**Power Electronics with Wide Bandgap Devices**
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**Lecture-36**
**WBG Applications-Reliability Analysis**

Welcome to the course on power electronics with wide band gap devices. Today I am going to discuss about wide band gap devices applications which is considering reliability analysis part.

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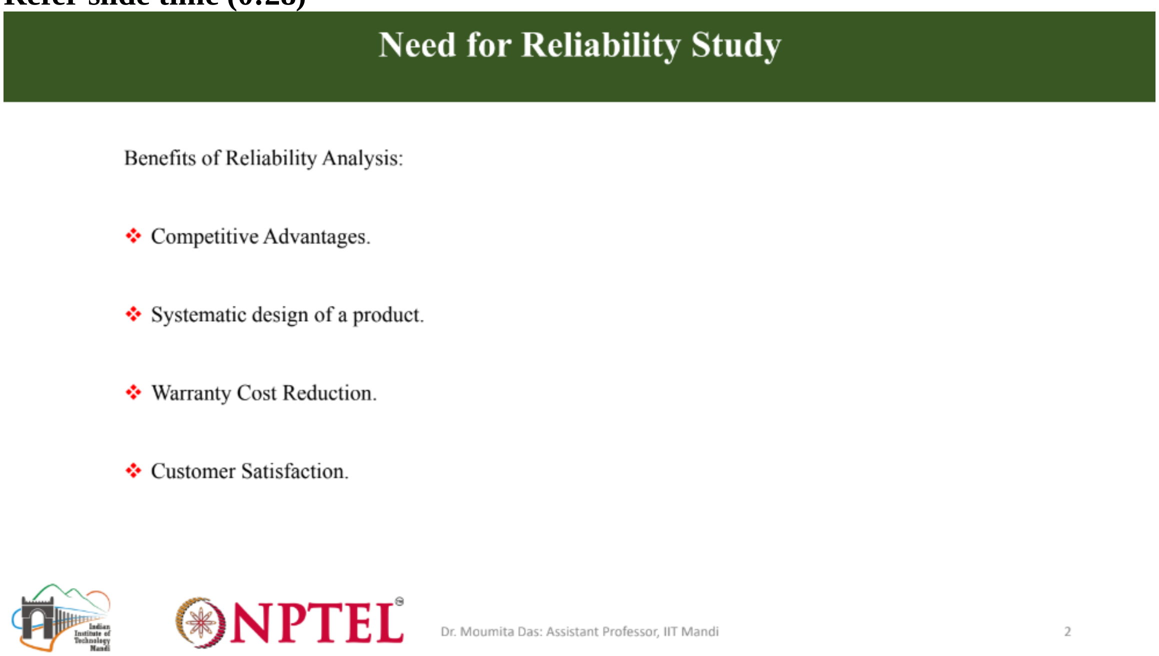


So basically whenever we consider any application let's say integrated motor drives, renewable energy source applications which I have discussed earlier right. so there before going into the application part we need to do the reliability analysis of the converter so why this reliability study is important basically there are benefits of reliability analysis which are given as competitive advantages what is the benefit of using any particular system over existing system so that benefit obviously from converter point of view there will be some advantages but whether the system will be reliable or not so that can be concluded from the reliability analysis part in the systematic design of a product so how the product should be designed what approach we need to use for any new system what are the modifications we need to do what should be the method we can apply in any system so that kind of design approach can be evaluated through this reliability analysis then warranty cost reduction so if we are going for a new system obviously there must be advantages with respect to economical point of view which will give us the benefit in terms of cost as I have discussed with you earlier like this wide bandgap devices from device point of view they are very expensive as compared to the silicon devices because of the manufacturing level is not as per the silicon devices so that's why we have to consider the overall system cost so we found that the overall system cost will reduce down as compared to the existing silicon device because you know there are like additional requirement for silicon devices which may not be that significant in case of wide band com devices so that is why the cost reduction will be there and obviously whenever we say cost reduction that we have to see for like throughout like how much time we can provide this solution is for  So basically how many years it can operate properly. So that kind of thing will be there. And then obviously customer satisfaction will depend upon if the system operates properly for long time.

So these are the advantages of reliability study. So that is why we need to consider reliability analysis. So I will just give you brief idea about this reliability study. How it can be done. For any new system so that you can use for any new device whenever it will be applied to any application  considering like power converter.

