Power Electronics and Distributed Generation
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Lecture - 25
Electrolytic Capacitor Reliability and Lifetime

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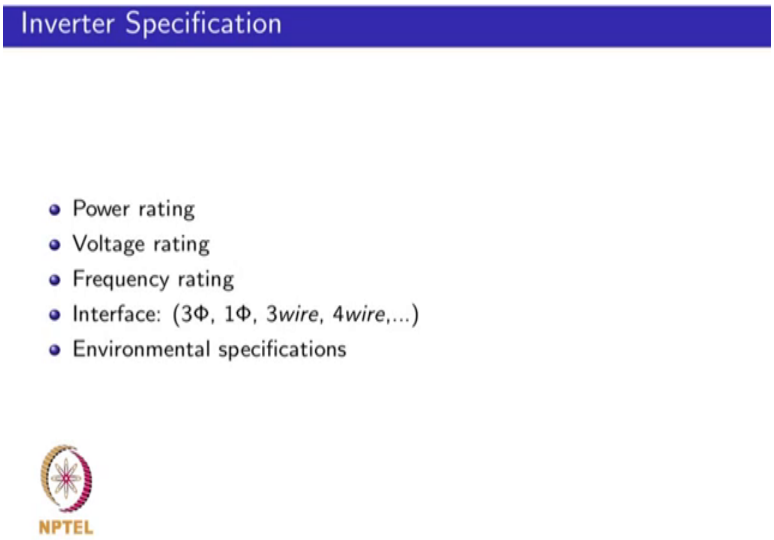

Welcome to class 25 in topics in power electronics and distributed generation. We will start this class by summarizing, what we have been discussing which is what we mean by the basic specification of a inverter. So, when we talk about a basic specification, you start off with something as elementary as a power rating. You are a c voltage rating, what frequency you are operating standard frequencies are 50 hertz, 60 hertz. Your nominal range of voltage, what is a range around the nominal, and which has implications on current rating, etcetera. The type of interface, whether it is a single phase interface, 3 phase interface, 3 wire 4 wires, we also discussed about the environmental specifications temperature, ingress protection etcetera, have actually a large impact on the design of the power converter.

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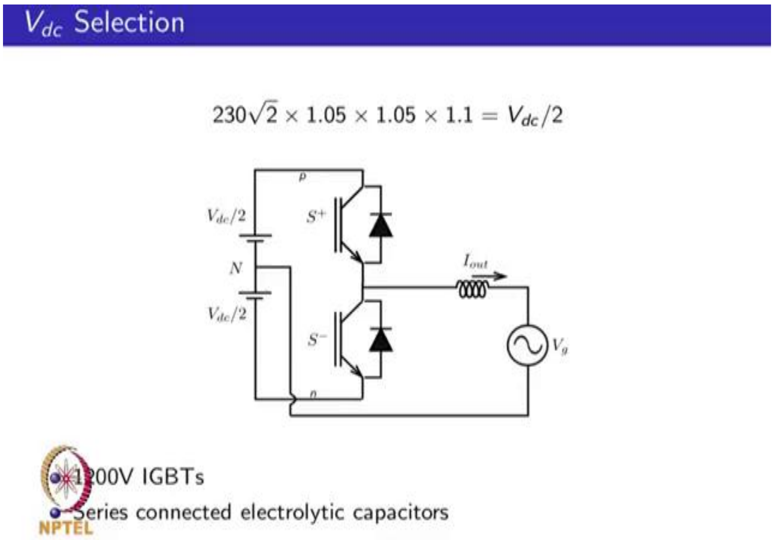

We also looked closely at the single phase, a simple single phase topology, which is essentially consisting of a split capacitor bank. We saw the implication of the ac voltage on deciding, what your d c voltage has to be? And the dc voltage we saw is related there are factors relating to the range around. You might have 5 percent above the nominal grid voltage, which you need to handle. You might have some percentage voltage, which gets lost as dead time on state drops of your devices etcetera. You might also have some range of voltage that gets dropped across your filter C voltage rating what frequency, you are operating standard frequencies are 50 hertz, 60 hertz your nominal range of voltage, what is a range around the nominal and which has implications on current rating etcetera inductor?

So, you are for a 230 volt system you might end up having two require a d c bus voltage, which might be closed to 800 volts, and this immediately would imply that. Now, you need a capacitor bank, if you are having 2 in series you are talking about 400 to 450 volts as a value of the voltage, that you need for the capacitors, and for the I G B T s or transistors and diodes. You need components, which commonly would be available at 1200 volts.

So, 10 you can actually look at what given this preliminary specification, what are the implications on your dc bus capacitors? We the starting value point is to discuss, what the voltage rating is? Then to look at what the current rating is? And we saw that there are varieties of current signals that can flow through the dc bus capacitor bank, when you are talking about a typical d g application, your actual capacitor bank your…

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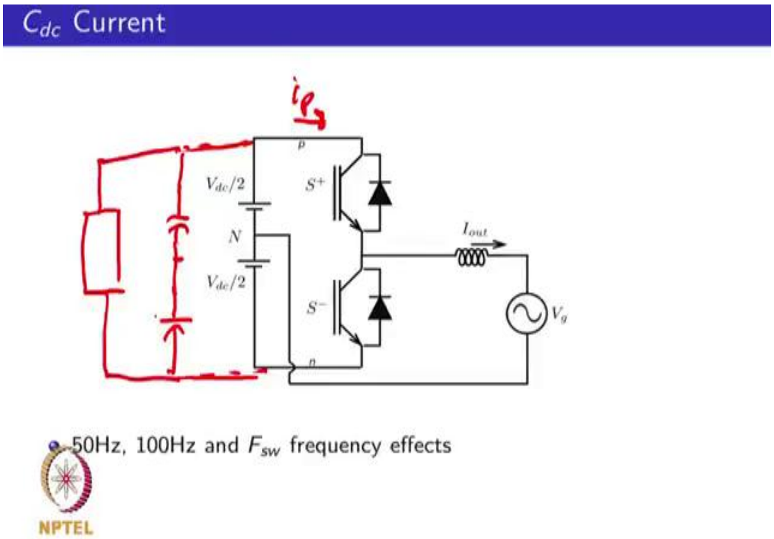

Voltage sources over here might consist of capacitor banks connected in series and your actual voltage source is a prime source connected in parallel with the capacitor bank. The capacitor bank is effectively acting as the voltage source on a high frequency, and intermediate frequency bases. And what you trying to regulate is ensure that the voltage across this capacitor bank stays ideally as close to the dc value that you desire, and then we looked at what would be the currents that can flow through your positive bus. We saw that there is a dc current, which is essentially, what transfers power in a typical d g application.

You have a 50 hertz component, especially in this centre tap topology, which flows through your capacitor bank and you have a 100 hertz, which would show up in a again phase topology or it can even show up in a 3 phase topology, if you have unbalanced in your ac voltage or unbalance in your ac system. You also have switching frequency components that can actually flow through your positive dc bus. We linked the current in your output i out to your current in your dc bus. We derived expressions for the dc current, your 50 hertz current the second harmonic 100 hertz current your switching frequency component.

These are relatively simple expressions to actually obtain, that can be obtained for your bus capacitor currents and then the next question is, how to actually make use of these currents? That you have evaluated in the design of your capacitors. So, the first thing that you when we are looking at. Say, the design of the capacitors are, there are variety of capacitors out there. So, capacitors are commonly classified based on the dielectric that is use in the capacitors.

