of paralleling of these devices to configure the high power modules. As you know like at high power applications, so basically we need to use silicon carbide device instead of silicon device. So, the temperature coefficient of this silicon and silicon carbide are quite close so that it will be possible to connect them in parallel. But if it is GaN, then we have to look like how to connect that in parallel and what kind of challenges we will face, right. This hybrid power module can achieve quasi-soft switching and therefore be able to significantly improve the converter efficiency at light load and medium load conditions.

The efficiency advantage of the proposed hybrid power module for RES power converters can be useful for like applications related to this solar PV and wind. So, this is like this is proposed in one paper. So, which I am actually taking here as the reference so this paper I have listed in the reference list so they are they have shown that this hybridizing of this device how benefit how much benefit we can get and what kind of challenges we will face okay so now as I told you like hybridizing means what so basically when we say hybrid device hybrid device right

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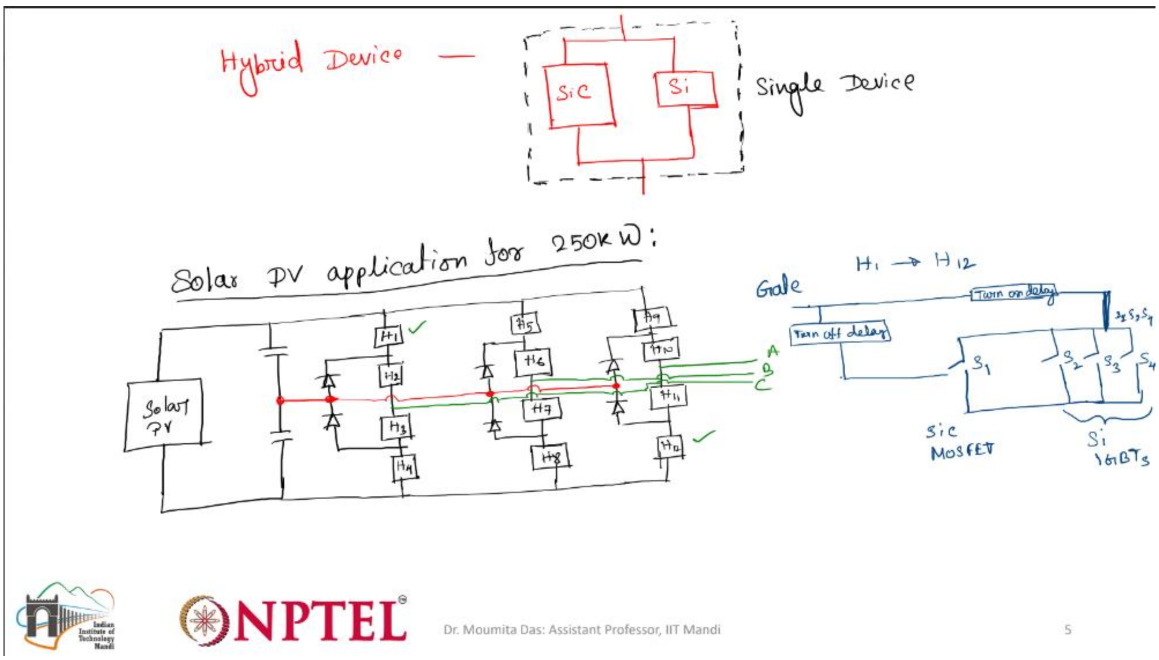

so basically what we mean so since like we are considering high power considering only silicon carbide type of wide band gap device in parallel connection with the silicon so that is what i am drawing here so it will be connected in silicon and this part can be connected like wherever it is needed to connect so basically this entire part will work as single device. So this is like what we consider as the hybrid kind of device. Now let's say one application of solar PV.

So let's consider solar PV application. for 250 kilowatt power applications right. 250 means it can be anything like large commercial or maybe utility grid connects any like whatever you want it to be so there you can use it. so now here one NPC converter is used so what is the configuration of NPC converter so NPC converter generally so like it is used for like high power application so where so the this is the solar pv it it is connected to the filter part here now here There are like different modules connected. So, I am writing here H1, H2, H3 and H4.