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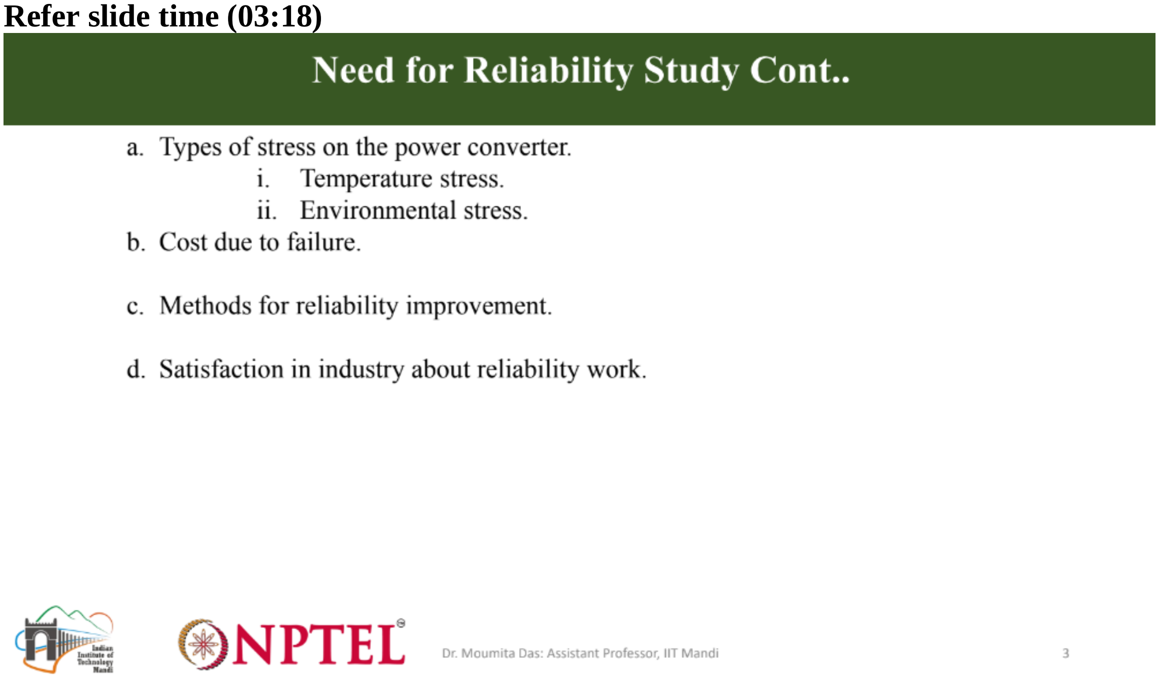


This need for reliability study anyway like I told you so these are the advantages but why we need this? So we need to find out the stresses. What kind of stresses we generally see in power converter? So generally we see this temperature stress which actually comes from the power losses. So basically  when I have shown you the analysis of the power converter how the temperature can rise so basically from like temperature calculation part where exactly I have shown you that the heat sink design part so there you have seen that from power loss we can directly calculate the temperature which will arise in that particular device or the system now when you have the temperature so then what you need to do then you can easily find out the type of heat sink will be suitable to take out the heat from the system if in case we cannot do that we fail to do that kind of operation then there will be stress in the device stress means temperature can change the property of the device that you have already seen so like if we cannot take out the heat then it will change the property of the device eventually it will increase further heat and then what will happen then it will ultimately destroy the system so that is why we need to have idea about the temperature how much it is actually generating in the device itself so this temperature stress we need to find out So second thing is the environmental stress. What are the environmental stress? Obviously there is like environmental effect in terms of temperature.