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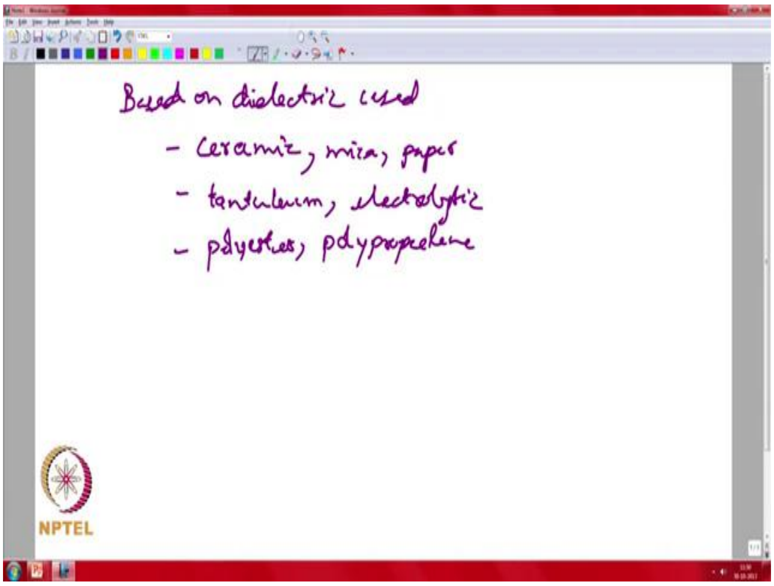

You might have ceramic mica paper; you might have tantalum, electrolytic, polyester, plastic capacitors and polypropylene, so depending on your application. For example, mica capacitors etcetera are really good at very high frequencies. The value of the capacitance that you would get is really small electrolytic capacitors have large value, but you may not get it in a ac rated, as in with ac rating. So, if you look at the common capacitor that is used in the dc bank of a voltage source inverter, which is used in a d g type of application. You are talking about commonly it is electrolytic capacitors.

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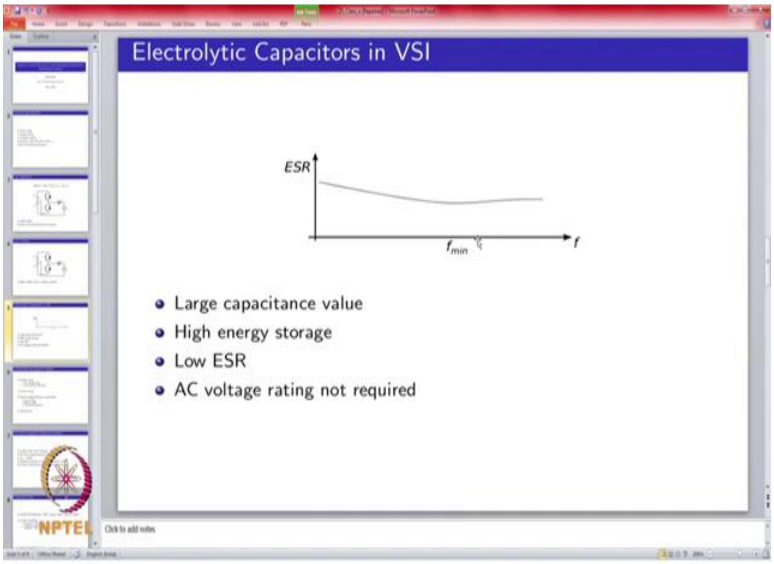

Once you have decided to say, you want to make use of electrolytic capacitor in your dc bank, then what are the advantages of using. An electrolytic capacitor one thing is you have electrolytic capacitors in 100s 1000 of micro farads or milli farads range. Also, depending on your v voltage rating, a larger capacitance means for a given current ripple, you are having smaller voltage ripple or better filtering.

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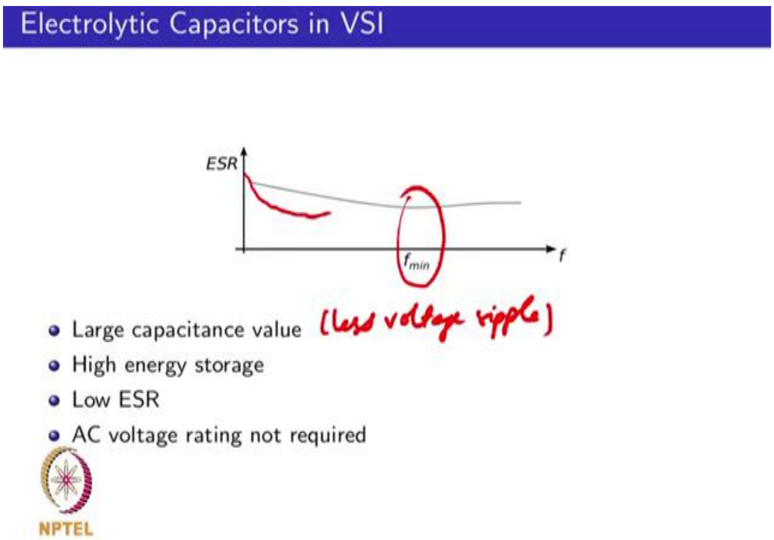

So, a larger capacitance implies, you have lesser voltage ripple a large capacitance half c v square is the energy stored in a capacitor and large value of capacitance means that you are emulating an ideal voltage source more closely. It can provide a large amount of energy without getting discharge or changing the value of the voltage. You also have a now capacitors electrolytic capacitors with low E S R is equivalence resistance.

So, low E S R again will see has a advantage in terms of dissipation live temperature rise etcetera. Today, commonly you get electrolytic capacitors with a low E S R capability, which has implication in the amount of ripple current that can actually flow through this capacitors. Another negative point of an electrolytic capacitor is that does not have ac voltage rating, but ac voltage rating is not required in the dc bus of a voltage source inverter.

So, even though it is a drawback, it is not a major drawback for electrolytic capacitor in a V S I application. So, depending on the nature of the E S R, you can also have different types of a electrolytic capacitors. You might have electrolytic capacitors where the E S R might be minimum at lower frequencies. You might have a electrolytic capacitors, where your minimum of your E S R might be at this the switching frequencies 10 of kilo hertz or few kilo hertz.

So, if you are having a specific capacitor, which is designed to have lower E S R at may be 100 hertz, 100 and 15 hertz. You might be having a rectifier grade electrolytic capacitor, which is used in standard diode rectifiers that you know, the most of ripple is going to be at lower frequencies. Sometimes, people referred to high frequency electrolytic as s m p s grade electrolytic, which are optimized for the ripple. Now, flowing at may be many kilo hertz, 10’s of kilo hertz etcetera. You also have other parameters of the capacitor, which is important.

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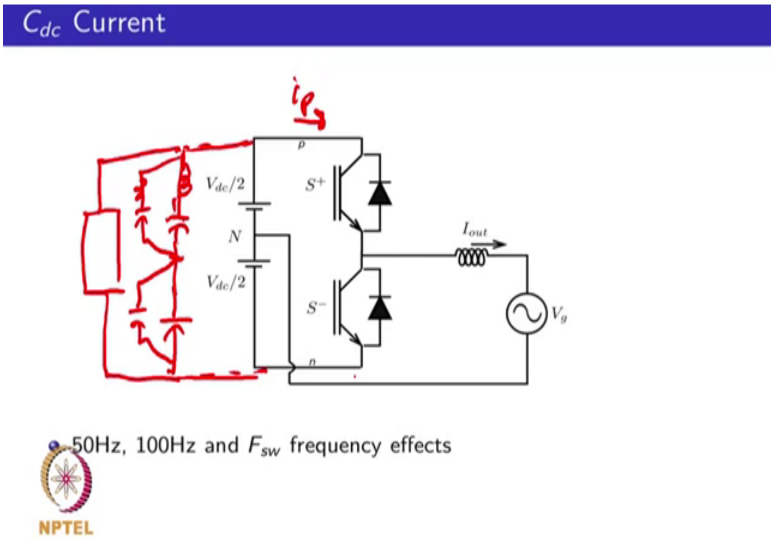

If, you look at a capacitor, which is acting as a equivalent voltage source in a bus of a of a inverter. You also have parasitic inductance which can actually come in series with the capacitance. These parasitic inductance actually can cause a significant problems because, the switching speed of your transistor. It can actually have very large d i d t d i d t's of the order of kilo amps per micro second to 10's of kilo amps per micro second. So, even a few 10's of nano henries of inductance can actually, cause a fairly significant voltage spike of the order of 100 volts 200 volts etcetera depending on the inductance. So, it is very important to actually minimize the e s l of your capacitors one thing that people might do is instead of just having a electrolytic capacitor. You might actually put snubber capacitors in parallel with a electrolytic capacitors.

