High Power Multilevel Converters – Analysis, Design and Operational Issues
Dr. Anandarup Das
Department of Electrical Engineering
Indian Institute of Technology, Delhi

Lecture - 41
Condition Monitoring of Converters

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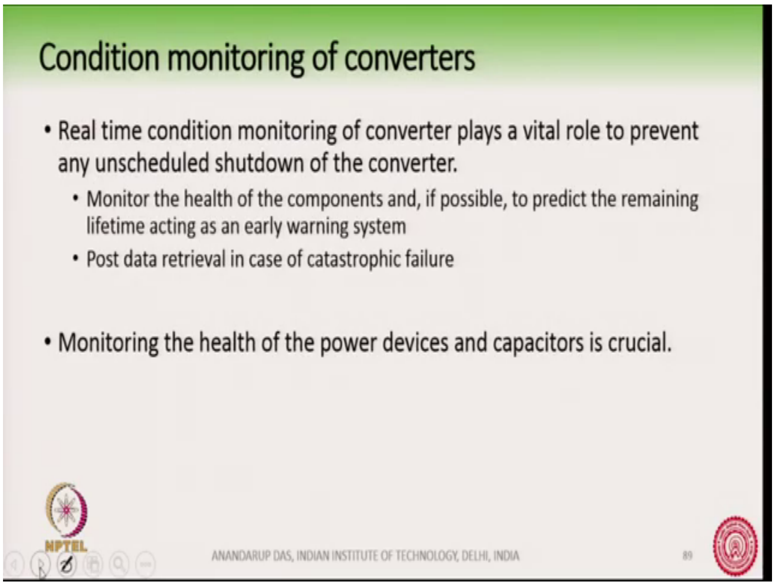

Next, we will talk about Condition Monitoring of Converters. Now again condition monitoring of converters is also a big subject and there are lot of things to monitor in a converter ok. The real purpose of having a condition monitoring is basically to know the health of components, in the converter. How are the components, how much is their life time possibly I mean how much is the life time remaining in the converter?

Now why is this important? In many cases these converters are part of a big process and those processes like are sometimes very critical process. I mean shutting down the process because of a failure in the converter can be quite costly, for the for a company or for the whole system.

So, many times manufacturers would like to know the status of the converter, like to know the health of the converter so that any unscheduled shutdown of the converter can be avoided. Of course, converters have to be have to undergo scheduled maintenance from time to time, but unscheduled shutting down of the converter can be very costly in terms of time and money.

So, condition monitoring in converter is used kind of like a as a prognosis that ok, this is the health of the converter the IGBTs will last for say another 2 years because some parameters we see that it is changing so, we expect that in another 6 months the IGBT will shut off or its life time is over something like that.

So, monitoring of the health of the converter and if possible to predict the remaining lifetime is very useful for the system developers, for the consumer and so condition monitoring is used in many cases. Another reason why condition monitoring is sometimes used is like a post data retrieval in case of catastrophic failure.

Sometimes when a failure happens some in specially when you are building a product then you are most likely to face cases where there has been failure in the converter and you would like to know that under what condition did the converter fail what exactly happened in the converter before, sometime before the failure during the process of failure and maybe after the failure. It is a good tool to know because then you will understand ok, this is how the transition happened and we should take care of it in future designs.

This is very similar to kind of like the black box in aeroplanes and so if there is a catastrophic crash of an aeroplane so investigators try to find out or retrieve the black box. So, as to know what exactly happened, what led to this catastrophe so that we do not make the same mistake again. In a similar way in converters also we would like to have this feature ok. So, here in this particular session I will only talk a little bit about the health of the power devices and the capacitors as part of the condition monitoring.

Condition monitoring usually takes place throughout the converter with all the components electrical components, mechanical component, junctions and all those, but sometimes visual inspection is good enough, but of course, for IGBTs or for capacitors visual inspection may not give you the full picture.

So, health of the power devices and capacitors we will see. So, first we will see how to do the condition monitoring of IGBT?

