Power Electronics with Wide Bandgap Devices
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Lecture-34

WBG Applications-IMD

Welcome to the course on power electronics with wide bandgap devices. Today I am going to discuss about application of wide bandgap devices in integrated motor drives or IMD as you can see in this particular slide.

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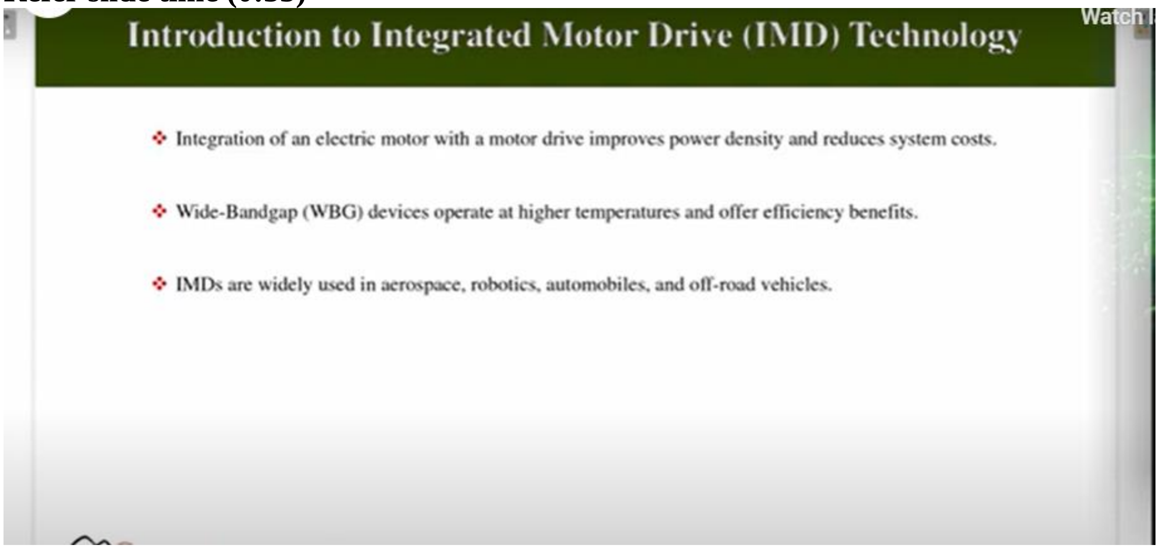

what is IMD or integrated motor drive so basically integrated motor drive as you can understand from this title it is basically combining motor and the drives together so basically integration of electric motor with a motor drive which improves power density and reduces system cost so it is expected to reduce the power reduce the system volume or improve the power density that is in the range of so volume of the system will reduce 10 to 20 percent right and it will reduce the cost of the system by 30 to 40 percent. the reason why people are focusing in this particular application is because it will reduce both size and the cost so this is like the kind of range which is expected to be achieved by using wide bandgap devices in place of silicon devices okay so now this wide bandgap devices it can be anything silicon carbide or gas operate at higher temperature and offers efficiency benefit as the system size reduces obviously the power density will improve and the thing is that when the wide band gap devices will be in use with by considering the application such as integrated motor drive so then what will happen it will be able to operate at much higher temperature so basically motor applications it is very important to choose a system which should be able to sustain at high temperature because the temperature which will be generated from the motor it will be much higher than the power electronics converter so if the converter is mounted on the motor itself then the system needs to be operated at that temperature so that is why we need WBG devices which is suitable to operate at high temperature and obviously the efficiency is something which we are looking forward to so that is also possible to achieve by using wide band gap devices so this integrated motor drives are widely used mainly in aerospace robotics automobiles and off-road vehicles okay these are the different things which is used so as you can see these are the main advantages of using wide bandgap devices along with it the another important advantage will be there so that is so basically it improves electromagnetic interference or EMI and electromagnetic compatibility or EMC due to direct connection of the drives to the motor right so this is one of the main advantages you know like most of the wideband gap devices as i have discussed earlier so the problem of emi is severe and in order to reduce this emi we need to measure this this emi whether it is within the range or not if it is not then we need to design the filter But this direct correction anyway will help to reduce this EMI. So, then it will be possible to reduce the use of filter in this particular application. So, the thing is that the modulization.