So, many times one may wonder, why is there a thousand micro farads capacitor and in parallel with that you are putting a 1 micro farad capacitor or a 4.7 capacitor. It is from a e s l perspective, where the e s l of your snubbed grade capacitor would be much lower and for higher frequencies. The e s l is also a significant factor in ensuring that you have voltage spikes that come across. Your capacitors also another aspect to keep in mind is when you just draw power converter.

You might just connect source to a transistor often, because your parasitic inductance is so critical, you might actually decide to make special dc bus connections. You might have parallel structures plate structures in your printer circuit boards or copper buses with a parallel structure to minimize these inductances.

So, as to ensure that even though your dc bus might be sitting at 800 volts and your device is 1200 volt. If, you do not pay close attention to what these strange inductances are even the capability of modern day, the transistors you can end up causing voltage spikes that can damage these devices. So, once you actually have had equated margin between your voltage in your d c bus. You know a preliminary value of the voltage.

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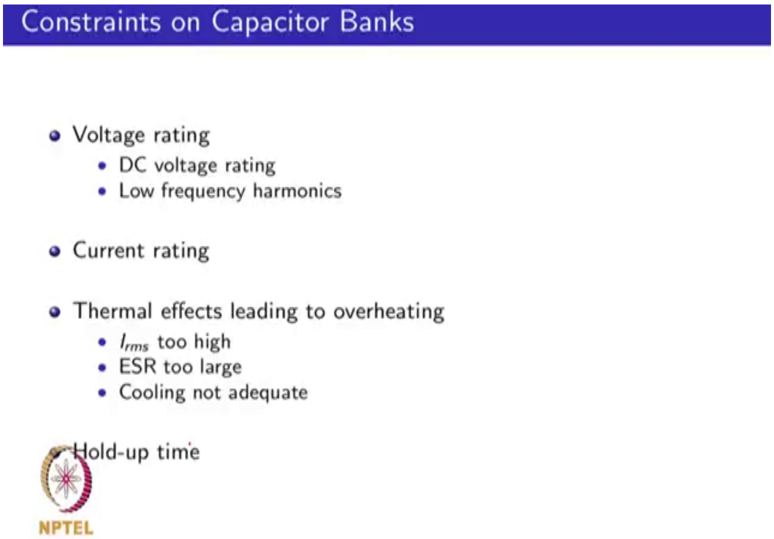

Then, you can ask, what are the constraints? That can happen on a capacitor bank and we saw that dc the voltage rating is a basic constraint your dc voltage rating is something that just we discussed in addition to the dc voltage rating. We know that we are low frequency currents 50 hertz 100 hertz. Also switching frequency currents, those currents can actually induce and cause ripple voltage and you need to ensure that. The ripple voltage is also adequately addressed, so you we also saw that the 100 hertz ripple might become, so significant that you might actually want to add an additional dc to dc converter etcetera. To prevent this ripple voltage from flowing back into your prime source and cause losses in your overall d g system.

Also you have current rating, which is a important factor in any component many times your terminals that you connect a component is specified by what current that terminal connection can handled. If, your current becomes too large, then your terminals, your screws, your whether snapping connections or your pc be insertion points they can over heat and can melt. So, current rating is a important aspect of terminals in connection points and also components and when it come to components.

The current rating reflects itself in terms of the thermal effects, which eventually leads to overheating. So, if you are having overheating in a component like say, the dc bus capacitor. One thing is you could directly say, you are passing to much current through a component. If, you are passing too much current one way to prevent say, large current is to parallel components. If, you have a given amount of current and you want to actually, you find that the current that is flowing is too large you can then connect components in parallel.

Then, the currents take the parallel paths and ensure that the current per device comes down. The other aspect, which can lead to higher thermal effects, so overheating in components is the E S R itself is being, is too large. If, you select a com capacitor where the E S R is large you are i squares r, the r part of it is given a current. The r part is too large, which means that you are having higher power loss and which in turn results in too much temperature rise.

So, you need ensure that whatever capacitor or component that you are selecting has E S R ensures that the temperature does not go to high, which was one of the criteria. In modern day electrolytic capacitors having low E S R capability, low E S R, which is actually a advantage. Another thing, you are I r m s capability might be you, your r m s current may be small, your E S R might be small, but given.

However, a small capacity power dissipation is having is occurring within a component, if the component is not being cooled the nit is integration process, where you are adding thermal energy into a component, where the thermal energy does not flow out. So, if the cooling is not adequate, then again you are going to wait overheating, which means that you need to consider. Say, whether your capacitor show is it packaged in such a manner, where you allow say, natural convection, if your capacitors are too tightly placed.

Then, there may not be possibility for air flow around it. If, it is kept in a horizontal configuration rather than a vertical configuration, it will determine whether you can have natural convection around a capacitor bank or you might be a simple as may be, you need to add a snaps for the capacitors. You might have this capacitor sitting in a seal cabinet and you might be having poor air exchange and you need to have some air circulation within whatever cabinet.

You have to ensure that your components does not get too hot and these, so there are multiple aspects, when you consider the thermal effect. It is not just a con question of just the current being too large, it can be E S R it can be cooling. So, all these factors have to be considered together also, if you are looking at the constraint another constraint on a capacitor bank is, how much energy is there in the capacitor bank.

So, for example, if you have a short term outage you your energy that is there as half c v square might be available to provide for a short term requirement within the power converter. So, this has implications on hold up time of your converter in many d g applications. People are talking about low voltage right through or 0 voltage right through, which means that you need some energies storage capability, which is becoming more and more important in d g applications.

Out of many of these constraints the holdup time thermal current voltage rating many times, when you eventually come up with the design. The thermal affects actually a major factor, which needs to be considered. So, close attention to thermal current would also in co operate the current rating issues and the voltage rating issues, because the current causes ripple the current causes overheating.

So, many times when you get to the detail of the thermal design you are in fact covering many of the other constraints in the design of your capacitor bank. So, then you could ask, if you have say different temperatures, what is the constraint? That, what is causing problems within your capacitors? So, if you look at a typical component say, you are talking about a electrical electrolytic capacitor and any chemical process.

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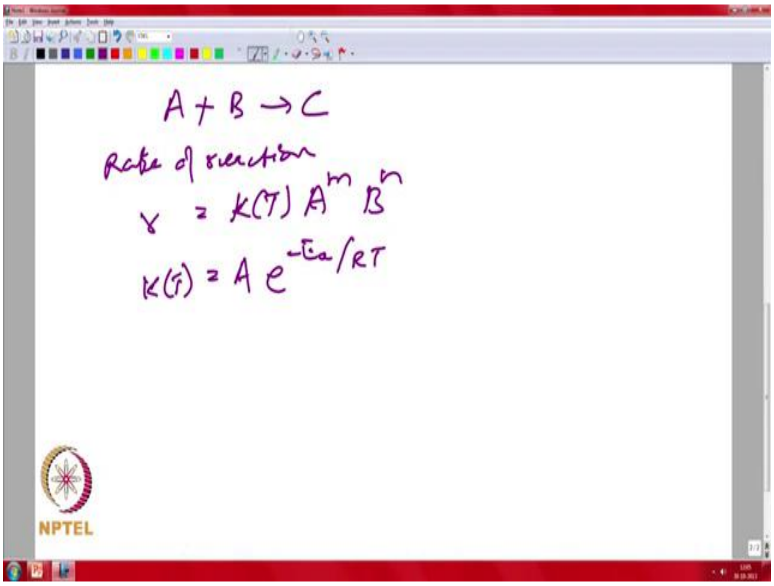

If, you are looking at temperature effects on chemical reactions say, you are having some A plus B reacting to form C. We know that the rate of a reaction can be expressed as some r is dependent on some rate constant K, which is a function of temperature. It is proportional to the concentration of your reactance A and B. These are the things that we have looked at studied in a may be a high school chemistry class. We know that these rate of reaction is actually a function of temperature.