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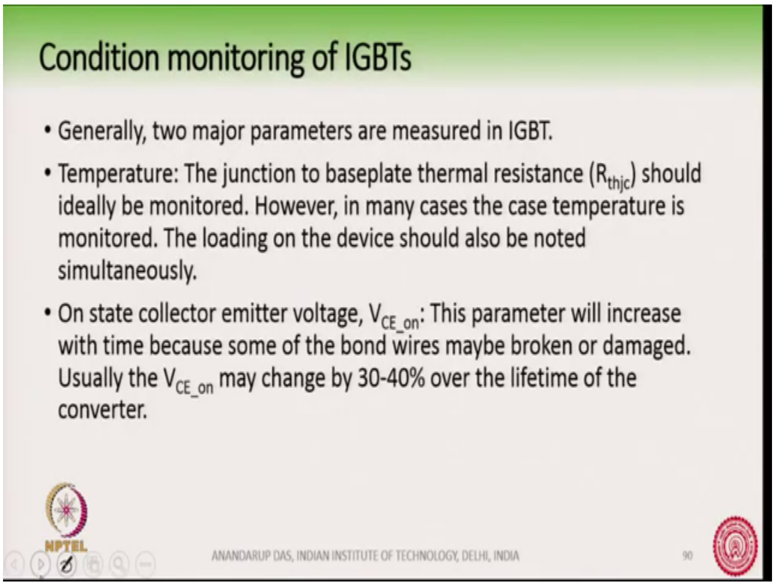

Now, again there are several parameters which you can measure, but most importantly there are two major parameters which can be measured. The first one is the temperature and the second one is the on state collector emitter voltage V CE on.

Now, these two parameters give some idea about how the IGBT health is how much time it will work in future like that. So, the temperature usually will increase for the same loading condition, the temperature will increase over time in an IGBT under the same loading condition. And why is this so? Because over time what happens the bond wires inside the IGBTs start to lift off and will cause additional heat dissipation over the existing bond wires which are present.

And, so the temperature of the chip or temperature close to the chip will increase ok. So, this junction to base plate thermal resistance if we can ideally monitor thermal resistance or the temperature there it should ideally be monitored, but in many cases access to that point is very difficult sometimes the manufacturers give a temperature sensor right at that point and that terminal is available.

But in many cases what happens is the case temperature is monitored accurately and along with the history of loading of the device, if you monitor or if you record the case temperature you will observe that as the device is coming near to the end of its lifetime, what happens is this temperature will go on increasing.

So, this is something which gives you an indication of the lifetime of an IGBT. Another very interesting parameter that can be observed is the on state collector emitter voltage V CE on again this will also increase with time because some of the bond wires may be broken or damaged.

Usually this V CE on in suppose in an IGBT this V CE on is about 1.7 to 2 volts like in this range often use, but it can go very large I mean go to 3 3.4 under the same loading condition ok. So, if you observe this V CE on over a long period of time under the same loading condition or under the same value ICE then you will see that V CE on is increasing and this will give you an indication that the device is coming to an end to its lifetime.

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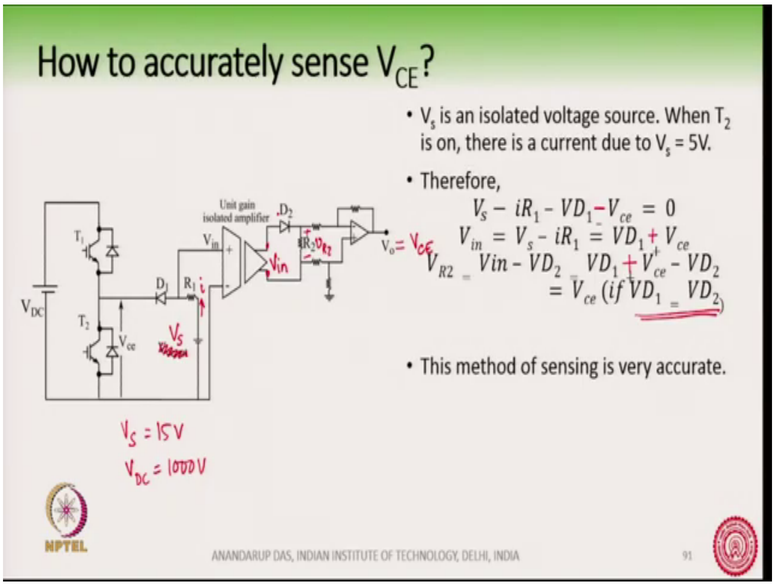

So, here I will show you a very a circuit which can accurately sense V CE on state V ce ok, we have to see the on state V ce not because at off state the collector emitter voltage is equal to the DC bus. So, at on state when the device has fully turned on how much is the V CE on ok. So, suppose this is the circuit, suppose this there is a voltage source isolated voltage source V S here and when I want to; I want to know the V CE on of this device T 2 ok. So, how will I do that? So, you can see there is a circuit here this is an isolated voltage source there is a resistance and there is a diode.