of wide bandgap devices can significantly enhance performance of integrated motor drive in fault tolerance, efficiency, power density and high temperature operation. So, these are the advantages of use of electric motor along with the drives together by using this wide band gap devices. means it is possible to use motor and drives together by considering silicon devices as well but it will not have advantages of wide band gap devices one of the main problem is that silicon based converters the size of the converter is much higher than that of the wide band gap devices so mounting of that particular converter on motor will be very difficult so that is the first disadvantage of silicon based converter and it will come in the middle for using that converter for IMD applications. The second thing is that this converter like silicon converter it is not suitable to operate at high temperature means the temperature limit of silicon devices is much lower than that of the silicon carbide or GaN devices.

It is expected to use this wide band gap devices till 300 or 600 degree Celsius right but whereas in silicon devices it is mentioned 200 degree Celsius it is mentioned in the data set it is not suitable for any application means the device can sustain till that temperature that means whenever the converter will be operating so the converter overall temperature we need to control it much below that level right as I have discussed the temperature related issues in the devices so the silicon device if we mount on the motor itself the temperature which will be generated in the motor and the converter both will be so much that it will exceed the limit of the silicon devices temperature maximum temperature so that is why it is important to use a device which should be capable of operating at much higher temperature right now wide band gap devices they are suitable to operate at much higher temperature it is expected that they will be suitable to operate for this kind of drives right.

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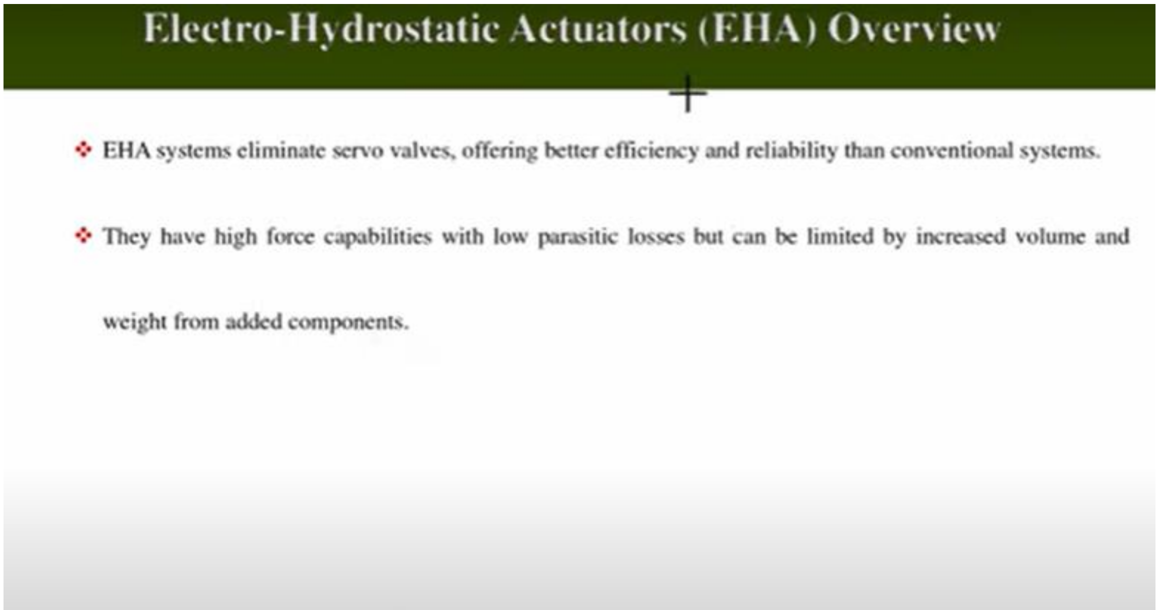

now you can see here this electro hydrostatic actuator so over view so basically it is the full form is electro hydrostatic actuator so it is known as EHA. EHA actually systems eliminate servo valves offering better efficiency, reliability than the conventional system. They have high force capabilities with low parasitic losses but can be limited by increased volume and weight from the added components. And the EHA utilizes an electric motor driven bi-directional magnetic pump in which the inefficient servo bulb is eliminated. Another advantage is that the overall efficiency of EHA higher than higher due to low parasitic losses while the hydraulic transmission system still provides which is already mentioned in the first point provides high reliability with extremely high force capability.