So, if you think about the chemicals within components like the electrolytic material etcetera. They degrade a at a higher rate at a higher temperature and often you are K of T. There is people express it as a rate law some a exponential activation energy gas constant, your Kelvin temperature. So, with factors such as this you can see that at a higher temperature, you end up with a higher rate constant. And often when you look at a many electrical systems a further simplification that people might make is to say that when you are increasing your temperature by say, if 10 degrees.

You might lose your lifetime by a factor of 2. So, these are again simplifications given temperature activation energy, but these can be some simplifications, which give you some insight into, how to actually select a component for a given lifetime or what are the implications of temperature on the operation of a given component?

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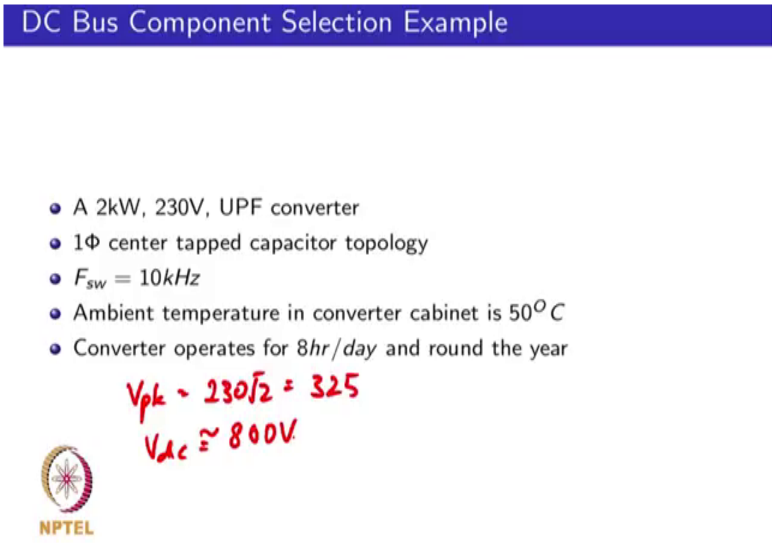

So, with this will look at say a design example of a capacitor bank, and will look at an example of say, a 2 kilo watt per converter single phase center tapped capacitor topology that topology we have been looking at 230 volts. It is operating as a unity power factor converter.

The switching frequency is 10 kilo hertz. Say, it operates at a ambient temperature of 40 degrees and maybe there is temperature rise between your ambient air temperature, and the temperature of your cabinet. This power converter might be sitting in a seal cabinet and your ambient may be 40 your inside cabinet temperature may be 50.

Say, you are operating maybe it is a solar inverter, it might be operating during the day time right hours a day and around the year 365 days, a year and the question is, how could you go about selecting a dc bus capacitor given a simple topology? We have discussed, so one thing that we can start off with is, what would be the voltage? We know that the peak voltage that we are operating is 230 root 2 is 325 volts. And based on the discussion that we had about the additional margin of due to dead band voltage variation, 5 percent voltage variation in the grid, again making assumption of relating to the filter design. We might talk about V d c roughly about 800 volts, and then given that we need 800 volts.

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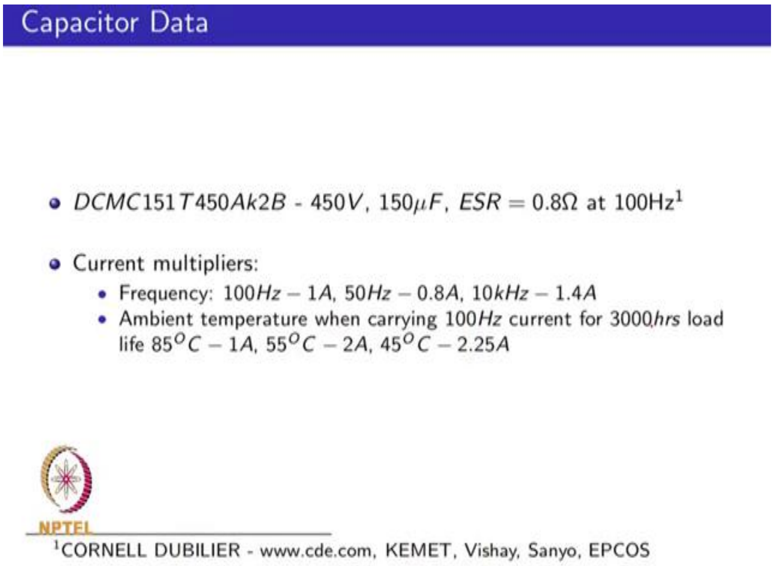

We might select a capacitor, which is may be 450 volts and we go to manufacturer's data sheet and take a look at, what are the ranges of capacitors that are available? And at as a starting point we might say, let us start off with may be a 100 and 50 micro farad 450 volt capacitor, and this I picked off manufacturer. CORNELL DUBILIER c d e dot com, you have many manufacturers came at Vishay, Sanyo, EPCOS. Many of these manufacturers provide data sheets of capacitors on their websites. When I, when you look at the capacitor they provide a values of, what E S R is? There a common frequency that people might specify, might be at your second harmonic, which might be a dominant frequency in such capacitor designs, depending on whether it is 50 hertz 60 hertz.

People might consider different second harmonic frequencies, we will assume second harmonic frequency or 1000 hertz and there is a .8 ohms resistance at E S R resistance at 100 hertz from the data sheet. We also have current multipliers, so the data sheet says that at100 hertz, you are able to carry 1 ampere of current, but at 50 hertz you can carry only .8 amps current at 10 kilo hertz.

You can actually carry 1.4 amps current, so when you are talking about different current levels, which can be carried different frequencies. You are assuming that you get same dissipation. Now, at with these different current levels in the a given capacitor. So, you are talking about the fact that now you are i square r effects because of the current at different frequencies are actually not the same for a given capacitor, also you in the data sheet. It is provided that when the ambient temperature is increased. For example, if it is 85 degree centigrade, I can pass 1 amp of current and expect about 3000 hours of load life in the capacitor, but if I now reduce my ambient temperature to 55.

I can actually carry 2 amps and get the same 3000 amp 3000 hours of life, if I reduce it to 45 degrees, I can pass 2.25 amps and still get the same load life. So, you can see that you, if you are able to reduce your temperature. You can actually get an improved life or on the other way looking at in another way you can actually have higher current capability depending on however you have cooling.

So, the quest, so the first question that you could ask, is this capacitor appropriate for this application from both may be current ripple and voltage ripple perspective, and if it is not appropriate? Then, what it should be may be, should it be 300 micro farads should it be 600, should I put many of them in parallel. How about, how can I go about deciding on what would be a appropriate capacitor to choose. So, the first thing that you can look at is then your current rating.