So, when, so this voltage V ce is fluctuating between V CE on and the VDC voltage here. So, when the voltage is V DC of course, V S is less than V DC. So, say V S may be around 15 volt and V DC may be 1000 volt ok. So, when the device is off this diode will be blocking this one so, there will be no path here. Now when T 2 has been turned on then V S will cause a current to flow here. How much is the? So, what is the KVL here when this transistor has been turned on. So, the KVL here is something like this, V S minus iR 1 minus VD 1 minus V ce is equal to 0 ok.

So, this is the KVL V S minus iR 1. So, the current flowing here is i, the current flowing here is i V S minus iR 1 minus VD 1 the drop across this diode minus V ce is equal to 0. So, therefore, this iR 1 now we are taking into an isolation amplifier unit gain isolation amplifier. The voltage here V in will be equal to iR 1. So, V S minus iR 1 V in is equal to V S minus iR 1 this voltage and will be equal to VD 1 plus V ce right VD 1 plus V ce. So, V so this isolation amplifier this voltage because it is a unity gain isolation amplifier the voltage V in comes here also.

V then pass it through another diode and get the voltage across this resistance R 2. So, this voltage V R 2 the voltage across this V R 2 is equal to V in minus VD 2 V in minus this drop. And then this V R 2 is passed through a differential amplifier and we get the voltage V 0, suppose this is a unity gain differential amplifier.

So, therefore, V R 2 is equal to V ce if VD 1 is equal to VD 2 right. So, this voltage V 0 is equal to V ce. So, we get this voltage here, but this diode drop has been taken care you see here VD 1 and VD 2 they are the same type of diode from the from similar same manufacturer and probably the same lot.

So, therefore, if we say that this much of current whatever current is flowing here I will allow the same current to flow here then VD 1 can be made equal to VD 2. And so a very accurate sensing of this V ce voltage can be obtained here. And why this has to be accurate?

Remember we are sensing a voltage of only maybe 1.5 to 3 volt in that voltage range and we are sensing it over a long period of time and we are just monitoring how much is V ce changing, and this is a very noisy environment ok, it is a power circuit. Lot of switching is happening lot of noises are there and so an accurate sensing of V ce is very important and this accurate sensing is possible in this circuit ok.

So, this voltage V 0 is equal to V ce without these drops VD 1 and VD 2. You can also have additional noise eliminating filters in this circuit so that get a very accurate value ok.

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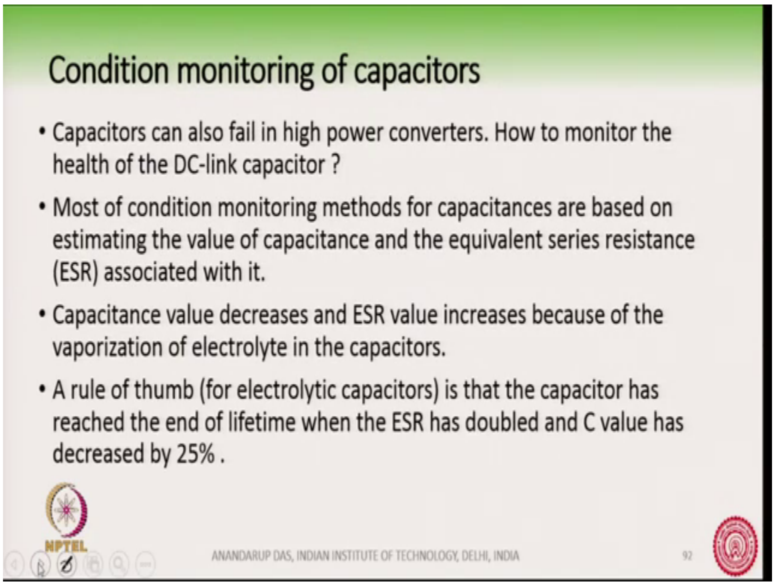

In addition to this capacitors are also weak links, in power electronic circuits capacitors can also fail in high power converters. Now how to monitor the health of DC link capacitors again there are many research articles on this, but the base basic idea is that capacitors, when you see the methods of monitoring the health of capacitance it is based on estimating the value of capacitance and the equivalent series resistance ESR of the capacitance ok.