But there are other effect also like if the system is placed in a steady location where only temperature is the part we need to consider or in addition to temperature there can be vibration effect also. So let's say if the system if we consider electric vehicle kind of applications. So there what happens the converter will be placed in a vehicle or the car so basically their car will be in the moving condition so then along with temperature there will be other factor which will also affect the device which will be placed in the converter or maybe if it is placed in the more aircraft application so then what will happen then it is like in space application or plane or anywhere so there will be vibration effect also for that so this will come under environmental stress ok so this stress if find out so then what we have to do we have to see how much time the system will operate properly in a given environmental condition temperature, high vibration everything so then we have to find out what are the factor that is going to get affected in the device so that will give us the failure rate okay so then once we have the failure rate we can actually provide warranty for that much period whatever failure time we will be able to get and then we can also find out ways to improve the reliability so let's say if any system is placed in any particular application let's say motor drives or maybe renewable energy so, then based on the application there can be different control methodology algorithm those we need to use then if any method is not suitable or maybe that can cause failure much higher rate than the any other method then we can actually provide suitable method we can for that we have to find out what are the failure rate and all this thing and also we can provide algorithm so that it can give us some benefits over existing kind of algorithm so this is important for development or manufacturing of any system related to wide band gap devices. So, this is what is essential for industrial development. So, until and unless they provide warranty of the system, they will not be able to use this for industrial application.

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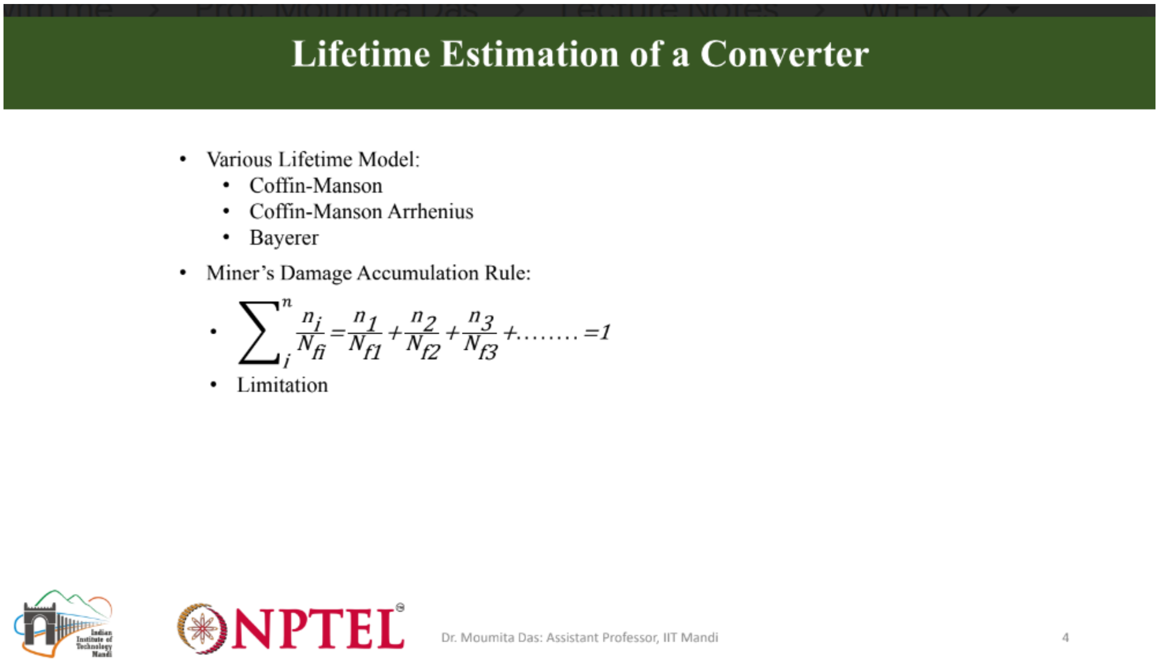


So, this is why it is very important. So, how do we get this lifetime model? So, there are various lifetime model which are existing for silicon based system. So, you can see this coffin mansion model, coffin mansion Arrhenius, barrier. So, all these models are there. So, what we need to find out? Then minus damage accumulation we need to find out.