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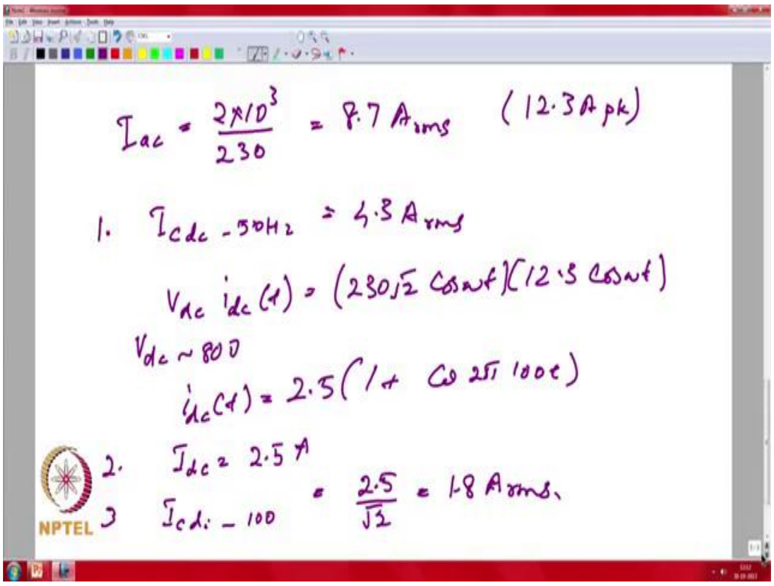

So, you are a c rating for this particular system, you are I ac is a 2 kilo watt system 2 into 10 to the power of 3 and 230 volts nominal. So, you have 8.7 amps r m s or 12.3 amps peak, so the first thing that you could immediately calculate is your 50 hertz component, because it is a center tapped dc bus topology. So, you are i in your C d c at 50 hertz is 4.3

amps. We know, based on your dc bus voltage, we have V d c times I p of t or i d c of t is 230 volts root 2 cos omega t and 12.3 amps peak cos omega t.

We know, your V d c is 800 volts nominal, so we have you are i d c of t to be equal to 2.5 amps 1 plus cos 2 pi 100 t. So, we know your d c current is 2.5 amps and your 100 hertz c a component of your current i c d c 100 is 2.5 amps peak or 2.5 amps by root 2 equals 1.8 amps r m s. So, then, so another thing that we could may be from the design you might start off with a switching frequency of may be 10 kilo hertz that is used in this particular application. So, we would like to calculate, what is the 100 hertz component of your current flowing through the dc bus?

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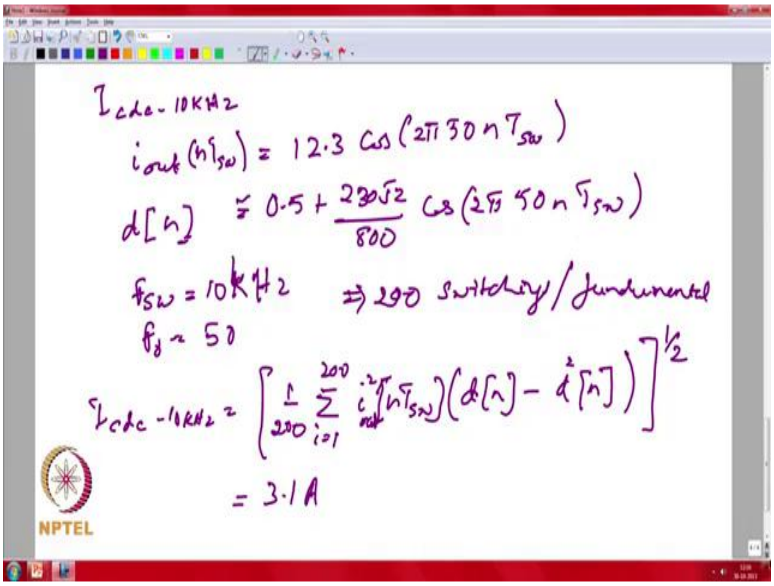

So, to calculate I c d c 10 kilo hertz, you know, you are I out, because it your switching at 10 kilo hertz will consider it as n switching instant. So, 200 switching instance in one fundamental cycle. So, you can think of it as your output current is 12.3 amps cos 2 pi 50 n T s w. So, depending on each switching instant you know what your output current is? Your output current is sin wave, which your trying to control to be a sin wave. You also know, duty cycle again depending on which instant you are operating is given by closed to 0.5 plus 230 root 2 by 100 cos 2 pi 50 n T s w, again this assuming that your ideally ideal grid voltage is reflecting back to your pole voltage.

You might have some small changes in the value because of the voltage drops, because of your filter, but it will not be majorly different. So, you could take this as an approximation and you also know that given f s w switching frequency is 10 kilo hertz and f naught is 50 hertz. So, your there are 200 switching is per fundamental and then you could calculate, what your 10 kilo hertz component is?

So, you are I c d c 110 kilo hertz is 1 by 200 summation i from 1 to 200 i square of n T s w into d of n minus d squares of n the whole thing under root. So, you could evaluate what this quantity is? You know, what your d is? What you are i out is, and you can calculate the current, you end up in this case of for around 3.1 amps.

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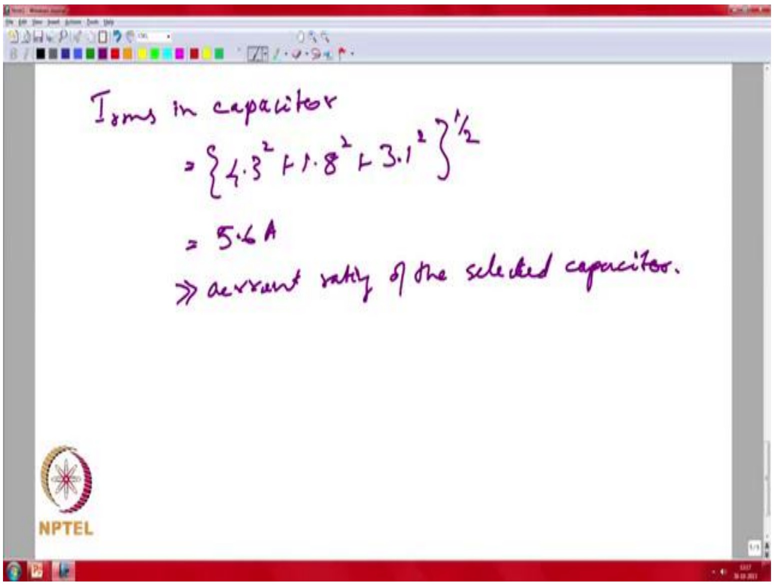

So, if you look at your total r m s current in that flows through your capacitor is now your 50 hertz, 100 hertz and your 10 kilo hertz component. So, I r m s in your capacitor, so we see that there is 5.6 amps and this is much greater than the current rating of the capacitor which was roughly around 1 amp. So, definitely 150 micro farad capacitor that we started off with is not adequate.

So, this is much greater than rating current rating of, so we need a multiple capacitors in parallel. We will also will now take a look at what the, what the E S R implication of having the different current level at the different frequencies mean. So, if you look at the capacitor data.

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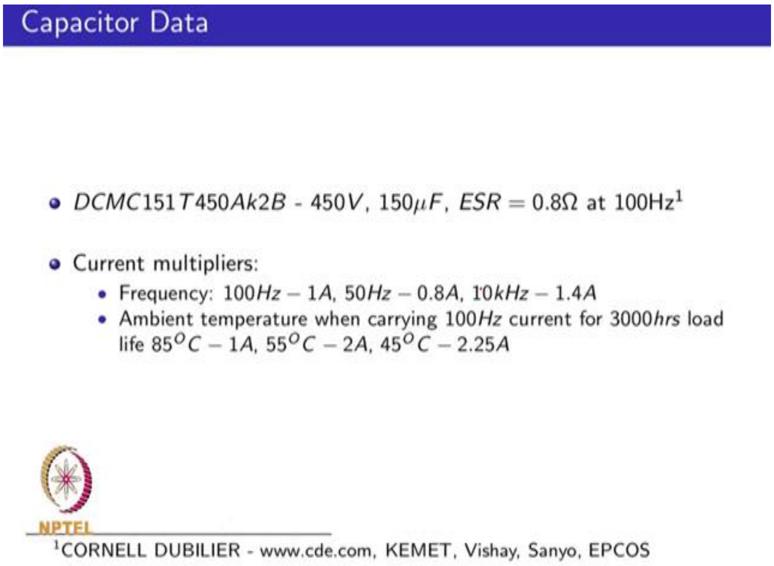

So, the that it can carry 1 amp at 100 hertz 0.8 amps at 50 hertz and 10 at 1.4 amps at a 10 kilo hertz, so if you look at what does that mean..