Usually what we have observed is that the capacitance value decreases and ESR value increases because of the vaporization of electrolytes in the capacitors over time, over a long period of time slowly the electrolyte will vaporize or will leak and the capacitance value will decrease and the ESR value will increase.

So, if we can observe this ESR value or the capacitance value if we can measure it in situ then it is possible to know the health of the capacitor. So, again a rule of thumb is that the capacitor has reached the end of life time when the ESR has doubled and the C value has almost like 20 to 25 percent if it is decreased then we say that the capacitance, the capacitor is now at the end of its lifetime ok.

Now, so how will you do this? So, when the increase in ESR happens the ripple on the capacitor the ripple voltage on the capacitor will also increase because the odd ESR equivalent series resistance has increased. So, under identical condition of operation or identical loading condition the ESR the ripple voltage on the capacitor will increase.

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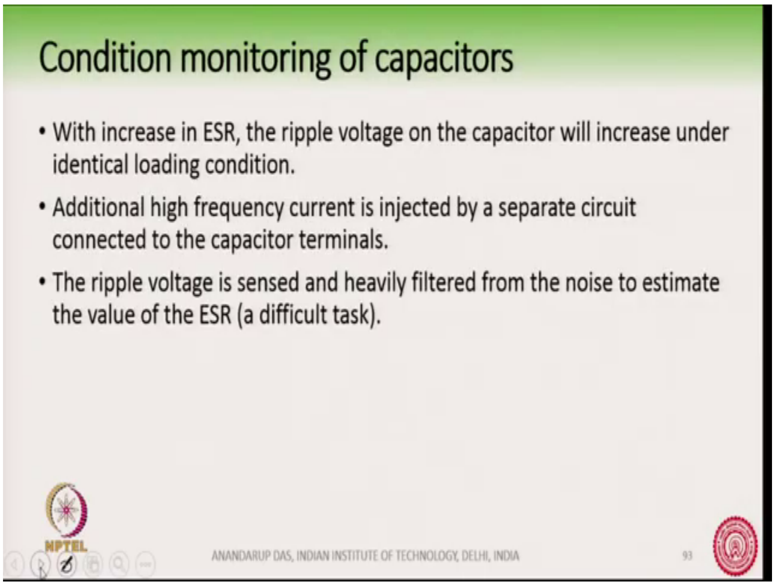

So, what they do is additional high frequency current is injected by a separate circuit which is connected to the capacitor terminals. Often this circuit is a very small circuit it is connected right across the capacitor terminals.

So, if there is a cylindrical capacitor there will be connected right on the it will sit right on the capacitor, and then it will inject a high frequency current and will observe what is the voltage over time. And when the voltage is slowly increasing the this ripple voltage it will be sensed and heavily filtered and then it will be used to estimate the value of ESR over time. So, this is one of the methods by which the capacitor monitoring is possible of course, there are many other methods so this is one method of doing it.

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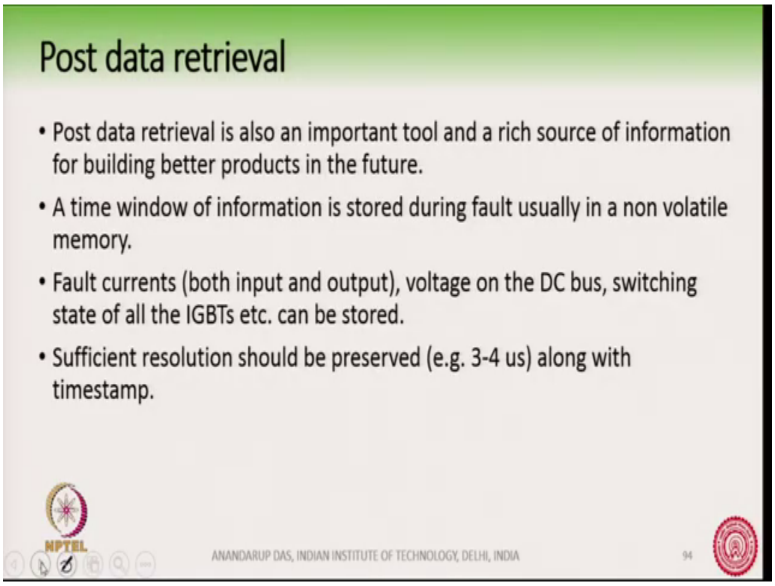

Along with this we also have something like a post data retrieval, as I said sometimes the fault can be very severe and the designers would like to know what happened during the fault.