So, this accumulation rule give us

Miner's Damage Accumulation Rule:

- $$\sum_{i}^{n} \frac{n_i}{N_{fi}} = \frac{n_1}{N_{f1}} + \frac{n_2}{N_{f2}} + \frac{n_3}{N_{f3}} + \ldots\ldots = 1$$

So, you can see summation of i to n in small n I divided by capital Nfi. So, capital N gives different temperature with respect to that what will be the damage accumulation. So, N1, N2, N3 are the damage accumulation with respect to different temperature. And As each cycle is completing let's say the system is running for few times like it is actually operating for few cycle initially then the temperature may be different and with respect to that the damage accumulation can be calculated.

now as the temperature changes then again the damage accumulation will be calculated after sometime the temperature may change due to environment or may be due to stress of the devices so anything can cause change in the temperature so then the damage accumulation with respect to the other temperature will be different so by adding all the temperature and the damage accumulation when it will become addition summation of all this parameter will become equal to one then the device will be completely damaged so means the damage accumulation is reached to the maximum level so device cannot operate in that time so these are the like methods which we need to use in order to find out like how long the system can operate then only we can give us that okay fine this much time it will operate properly after that you have to see basically check the condition of the device or the system and then you you need to like replace it or maybe repair it so whatever will be suitable.

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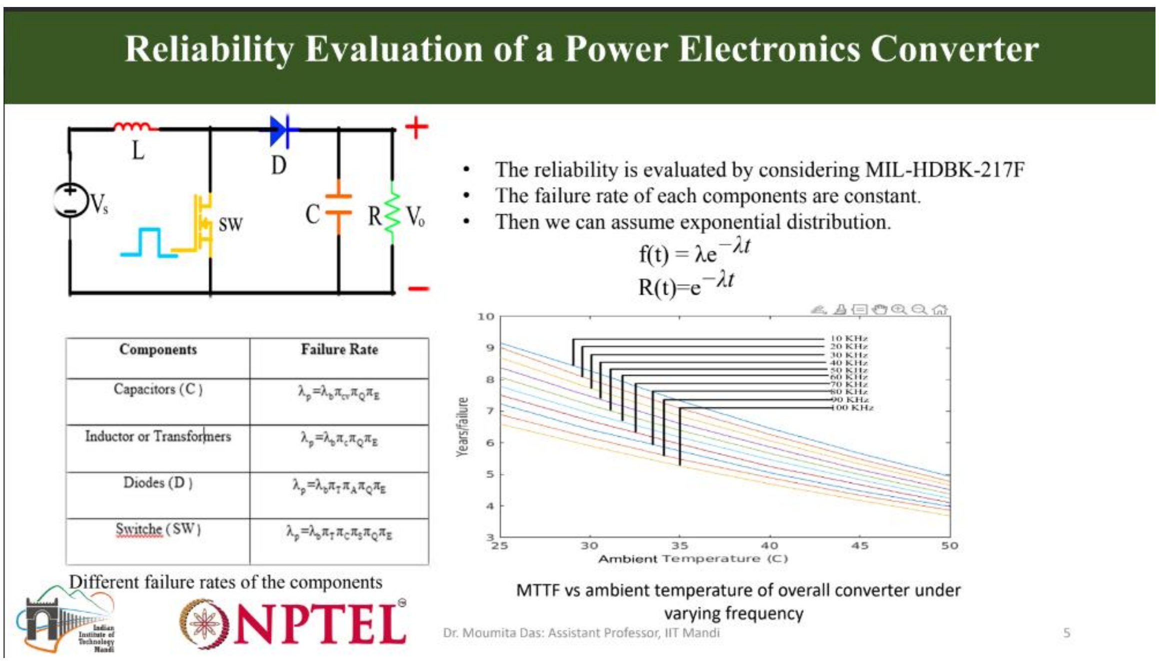


So now if we have to use this in a power converter then what we need to do so this is simple boost converter anyway like I have discussed about boost converter simulation and then PCB design so now we are going to see this simple boost converter analysis with respect to the reliability part like to see that what are the parameters we need to consider so you can see this boost converter obviously It is having this input voltage source, then input inductor, switch, diode, capacitor and then output load. Load is shown here as the resistance. And voltage across the resistance is shown here as V0. So, then the reliability in this case is evaluated by considering MIL-HDBK handbook 217F.