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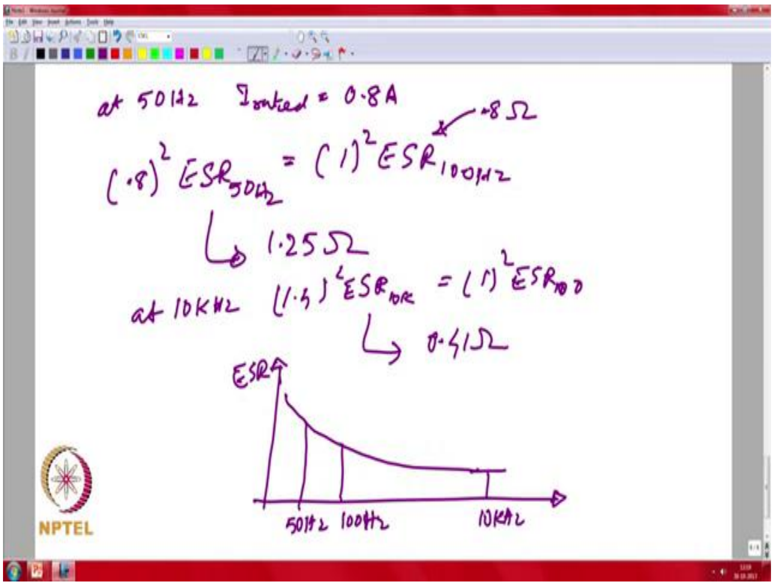

So, at 50 hertz, I rated equals 0.8 amps, so if you look at your 0.8 is your E S R at is your current i square r E S R at 50 would be similar. Now, you are i square r at 100 hertz and we know, at our E S R is at 100 hertz is 0.8 ohms, which was there from your data sheet. So, you know that now your E S R at 150 hertz at 50 hertz is actually 1.25 ohms, so similarly, you can do a calculation at 10 kilo hertz. You know, you are i rated is 1.4 amps, so 1.4 square E S R at 10 kilo hertz.

You can evaluate equate that into 1 square into E S R at 100. So, you get E S R at 10 k to be 0.241 ohms, so in a 8 giving your current multiplier at different frequencies is giving, you the same information is E S R as a function of frequency. So, me manufacturers might actually give you a plot of E S R at different frequencies. So, you in this case you might have a plot that looks like this where E S R is reducing with frequency, so you had 50 hertz. You have some value at 100 hertz and some value at 10 kilo hertz, so the other parameters.

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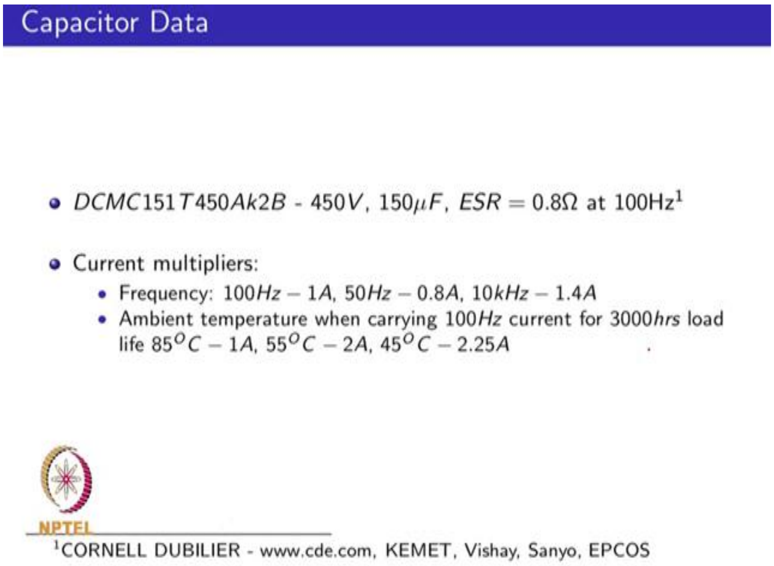

That we can actually look at the form the temperature multipliers that we are provided to us is that, we were told that at for 3000 hours of life you at 85, you have 1 amp at 55 degrees ambient for the same life; you can carried 2 amps etcetera. Now, with that information we can actually calculate, what is the thermal impedance between the core of your capacitor and you are ambient, and also what is the actual core temperature at which this particular number is being specified.

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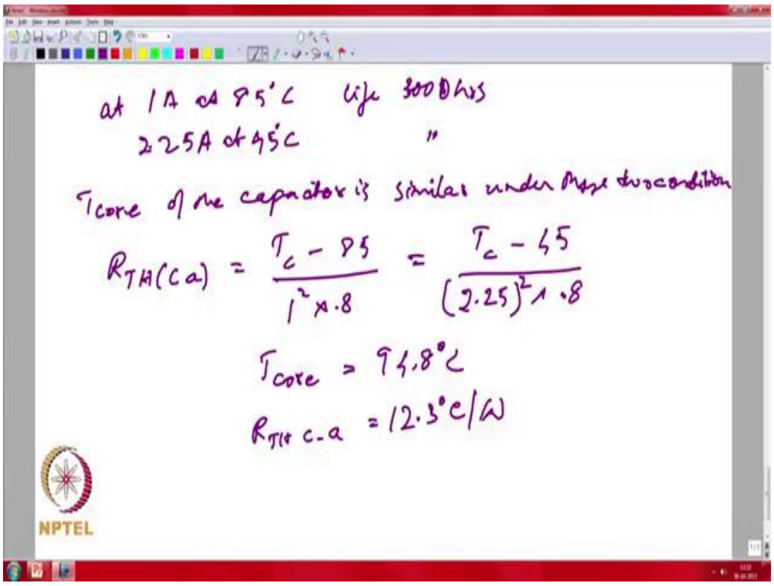

So, if you look at the number, at 1 amp at 85 degree centigrade, your life is 3000 hours and 2.25 amps at 45 degree centigrade you have the same life. So, your T core of the capacitor is similar under these two conditions, because the degradation within the capacitor happening at the same temperature, because it results in similar lifetimes. So, if you look at your thermal impedance are thermal between your core of your capacitor and your ambient. So, you have T core minus 85 by your participation is 1 square into 0.8 ohms, which is your E S R is equal to T core minus 45.

Now, you can carry actually instead of 1 amp 2.25 amps into again the resistances still 0.8 ohms it implies that you can solve for, what your T core is? So, the T core that is probably being used by this particular manufacturer is 94.8 degree centigrade. The thermal impedance under the measured condition your R T H from your core of your to get a capacitor to your ambient is about now, 12.3 degree centigrade per watt dissipation in the capacitor. Now, you based on the current, currents at we know is that are flowing through the capacitor, you could then say, what is a equivalent 100 hertz? Current that might be flowing in the application that we are considering.