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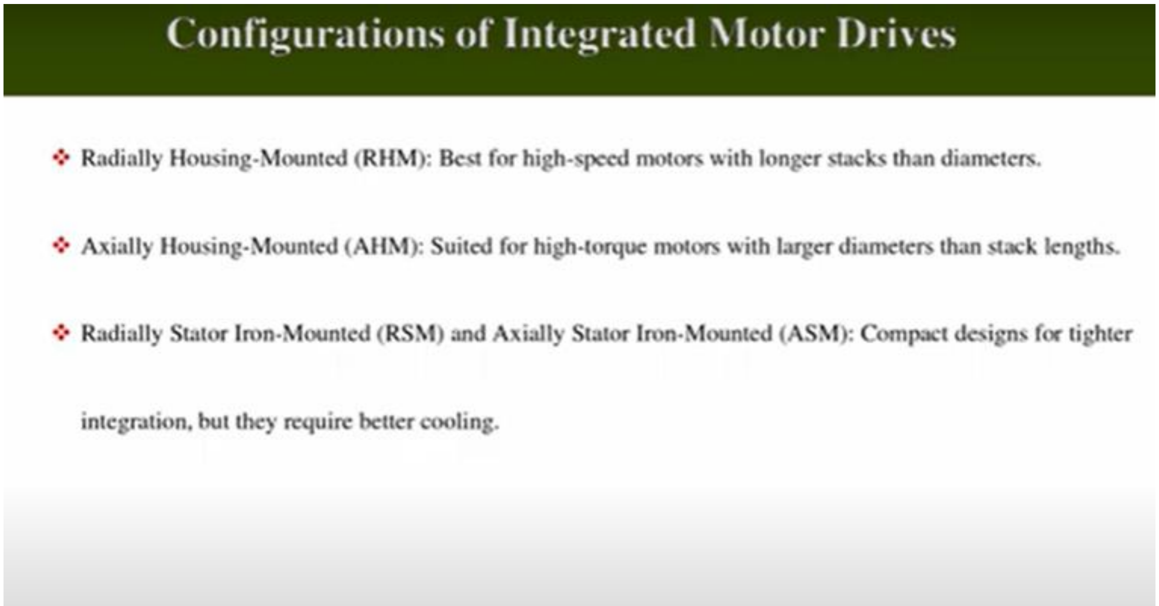

Now, how to configure this integrated motor drive? So, there are like various configurations. So, in the reference these configurations are also given along with the diagram. So, basically there are actually basically four types. You can see here. So, radially housing mounted which is also known as RHM which is best for high speed motors with longer stacks than diameters.

then the second one is the first one is this one second one is axially housing mounted so it is suited for high torque motors with larger diameters than stack lengths third one is radially stator iron mounted and the fourth one is axially stator iron mounted this is suitable for compact designs for tighter integration but they require better cooling medium, right. So, these are the four different types of configurations which are used for the integrated motor drives. since drives will be connected to the motor the positioning of the drives how it is going to be in the motor so that defines these four different categories so the pictures you can get from the references so obviously it is related to the construction of the machine so different types comes so any of this can be used in any type of the motor so that depends on the application and the advantage of that particular type then it will be considered as integrated motor drives so now why we need to consider wide band gap devices it is the basic principle of the wide band gap devices again will be used so low switching losses high power density high temperature operation right these are the benefits but obviously there is also disadvantage of this wide band gap devices used in the integrated motor drives that is the cost is still much higher than that of the silicon devices although the cost is much higher in like WBG devices any of the devices as compared to silicon but the saving in other areas like cooling and the passive components that overall Result will be reduction of 30 to 40% of the cost even though the device cost is much higher. So that is why people are focusing into the application where it is very important or probably it is like it will solve many other purpose. okay so now when we say wide band gap devices we are going to use so we cannot directly use as I have discussed earlier the challenges of using wide band gap devices if we have to use wide band gap devices again the technological development should be such that one thing is that cost need to reduce down but at this moment that is not possible that is not a problem but the converter configuration how it is going to be conventional silicon devices when it is used for any application So the converter configuration, it can be such that which will be suitable for application of silicon devices.