So, okay. So, this handbook provides the reliability analysis part but that is by considering the silicon devices obviously wide band gap device is much different than that of the silicon device there are some differences there so then what we need to do we need to check the failure rate of each component so that so here they have considered the failure rate of each component are constant so then each component means you can see here this capacitor inductor or transformer like basically magnetic component they are considering then diode and the switches so these are the formulas for the failure rate now these formulas are directly taken from the handbook if you want to know more details about this particular this different component in this formula so you can actually refer this handbook so there are actually different components are like quality factor so the environmental factor then failure of the devices they are related to different parameters so this you can see here so now This is like considering the exponential distribution f t equals to epsilon e to the power minus epsilon t r t equals to e to the power minus epsilon t. Now this will give us basically ultimately getting failure rate of each component will give us what will be the years or failures. So basically year of failure for this particular system considering different ambient temperature. As you can see here so like this as the frequency is increasing so as you can see here so the failure rate it is actually much higher means the years it will be able to sustain properly that is actually much less than that of the operation at lower frequency so this is very much important because you know as we are considering wide bandgap devices obviously we are actually looking for high frequency operation so here the frequency ranges are shown from 10 kHz to 100 kHz. So 10, 20, 30, 40, 50, 60, 70, 80, 90, 100.

So you can see here so there are different lines are shown. So the 10 is the line which is the top most line. So, which is giving here as the temperature increases obviously failure rate it is increasing but any particular temperature if you consider let us say 30 degree Celsius. So, 10 kilohertz number of years it will be able to sustain it is more than 9. and when we are considering as 100 kilohertz then number of years it will able to sustain it is around 6.

5 years so that is how much it is shown here so as we are actually considering this high frequency operation obviously the failure rate will increase then what we need to do we have to find a way so that we can maintain the failure rate means let's say it is nine years and it is six years so instead of nine six years how to improve the failure rate to nine years even at 100 kilohertz operation that is the part our role comes so probably we can provide methods or maybe different like design for the power electronic converter or we can evaluate like how this temperature effect stress environment stress can be less can affect the system less so those are the ways we need to find out and implement. For any like new device based system so that we can maintain at least the years of failure to the like previously existing system without like obviously the other advantages should come here. So but like we should not affect the failure part okay .

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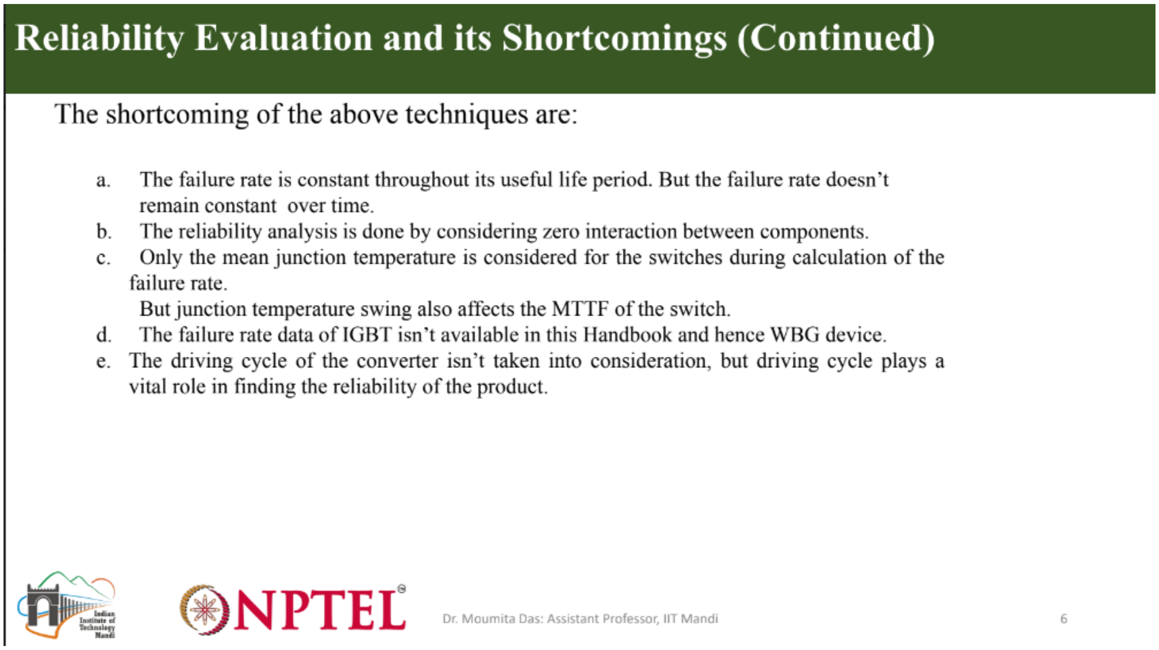


So in terms of reliability analysis what are the shortcomings given in the handbook so basically the handbook which is given for the silicon based devices so there the shortcomings are the failure rate is constant throughout its useful life period means like this failure rate it may not be constant but the failure rate doesn't remain constant over time so that is the part we need to include in the given method or maybe for the new devices. The reliability analysis is done by considering zero interaction between the components.