Okay. Now like this three legs will be there, similar to that. So let me just draw this H5, H6, H7, H8. thenH9 H10 H11 H12 okay So this is how it is connected and then there will be obviously there will be diodes. So these diodes will be connected this way. so now from the midpoint of this capacitor it will be connected to all the diodes right now different phases can be taken out so let me take different color so this is one phase this is another phase and this is another face okay let's say this is a b c so now here you can see there are different modules which i have drawn here h1 to h12 so you can see this is h1 this is h12 so out of like this 12 modules are there now these 12 modules we can actually consider either single switch or hybrid switch.

Single switch means like it can be either silicon switch or silicon carbon switch or maybe hybridizing as I have shown here in the single device. So, in this, so what authors have done, so they have actually considered this hybridizing of the device. So, how they have considered this hybridizing? so let me just use this h1 to h12 so they have used the hybridizing device so there are actually four devices which are connected in parallel so one is here this one is silicon carbide mosfet So, this is connected in parallel with silicon devices. So, this is three silicon devices are connected in parallel.

So, these three are silicon IGBTs. Right. Now, This is not the only thing means we can definitely connect in parallel it will operate fine that is not a problem. something has to do with the gate switching signal so how this gate switching signal is connected here so basically so you can see here so this is like let's say this is silicon carbide s1 and then silicon IGBT is there s2 s3 and s4 so the gate signal which is provided here to the gate of this of this devices right so then it is provided such that there will be some turn on delay turn on delay provided to the silicon devices so basically it will go to all the silicon devices S2, S3, S4, these three devices. Now, the gate signal of this silicon carbide MOSFET, there will be providing some turn off delay, turn off delay, right. So, it is provided to the silicon carbide MOSFET.

So, turn on delay means like silicon carbide MOSFET will turn on first in order to achieve the benefit of soft switching that is already mentioned here. You can see here quasi soft switching in order to achieve this. Now this turn off relay it is provided means like silicon IGBT will turn off first and then silicon carbide MOSFET will turn off. This is again to achieve the benefit of quasi soft switching.

Right. So this is how these devices are connected. Let me just show you the switching cycle how it is going to be when I mean that like turn on delay or turn off delay.

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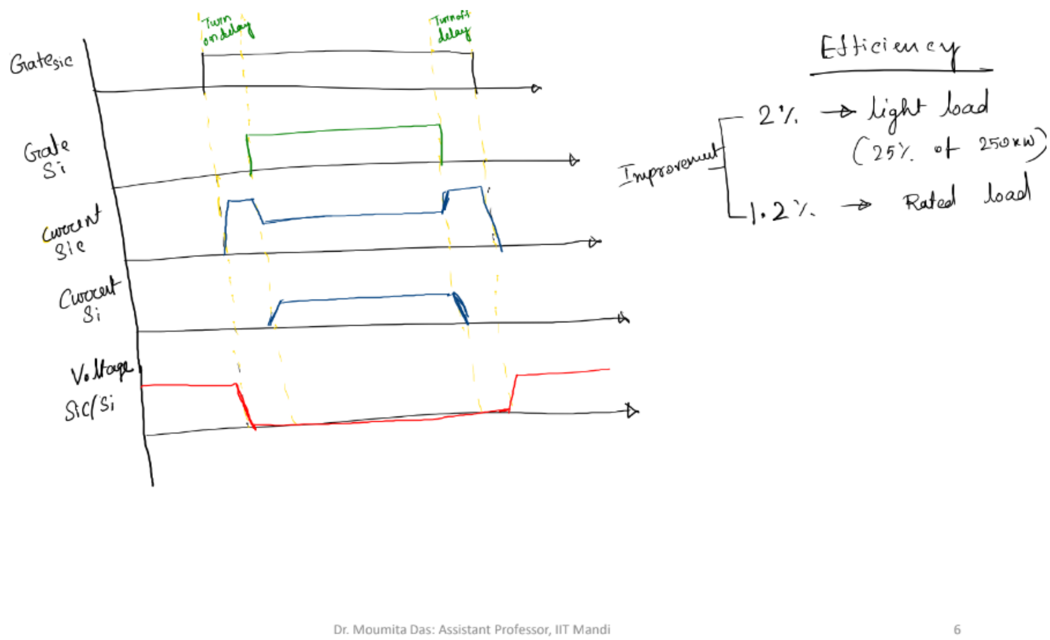

So whenever the gate signal is provided for silicon carbide MOSFET. let me just write this in this way gate of silicon carbide right so let's say this is on for this much time then the gate of silicon IGBT then there will be some turn on and turn off delay So, let me just keep this as turn on and turn off delay.