But now as we are going to consider wide band gap devices, it has different requirements in terms of drives, in terms of application or maybe as I have already mentioned in the previous slide. So it is actually suitable for fault tolerant application. Now if we are going to consider fault tolerant application so then obviously the converter configuration should be such that it will be able to handle the fault which is happening in the motor.

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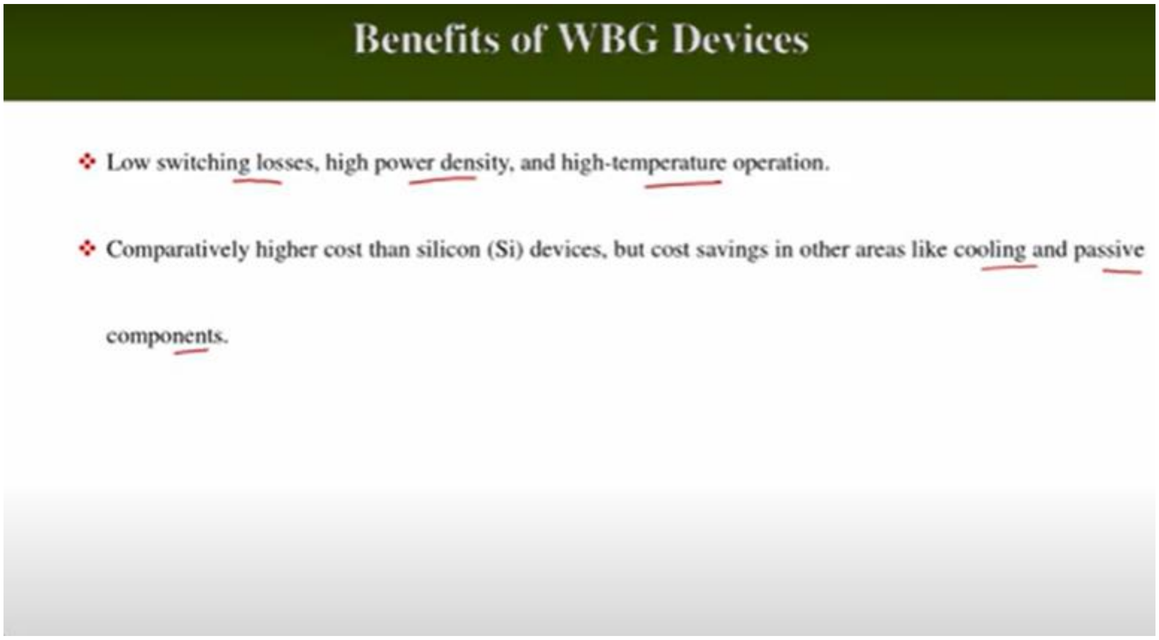

Then how the converter configuration should be? So one of the important thing I have discussed like this wide band gap devices application should be such that we can use Advanced converter configuration, how this is going to be?

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So, if we say this is fault tolerant and modularization, IMDs are modular, provide better integration, curved surface and fault tolerant operation. But we have to see what kind of converter will be suitable or we need converter which will be novel for this wide bandwidth device applications.