So, components they interact with each other means there will be different parasitic components. So, how to include the parasitic component for failure analysis that part we need to look into. Only the mean junction temperature is considered for switches during calculation of the failure rate. But junction temperature swing also affects the MTF of the switch. So that we need to consider.

The failure rate data of IGBT isn't available in this handbook and hence WBG device we need to consider. Like we need to provide new method using WBG devices. The driving cycle of the converter isn't taken into consideration that we have to consider like what will be the different stress because as the driving cycle changes, stress in the devices will change and that is going to affect again the failure rate. So, this driving cycle plays an important role in finding the reliability of the product, okay. So, these are the things we need to consider which is not given in the handbook, existing handbook, okay.

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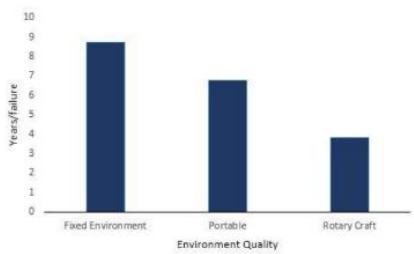
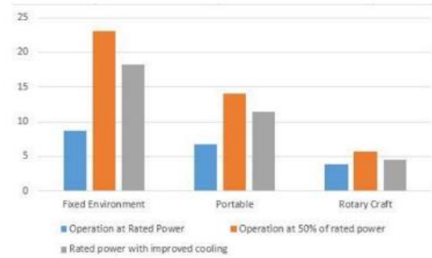
## Effect of Power, Frequency, Ambient temperature and Vibration




Comparison of lifetime of converter operated at rated power under different environment




Comparison of lifetime of converter operated at rated power under different environment

- The vibration also affecting the time to failure of the converter significantly.
- MTTF can be improved by properly selecting power level, frequency and cooling.



so you can see here so this is one example is given so like how this like environmental factor will change and the power level will change will affect the failure rate so you can see the left hand side the first like which is shown here so it is with respect to the first one is the with respect to fixed environment second one portable environment like for EV application so where you can carry it Then third one is the rotary craft. So, particularly aircraft application. So, you can see here as like the fixed environment you can see the number of years it will be able to sustain is much higher than that of the rotary craft. So, comparison of lifetime of converter operated at rated power under different environmental condition.

Okay. So, this is the part which is shown here. so the vibration also affects the time of failure of the converter significantly this MTTF wave obviously can be improved by properly selecting power level frequency and cooling so you can see here this right side waveform is with respect to the different power level so here the operating at rated power so this is blue one operated at 50 rated power then orange one it is much higher rated power with improved cooling so it is actually grey one. okay so you can see here so low power level it will be able to operate much higher means like failure rate will be less and in the whenever it is like having rated power then what will happen so then this number of failures will be much higher then years of sustain will be less so the here comes the driving cycle part you know like whenever the driving cycle we have so that time we will have the information about the system power level whether the system is operating at rated power or half of the rated power 10% ,20% of the rated power so then that way the failure rate will change until and unless we have the driving cycle So we will not be able to comment properly on the reliability part. Maybe if we have the driving cycle let's say let's take an example. So if we consider the reliability of the system considering the rated power condition maybe it will be able to sustain for 5 years.

Now if we consider the system using half rated power then it will be able to sustain for 15 years. Now our system if we have driving cycle maybe sometime it is operating in half power system half power level sometime it is operating at full power level. Maybe if we have the information of the driving cycle then we will be able to get the reliability as 10 years. So until and unless we include the driving cycle we cannot really comment on the reliability. Either we will come in 5 years or 15 years, both are wrong, right? So that is why it is very important to include driving cycle and that is where the application part come and that is where the power converter part come.

So power converter we need to fix first, then where exactly we will be applying it. So these two part are very important for studying. the device in actual application. So there comes the actual application related reliability analysis. So this is very much essential for industrial application or industrial design or maybe using the system for like any product.