I hope this color is visible to you. So, here I am just I am going to use different color so that it will be clear for you. So, this is gate of the silicon and this part like the like part which is close to turn off this is turn off delay. As I told you in the previous slide, turn on delay, right. So, this is how the devices are operating in order to achieve the benefit of this quasi-swap switching, right. Now, if we provide the gate signal like this, then what will happen to the current? So, current for this silicon carbide MOSFET, so basically current of silicon carbide, so this will look like So, initially there will be some peak current during that because not basically it will take some time to reach that peak current I am not drawing here.

So, it will go to the maximum point when there will be turn on delay and turn off delay. So, the entire current will flow through only the silicon carbide switch because silicon devices are not on in that time. So, this is the entire current which is flowing through the silicon carbide switch. And now current through this silicon IGBT.

So, this will be. So, this will be. like this so here so the like the current difference which you can see here so like in this particular point during the turn on delay so the additional current will flow through this silicon device now this i hope this is clear to you like how this is working this this is due to the turn on and turn off and that we are providing in order to get the advantage of this hybrid switching Now, how this voltage of these devices will look like? So, this voltage you have to think about. Now, you will think probably, you know the current of the silicon IGBT, it is actually starting late. So, that means this voltage, let me just write down first, this voltage Of IGBT or MOSFET. Or maybe I can just write silicon carbide or silicon.

So, it will be same. You know like because we are actually considering the devices which are connected in parallel. Right. So, this will remain like this until it will like again all the switches are on. So, since it is connected in parallel, once one of the devices is conducting, so it is kind of like behaving like short circuit.

So, the voltage across this device will be 0. Since all the other devices are connected in parallel, so voltage across those devices will also be 0. As you can see from here, if this S1 voltage is 0, so that remaining like switches, even though it is not conducting in that particular time, turn on and turn off delay, So, that time also it will be 0, right. So, this is how we are actually achieving this quasi-soft switching pattern. okay so yeah so this is the benefit of this so this can be used now by using this gate switching signal like in order to have the advantages so we can see anyway like the switching losses are reducing and efficiency is increasing how the efficiency is increasing so now if we have to comment on the efficiency part So efficiency part it is increasing 2% in light load. Light load means it is around 25% of the 250 kilowatts.

And now in full load so basically in rated condition it is achieving 1.2% efficiency improvement. So, these are the improvement we are getting because of this hybridization. So, this obviously it is beneficial like 2 percent of 250 kilowatt it is a lot right.

So, you can see this is 250. So, you can just 2.5 multiplied 2. So, you can see that 5 kilowatt of power you can actually save or maybe output will be 5 kilowatts more just by using this hybrid kind of switches so it is like nothing else we are considering the same converter prototype only the switching switches are changing and also the like gate signals like we are we need to give some delay time so for that that is actually changing other than that everything remains same If we now in this hybrid condition also we are achieving some efficiency improvement. So, if we can go for like complete wide band gap devices, obviously by solving this EMI, DBDT, DIDT problem. So, then the efficiency improvement will be much higher. Obviously, this is much more beneficial to use this kind of switches for renewable energy applications, right.