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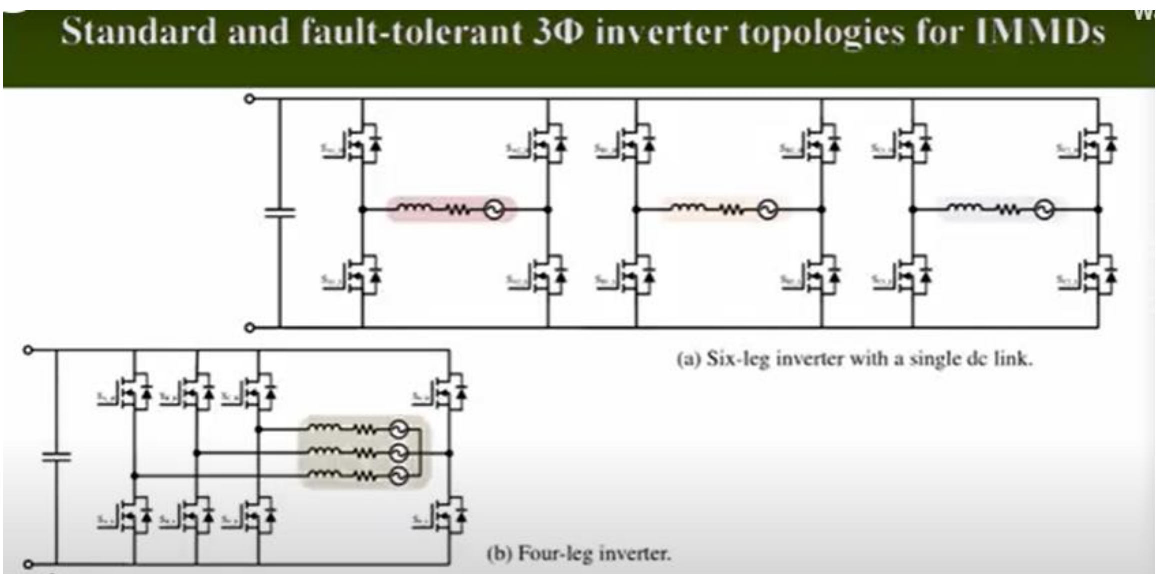

different inverter topologies such as 4 leg 6 leg offer varying level of fault tolerance right so we have to focus on the converter which will be fault tolerant converter so it is one of the converters so you can see here in figure a it is six leg inverter with single dc link so the dc link which is at this particular point And the inverter it is having 6 leg. So, 6 leg each leg. So, basically combinations of 2 leg it is connected to one of the phases. So, if this is phase A let's say and this is phase B and this is phase C. So, what is happening? 2 legs are connected to phase A, 2 legs are connected to phase B, another 2 legs are connected to phase C.

and it is having obviously some inductance and the resistance in between okay so this is six leg inverter with a single dc link so this is used for fault tolerant three-phase inverter for integrated motor drive applications Now, this is another one is that this is four leg configuration. There are like different type of configurations which are used for fault tolerant operation. The previous one was six leg. Now, this is four leg. You can see here.

So, here also single descending key is there. And then three legs each are connected to three different phases. Right. A, B, C. And the common point is connected to two legs.

So, this is how this converter is used for fault-tolerant applications. So there are other converters also you can see here this is cascaded inverter with separate DC link. Instead of using two different links, we can have two different converters. Means it is six links. So, six link inverter.