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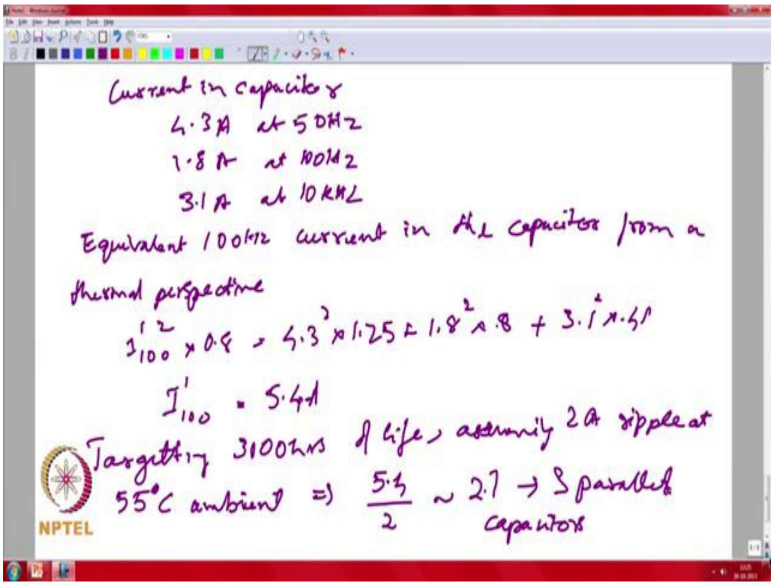

So, the currents in the capacitor is 4.3 amps at 50 hertz, 1.8 amps at 100 hertz and 3.1 amps at 10 kilo hertz, so equivalent 100 hertz current 100 hertz current in the capacitor from a thermal perspective. So, in terms of what gives the same in temperature rise. In your capacitor is say some i prime square 100 into 0.8 is 4.3 square into 1.25 plus 1.8 square into 0.8, which is a E S R 800 hertz plus 3.1 square into 0.41, which is the E S R a 10 kilo hertz. So, you are talking about i prime 100, we are talking of something like 4.5.4 amps and if you want to say, target in your application 3000 hours roughly 3000 hours of life. And we know that 2 amps of ripple can flow, if your ambient temperature is 55 degrees, which is the multiplier, given to you at 55 degrees.

So, targeting 3000 hours of life, assuming 2 amps ripple at say 55 degrees, because your cabinet temperature is 50 degrees not too far away from 55 ambient. So, one would need about 5.4 amps divided by 2 amps, so you are talking of 2.7 capacitors round it off to 3. So, you need a roughly 3 capacitors in parallel, so instead of 150 may be you selecting a 450 micro farad capacitor, might be a good starting point. So, then you could ask now, if you take 3 capacitors in parallel, what would be the power dissipation in each of these 3 capacitors? That you are going to put in parallel.

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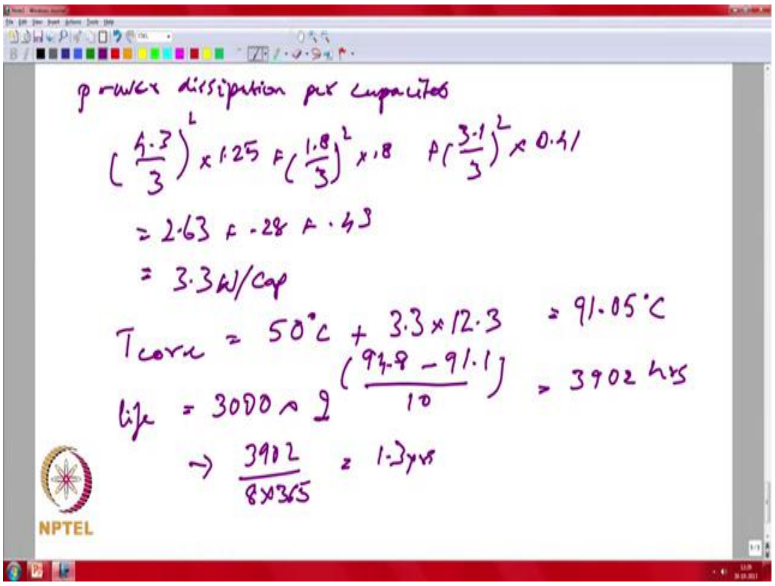

so the power dissipation per capacitor in this parallel combination of 3 banks is 4.3 divided by 3 squares into 1.25 plus 1.8 divided by 3 squares into 0.8 plus 3.1 by 3 square into 0.41. So, you have 2.63 watts plus 0.28 watts plus 0.43 watts. So, you have about 3.3 watts dissipation per capacitor in the parallel combination of 3 capacitors and then you could immediately say, what your core temperature is given that your cabinet is sitting at 15 degree centigrade?

So, your core temperature in this particular case would be your 15 degrees, which is your inside cabinet ambient temperatures, given for your application plus 3.3 watts participation per capacitor. We know, at your thermal impedance from ambient to core which is 12.3 watt degree centigrade per watt. So, your actual core temperature, if you use say 3 capacitors in parallel be about 91.1 degree centigrade. Then, you could actually calculate, what would be the lifetime of this particular 3 bank of 3 capacitors. We know, life is approximately 3000 hours for your nominal core temperature.

So, it is 3000 hours into will again use a simplifying assumption of decrease in life by a factor of 2 for 10 degree temperature rise. So, it is 2 to the power of 94.8, which is your nominal specified temperature at which we made those specification being made your actual temperature is 91.05 divided by 10 to reflect the factor of 10 change having a multiplying a factor of 2. So, you are talking about now 3900 hours of operation of this particular bank. And then if you look at what it is in terms of 8 hours per day 65 days per year, so this implies 3902 divided by 8 into 365. So, you are talking about 1.3 years is what you could roughly expect from this bank. Then, you could ask, what is the power dissipation in this bank?

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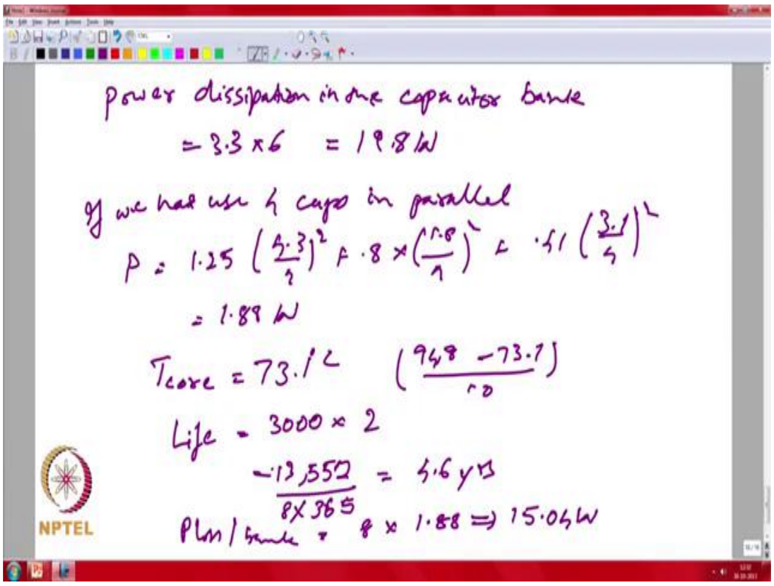

You have 3 capacitors on top 3 capacitors at the bottom and the power dissipation in the capacitor bank is 3.3 watts per capacitor into 6 capacitors. So, there is about 19.8 watts of dissipation happening in this particular capacitor bank. So, you can see that you now have a way of linking a the selection of the capacitor to your current ripple. I mean there are many other things that we need to calculate that voltage ripple, but we could start off with some simple design tradeoffs, what say may be a basic question could be instead of, why we did select 3 capacitors in parallel; we could have put 4 in parallel.

So, what would be the implication of putting 4 capacitors in parallel rather than 3? So, if you do your power calculation for 4 capacitors in parallel, your participation per capacitor is 1.25 into 4.3 by 4 squares, so in instead of 3.3 watts per capacitor. Now, you get 1.88 watts per capacitor, so your power dissipation has come down, because your gone to larger number of capacitors. Your core temperature now comes down from the 91 to about 73, and your life now comes goes up.

So, it is 3000 hours into 2 to the power of 94. 8 minus 73.1 by 10. So, you are talking about 13500 hours by 8 into 365. So, you are talking about 4.6 years rather than the 1.5 1.6 years that we previously looked at when you had 3 capacitors. So, you can see that your lifetime has increased, because now you are able to bring down the temperature. You could now circulate your power loss in your capacitor bank when you use 4 in parallel is now 8 capacitors dissipating 1.88 watts.