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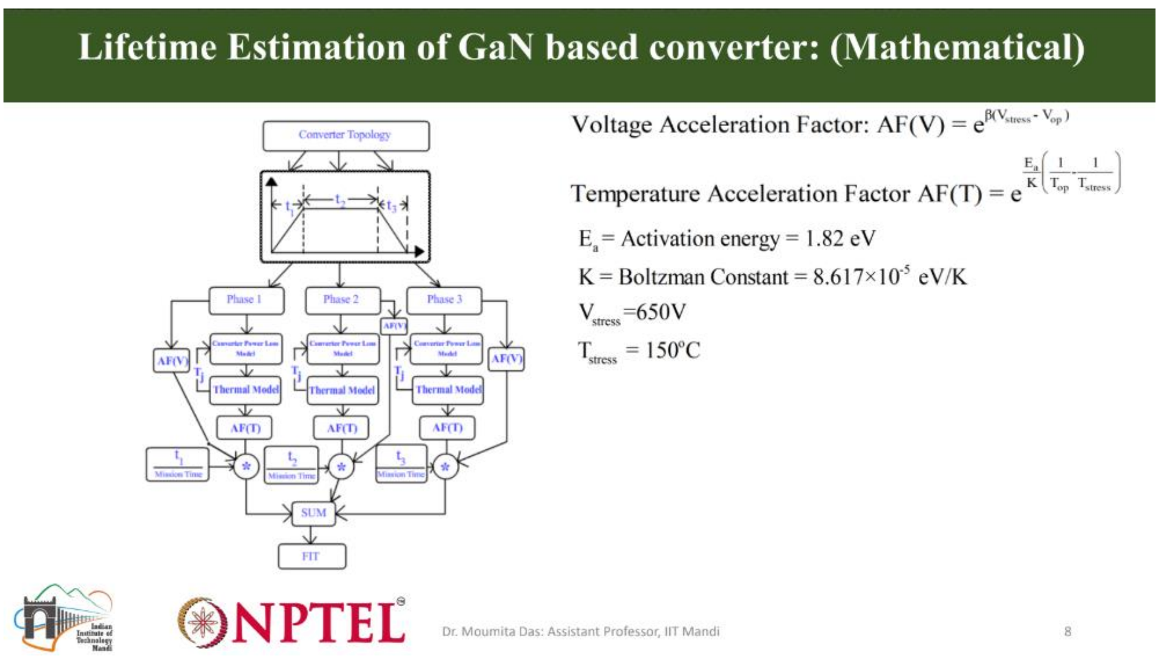


So this is very important part. So, this is considering lifetime by particular driving cycle. So, you can see here. So, this is maybe let's say this is the driving cycle of the converter topology. Initially for T1 period, so the power level is increasing.

So, for T2 it is fixed and T3 it is again decreasing. So, there are three phases you can see here. So, it is actually divided into two. phase 1 phase 2 and phase 3 so three phases are divided and now based on the three phases again this voltage acceleration factor you can see here it is given in the equation this is from the handbook SF(V) so

Voltage Acceleration Factor: $AF(V) = e^{\beta(V_{stress} - V_{op})}$

Temperature Acceleration Factor $AF(T) = e^{\frac{E_a}{K}\left(\frac{1}{T_{op}} - \frac{1}{T_{stress}}\right)}$

$E_a$ = Activation energy = 1.82 eV

K = Boltzman Constant = $8.617\times10^{-5}$ eV/K

$V_{stress}$ =650V

$T_{stress}$ = 150°C

e to the power beta v stress minus v operating so this is actually calculated, accelerating factor. And then similarly, voltage accelerating factor, we have the temperature accelerating factor.

So, this can be calculated by using e to the power Ea by k, 1 by T operating minus T stress. So, Ea is the activation energy which is given as 1.82 eV. K is the Boltzmann constant which is 8.617 into 10 to the power minus 5 eV per Kelvin.

And V stress is taken here as 650 volts and T stress is taken here as 150 volts. So, stress means this is the maximum. V stress is the maximum voltage and T stress it is maximum temperature. Okay then based on the operating temperature obviously this accelerating factor will change. Then again the operating factor temperature depends upon the converter driving cycle.