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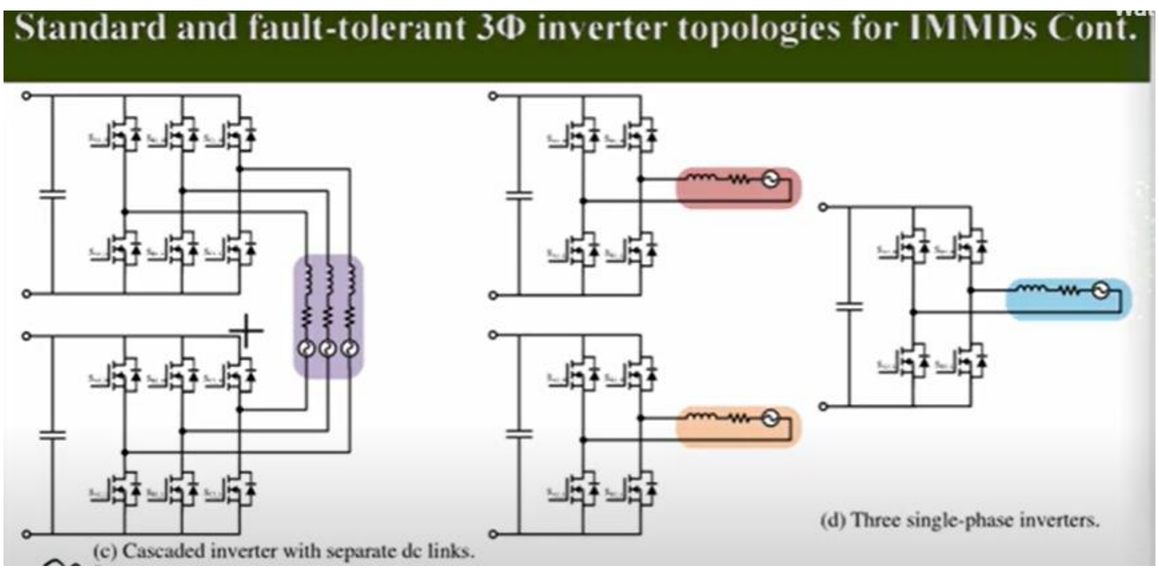

Here also six links are there and in this case also six links are there. But here what is the difference? The DC link are separated. So, it is divided in two DC link rather than one DC link. So, here it is DC link and DC link Okay, so now it is like conventional voltage source inverter. So, this is three link.

So, it is connected to A, B, C. Similarly, this is also connected to A, B, C of the other DC link. Okay, now There are other converters also 3 single phase inverters. Instead of connecting single DC link, separate DC link can be connected to separate phase. So, like in 6 legs, so there are like 2 legs connected to the phase.

So, here also the same thing is there. So, the configuration remains same. Only thing is that DC link now is divided for each phases. So, DC link 1, DC link 2. to DC link 3 so you can see here there are like this converter configurations they are not very different from the conventional converter configuration but the way this phases are connected that will help the converter to protect during faulty operations so fault tolerant kind of converter right So this kind of converter can be used for this integrated motor drive applications.

So now these converters anything if it is in use. So the important point is that the requirement of the cooling what it is going to be. Because you know for motor drive application cooling has to be proper in order to reduce the heat. Whatever will be generated in the converter itself or due to the motor, the device, whatever heat will be generated in that system. So, that we need to take care of.

So, there are actually various industries, they have used this wide band gap devices for IMD applications and they have different kind of cooling medium. So, one of the important cooling devices that so I can just write down here so basically the important technologies the key enabling technologies for the IMD's are the advanced cooling system. So, this tells us advanced converter configurations So, along with advanced converter configuration, we need advanced cooling system as well. Right. This cooling create water screen between motor and the drives.

So, this cooling system like conventional cooling system will not be suitable for IMD application. We need special kind of cooling and for that exploration in the cooling area is very important for any of the application of wide band gap devices. What are the different cooling are in use by the industry, right? So, Siemens so you all are familiar with the siemens technologies so siemens what they did so they are actually invented one cooling cooling operates water screen as water screen between motor and drives. Now another industry which is known as Nidec. what they are using so basically Nidec develops it is silicon carbide based motor drives suitable for high frequency high temperature with significantly reduced volume and weight.

So like different industry they are using different methods in order to use the system for IMD applications. Now this Yakawa, what they are using, it is actually developed, a compact and finless 3 kilowatt gallium nitride based boot or drive which generates much lower losses compared to So, you can see here the Siemens, Nidex and Yakawa. So, Siemens basically they have developed the cooling medium. Then Nidex they have developed the silicon carbide waste motor dry and then Yakawa developed gallium nitride waste motor dry. So, depending upon the kind of devices, this drive can be taken from that particular industry and then again it will be connected to the motor.

So, the cooling medium can be selected from the suitable places. So, here Siemens cooling can be operated in between the motor and the drives. So, like that is how the system can be jointly connected together. right so these are the advanced converters as i have discussed.