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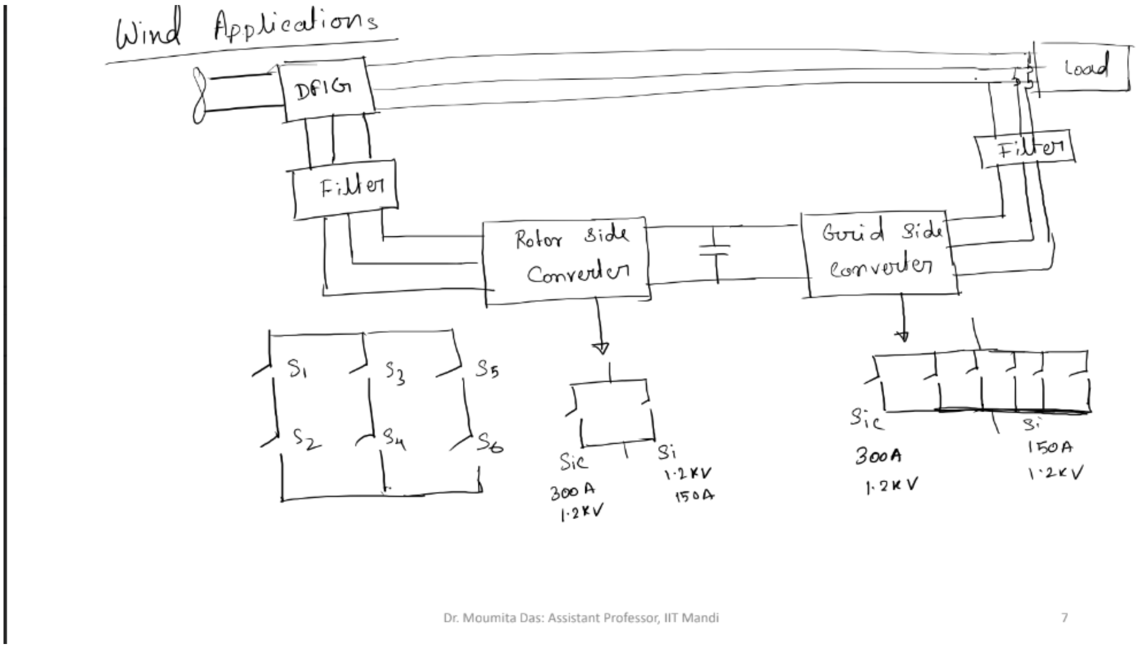

Now, this was with respect to solar PV. Now, if we consider wind applications, so I am just considering two applications of renewable energy sources because you know like these two are the common applications for renewable energy sources. So, other applications you can go through like if it is available. to see the benefit here also in wind applications also it is by using the hybrid kind of switches so how this wind application looks like so you can see here so there are actually this will be connected to DFIG so this is not the part we are interested in but the part which will be coming after the DFIG that is the filter part, input filter and then it will have the converter part, rotor side converter Green side converter. So this configuration also I have taken from literature and I have listed it in the reference so you can go through in details if you are like interested in this kind of application.

Filter part will also come. right this rotor side converter it is basically rectifier and grid side converter it is inverter so three legs rectifier and the inverter are in use so control full control rectifier is in use so here the configuration it is having three different legs right like this So basically 6 switches. Now out of the 6 switches for rotor side converters let's say this is S1, S2, S3, S4, S5, S6. How this S1, S2 look like? So, it is actually combination of silicon carbide with silicon. Again the MOSFET and IGBT combination.

This is silicon carbide and this is silicon. And the grid side converter the similar kind of configuration but it is inverter kind of three legs inverter. Now, here the configuration is such that, so here one silicon carbide device is connected in parallel with the 5 silicons. This is silicon carbide and remaining 5 are silicon. sorry this is only one silicon carpet five silicon so here the rating of this devices are also very different so you can see this is the case 300 ampere 1.

2 kilo volts here it is 1.2 kilo volts and it is having 150 amperes you can see here one of the important thing is that silicon carbide rating is much higher than that of the silicon in terms of current voltage ratings remain same so the reason is that silicon carbide initially when there will be on like after turn on delay the silicon will be on so the entire current should pass through the silicon carbide device that's why rating of this device current rating is much higher as you have seen in the previous slide so here in this case also it is the similar kind of concept so basically silicon carbide is 300 amperes 1.2 kilovolts and here like much lower voltage like 150 amperes silicon devices are connected in parallel. So, this kind of hybridization again will give efficiency improvement, right. So, these are the applications of renewable energy sources. You can actually go through the references, these are the references for the like this slide.

So, obviously there is like clear benefits of using this devices as high in like at this moment as hybrid kind of switches as part of the hybrid switches. Later on like if the all the challenges can be like whenever it will be addressed. So, that time only wide band gap devices can be used in order to get complete benefit of the wide band gap devices in renewable energy source applications. Thank you. That is all for today.