So, for that what is done is that certain variables in the converter certain important variables in the converter are stored in some kind of a storage, in a non volatile memory in the memory of the microcontroller or some kind of a board. So, this memory will contain some important variables maybe say for the last 2 minutes or something like that you can define a time period.

So, it will go on continuously sampling the important variables for example, input current, output current, voltage on the DC bus, switching state of the IGBT. So, it will go on doing this it will sample these values and will store in a memory which will be again overwritten from time to time ok.

So, that you have a finite amount of memory. So, you can keep a window of last 2 minutes so that if there is a fault then you can retrieve that memory and then you can see what were the variables just before the fault. Sometimes if you want to really go very deep into what happened so, you have to take that is data with a sufficient resolution maybe up to 3 4 microsecond because you know IGBTs can be shut off within 10 microseconds. So, with very high precision and resolution you will collect this data and you will store in the memory.

So, after the fault you will collect the data from the memory and will analyze ok, this is how it happened. So, probably this IGBT failed and probably because of the gate driver there was a glitch there was a noise for which the 2 IGBTs got shorted in the same leg and there was a huge current flowing through the DC bus and that destroyed the device so you will get a picture.

So, sometimes this post data retrieval is very useful for such high end converters and many converters actually implement them.

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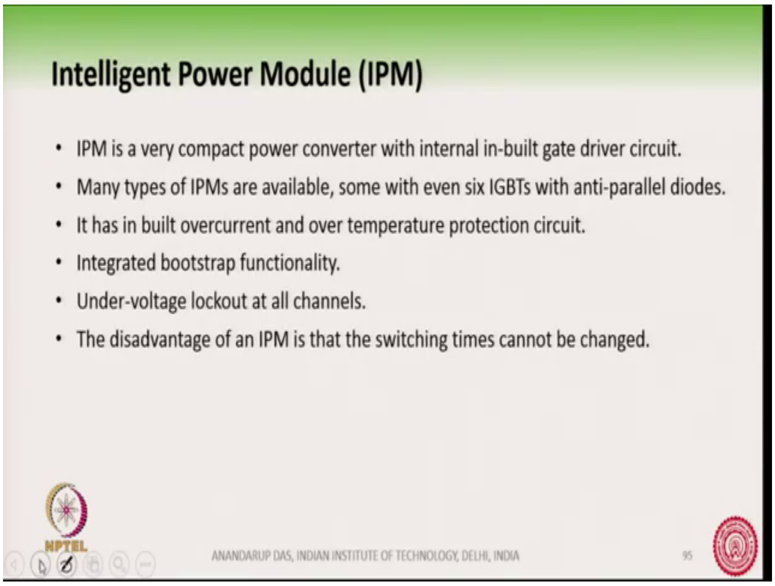

So, the last part is what is called the Intelligent Power Module IPM ok. So, IPMs are very compact power converters with internal inbuilt gate driver circuit ok. It is very compact and it is has very it has many built in features ok. So, many types of IPMs are available some with even 6 IGBTs and anti parallel diodes ok. So, it has built in over current and over temperature protection it also has this integrated bootstrap functionality under voltage lock out. So, many protective features are present in the IPM means it is all is present and it is very compact in size.

So, where size is premium, where you want to reduce the size IPMs can be a very good choice ok. But the disadvantage is that you cannot because the built gate driver circuit is inside the device so you cannot change the switching times so you cannot change the losses. So, once it is designed it has been designed ok.