So, this is 15.04 watts, so previously you had 19 watts, when you had 3 capacitors is come down to 15 watts, when you are putting 4 capacitors. So, you can see that you have now a framework, where you could address the, what is the effective initial cost of selecting a single component does the capacitor because between 3 and 4 capacitors. You know, what the cost difference is you will have a way of evaluating your operational maintenance life, and you have a way of looking at your net percent value of power loss, which is going to be happening in your capacitor bank.

So, a framework where you can actually do a such an evaluation on a per component bases of each component that goes into a power converter, can actually? Then, be rolled together to do a overall design of your bigger system or your overall power conversion power conversion system.

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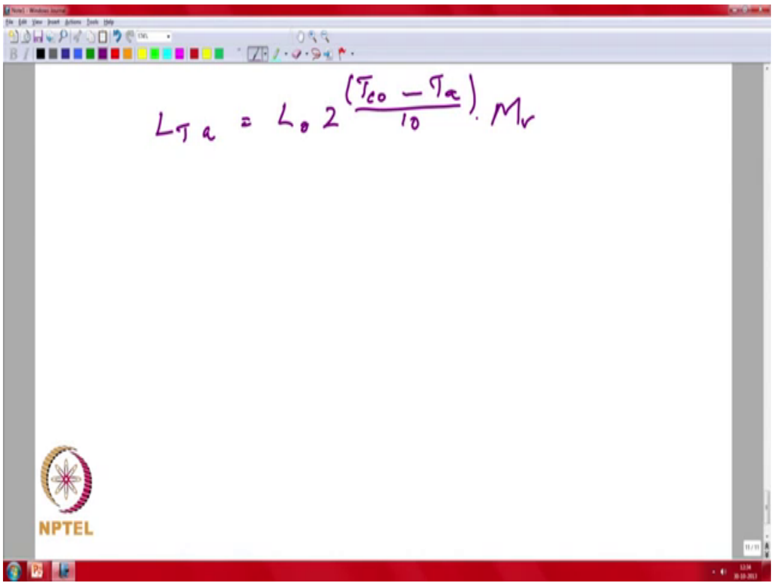

So, if you look at again the factors that we looked at in the life calculation of this capacitor. We had essentially your life at a given temperature, where is related to some nominal operating life given by a manufacturers. You sing a simplistic assumption of 2 degrees per differ, I mean factor of 2 in life for 10 degrees change.

So, you have a t core minus t actual by 10 degrees into you also have a multiplying factor based on your voltage. Suppose, you have a dc bus capacitor bank rated at 415 volts, and you are using it very closed to 215 volts. Then, your you have a factor, which imply effects on your life because you are operating very closed to the rated voltage as you bring down your voltage of your capacitor. You can have some small improvement in your life. So, you could in cooperative factors that address different issues like temperature margin. Your thermal margins etcetera as we have just calculated and just for simplicity may be you could take your voltage factor to be roughly 1.

As long as you are ensuring that your voltage does not exceed your rated voltage during operation of your power converter. So, you can see that with this you could also ask a question, what does it mean by having a capacitor, which is going to last 4 years of 4.6 years or whatever number?

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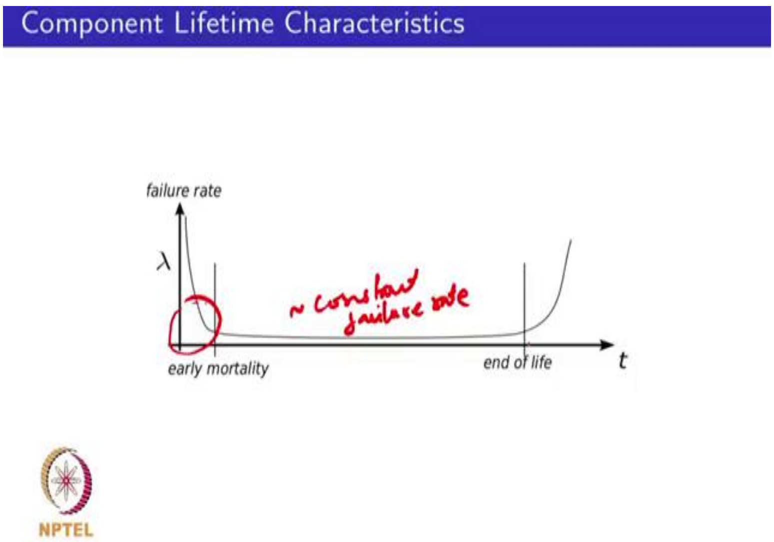

You have evaluated and that typically is reflected in terms of what is the failure rate of a typical component? People talk about mean time between failures of a component failure rate or when you look at a typical component essentially at the point that which it is initially builds. You might have large failure rates, you might do some initial tests within your factory to ensure that some initial tolerance, which is not being met in the component does not get shift out of your factory. So, you might do some initial tests to ensure that you do not see what people talk about early mortality or in fin mortality of your components in your power conversion systems..

So, once you pass your qualification test within your factory, whatever gets shifted out has fairly low roughly constant failure rates. It is not that the failure goes to 0, it might be a you might have a random failure depending on, what a parameters? The complexity of your component etcetera is, but you would have a low roughly constant failure rate.

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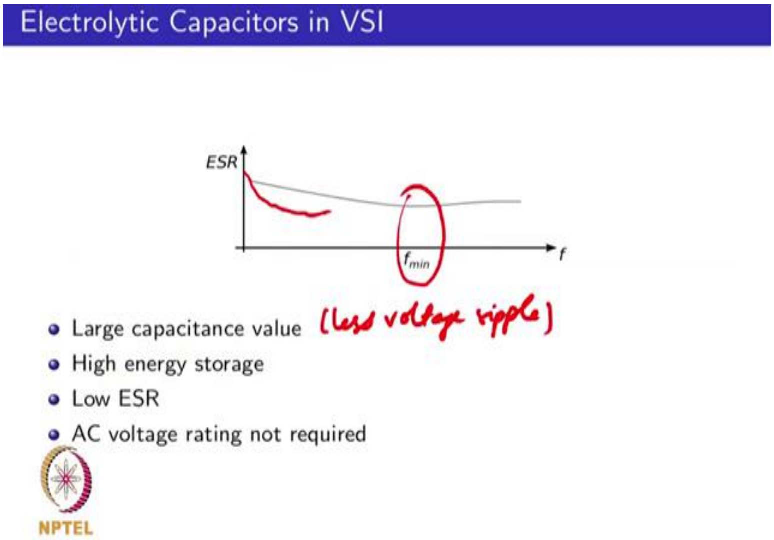

So, after a while, you start the failure rates, starts picking up it no longer states that a no value, it was because of operation, because of the usage of your component you might end a reach a end of life value at which point your failure rates starts increasing. So, in the case of a capacitor, what would want considered to be a end of life? So, your physical capacitance value might actually change with time. Your leakage current in your capacitor might change with time after a long time; your leakage start current through the capacitor might suddenly start increasing or if you look at your E S R of your capacitor.

Initially you might have a E S R of 0.8 ohms, but after some 5 or 6 years you again measure the E S R of the component, it may not stay the same 0.8 ohms, it might increase to a different value. So, manufacturers have different specifications of, what it means for a common to be reaching end of life. In case of say, a capacitor common specification might be the E S R ages up by a factor of 2 at the end of life. So, if a E S R goes up by a factor of 2, given the same r m s current that is flowing through the capacitor, it means that now your participation has doubled, which means that again your temperature is going to accelerate up.

So, your degradation is going to now become more and more rapid at the end of the life you are quite quickly going to reach a point where you might end up with a failure of the device. So, you can see that it is possible to actually look link the operation of the components to the operational life and try to incorporate these factors in a design. We have still to consider, what is the impact of looking at? The voltage ripple, because we have looked at the current ripple. So, we also have to look at the voltage ripple to see whether the capacitors election would be adequate for, a for the design.

Thank you.