So based on this like this temperature accelerating factor and voltage accelerating factor. We can actually check converter power loss by using converter power loss model. Again for converter power loss we need to have the information of the converter prototype itself. Once converter power loss model we have from there we can get the thermal model. So you can see for phase 1, phase 2, phase 3 it is same.

Converter power loss model and from there we are getting the thermal model. And thermal model we are getting the temperature accelerating factor. and obviously for phase one also like voltage accelerating factor we will get separately and temperature accelerating factor voltage accelerating factor we are like here we are multiplying with the t1 by mission type and then summation will give us the basically total reliability or total time it will be able to sustain. Now this is the whole system.

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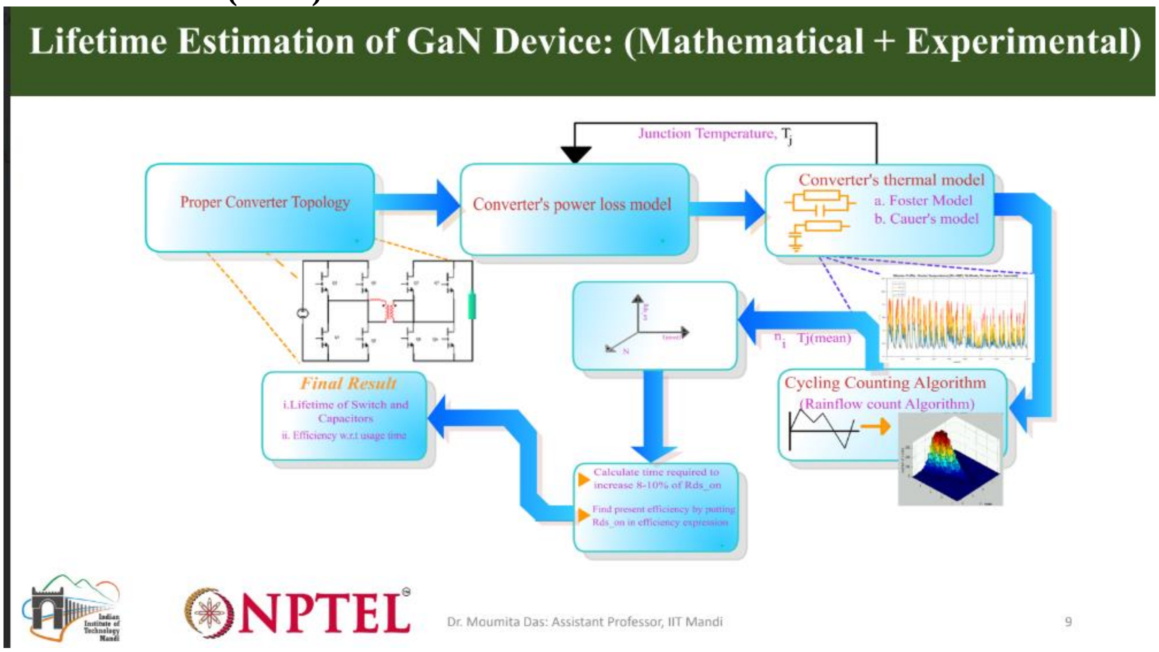


So basically we need to have idea about the mathematical model and the experimental data.

Then only we can comment on the system reliability. So we have to fix the power converters. Let us say this is one converter. It is fixed. Then from here for each power converter the power loss model will be different.

we need to get the power loss model. And then from power loss model, we need to get the thermal model. So, anyway this Foster and Cauer's model, I have already discussed with you long back. So, there you can refer that. And then by using the rain flow count algorithm cycling, like how many cycles we can get, so that we can count.

So, this can be given here as T j min. So now calculating time required to increase this like 8 to 10% RDS on and find present efficiency by putting RDS on in efficiency time. This we can actually use in the final result for calculating lifetime of switch and capacitor and efficiency and the usage time. So these are the total thing we have to do in order to find out reliability of the system using RDS. any device or from the device perspective right so thank you that is all for today so yeah so this is all about this particular course so i hope this is beneficial for you and you can use this device by using by referring this particular course you will be able to use this device for development of any product or any system which will be useful in industry Okay, thank you very much. Thank you.