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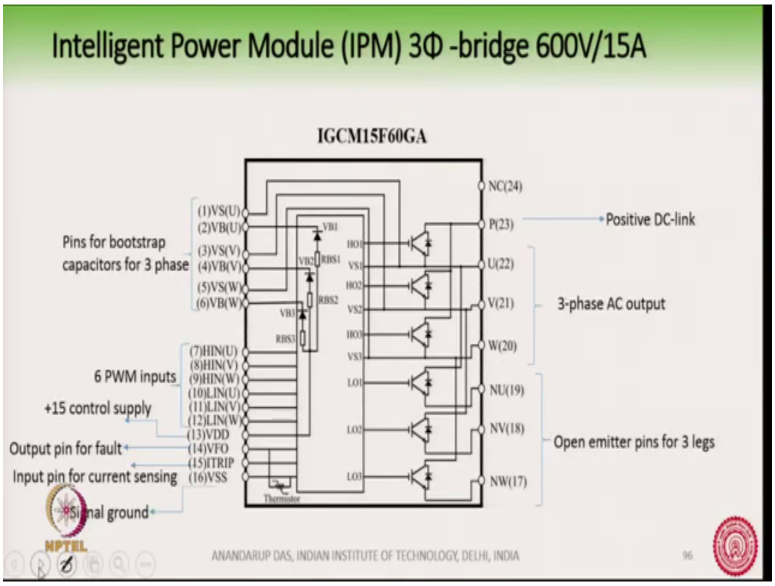

So, suppose you can see this for example, and IPM and this is one of the manufacturers Infineon's IPM and you can see there are 6 IGBTs here inside the IPM and 3 are the upper IGBTs having the positive DC link and then you have the negative side open emitter pins for the other 3 legs.

Here you can see that the bootstrap diode as well as the resistor is already given inside this IPM IC and only what you have to do is to add the capacitor ok. And then here you will apply the pins the PWM pulses to this 6 devices so then this 6 devices so gate driver is inside here.

So, you just apply the PWM input from the microcontroller. The IPM has fault features so it over current fault then it will give a trip signal and then if there is a fault it will give an output pin VFO pin will go down indicating a fault, for the if there is anything which is happening wrong here ok.

You can apply the DC link this is the positive DC link P and there will be this NU there will be an N DC link here also, and then you have a 3 phase AC output right. So, the whole thing this whole thing the advantage is the power devices is inside, the gate driver is inside, the even the R boot the boot strap resistance and diodes are inside and also you see there is a thermistor so there is a temperature sensing inside there is also some additional protections for this, all of them are inside this IPM module. So, what you have to do is to give the PWM from the microcontroller.

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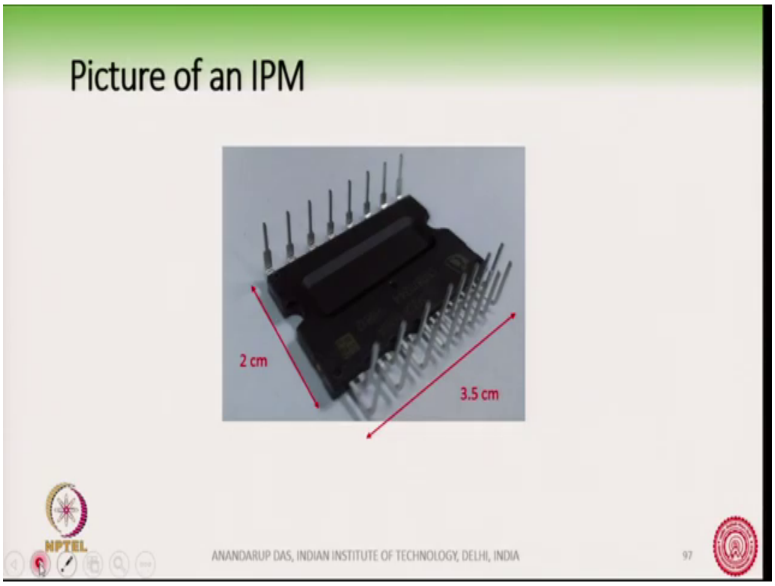

And this whole thing comes in such a size, 2 centimetre by 3.5 centimetre. So, this is the advantage, it is very compact so, you place it on a heat sink and place a PCB and then you can run this converted it is a full converted, we can see here this is a three phase voltage source converter ok.

Can have a 3 phase 6 IGBTs are there are different current ratings this current is 600 volt and 15 ampere is 400 volt maximum into DC bus 15 ampere, but there are different versions of IPM and all manufacturers produce IPMs very compact. And it is very useful when you are doing for readymade applications.