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Table - SiC Switching Device Options For IMD

Manufacturer	Cree	Infineon	Powerex (Mitsubishi)	STmicro	GeneSiC	Microsemi	USCi	ROHM	Semikron
Voltage [V]	900-1700	1200	1200	650-1200	600-1700	700-1200	650-1200	400-1700	1200-1700
Current [A]	5-300	10-300	20-100	12-100	10-160	25-80	10-40	4-120	25-550
T_{JMAX} [°C]	175	-	200	200	210	175	175	175	175
Structure	M	M	M	M	JT	M	J/C	M	M
Packaging	TO-247/263	TO-247	Module	HiP247	Baredie/TO-46/257	TO-247	TO-247	TO-247	Module
Thermal Management	Heatsink	Heatsink	Heatsink	Heatsink	Heatsink	Heatsink	Heatsink	Heatsink	Heatsink
Availability	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Comment	Leading provider	SBD	Modularized	High T_J	High T_J	-	Normally-on device	-	Augmented turn-off

M – normally-off (MOSFET) / J- normally-on (JFET) / C- normally-off (cascode) / JT – normally-off (junction transistor)

so now what are the devices which are suitable for this application so you can see here so there are like different industries they have different devices like Cree infineon Mitsubishi STmicro genic sic Microsemi usci ROHM semi cron so these are the different manufacturers so the voltage level here we are focusing at like higher level so you can see here the voltage level it is from 900 to 1700 from from Cree that is infinite 1200 and then the semicron it is like 1700 So the current level as you can see here so current level minimum it is 5 ampere and maximum it can go till 300 ampere so that it should be suitable for megawatt level power level application so the junction temperature you can see here so the junction temperature for silicon carbide devices it is expected to be able to handle till 150 degree celsius the device itself is suitable to operate at much higher temperature but when it is connected to the system so it should be able to handle this much temperature and the structure type is also given the packaging is also given the thermal management whether like what kind of thermal management is required here heat sink is mentioned for all the devices And then it is like the different like it is leading provider, SBD, modularization, different type of devices are mentioned here and all these devices are suitable for IMD application. So, similar to silicon carbide devices, the gallium nitride device is also suitable for these drives applications.

So, you can see here, so the gallium nitride devices, obviously the power level will be much smaller than that of the silicon carbide device. Silicon carbide device is suitable in big award level, whereas the gallium nitride device it is suitable in to much lower power level in kilowatts level so you can see the voltage level it is like 15 to 300 volts from EPC transform it is 600 to 1200 again like GAN system it is 100 over to 650 TI it is 48 to 600 so these are the different voltage levels are available now current is also given so maximum current is given here 90 amperes so what kind of substrate are in use so like they have different substrate for different companies some is using silicon some silicon carbide some gallium nitrate sapphire And the maximum temperature here also is mentioned as 150 degrees Celsius. One of the important thing is that so when the device is operating at high temperature the properties of silicon carbide is much better than that of the silicon or the GaN devices. GaN device is having much lower junction capacitances which will allow it to operate at much higher frequency. But when it goes for the high power level, then the silicon carbide device is suitable than that of the GaN device.

So now the operation of silicon carbide device at higher temperature is also much better. So the packaging type is also given. Here the thermal management for GaN devices either heat sink or through the PCB. right and also like the different uh packaging type is also given low voltage no packaging conventional packaging integrated gate driver so these different packaging are given so you can explore all these devices you can see what will be suitable for imd applications accordingly you can choose So, the challenges is that so whenever this wide band gap devices are in use for any integrated motor drive application the issues include synchronization of multiple controller and the need for sophisticated kind of cooling system. As I said cooling some of the cooling like is currently available so that can be used but like advanced kind of cooling system what will be more suitable so that kind of work is still going on.

now the permanent magnet switch reluctance motor machines offer opportunities for improved performance so like the applications of integrated motor drives in this kind of motor how it is going to be so that kind of exploration need to be done okay so these are the references for this particular discussion okay thank you that's all for today