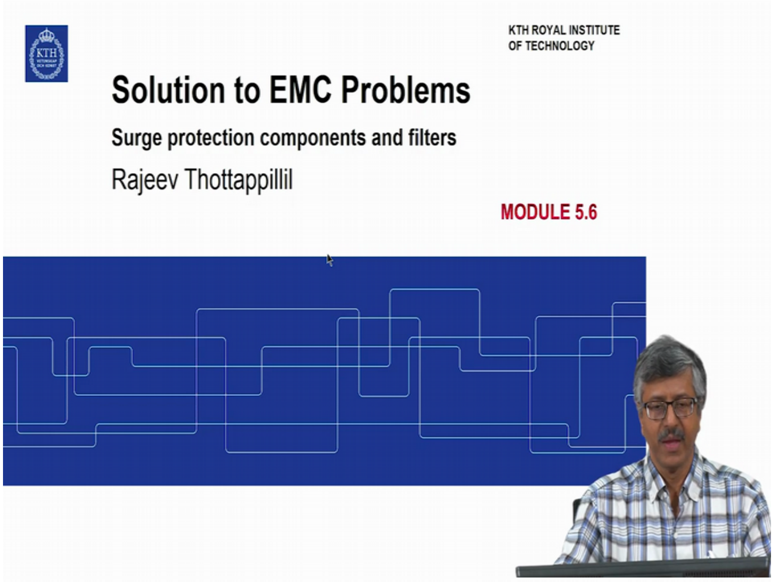
Electromagnetic compatibility, EMC
Prof. Rajeev Thottapillil
KTH Royal Institute of Technology
Module 5.6 Solution to EMC Problems
Surge protection components and filters

(Refer Slide Time: 0:20)



KTH ROYAL INSTITUTE
OF TECHNOLOGY

Solution to EMC Problems

Surge protection components and filters

Rajeev Thottappillil

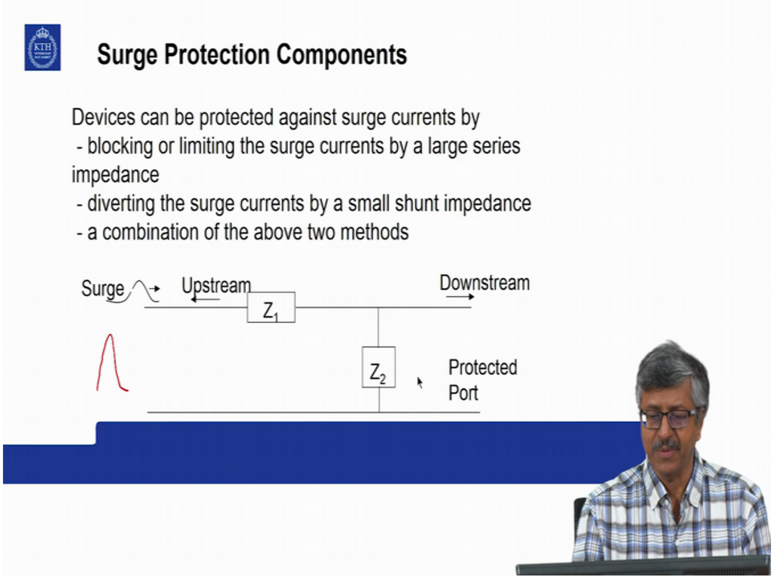
MODULE 5.6

Surge Protection Components and filters

- Gas DischargeTubes (Spark gaps)
- Varistors
- diodes
- filters

Solution to EMC problems, surge protection components and filters, module 5.6, so here we will describe gas discharge tubes, varistors, diodes and filters some very basic information will be covered for more details you can refer to other literature.

(Refer Slide Time: 0:48)



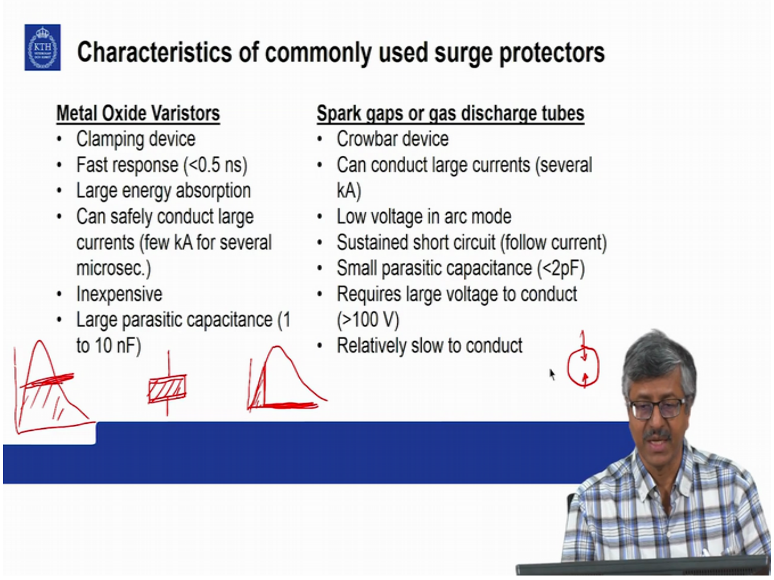
Surge Protection Components

Devices can be protected against surge currents by
- blocking or limiting the surge currents by a large series impedance
- diverting the surge currents by a small shunt impedance
- a combination of the above two methods

So devices can be protected against surge currents either by blocking or limiting the surge currents by a large series impedance or by diverting the surge currents by a small surge impedance or one can use a combination of both methods, so while discussing the high-frequency behaviour of components we have seen already some components suitable for blocking or diverting, say for example if you have capacitance we have seen that capacitance can have very low impedance at high-frequency.

So what are the characteristics of a surge? A surge will have a characteristic in which the price time of the wave is very high, so you have large frequency content in it, large frequency content will be diverted through the capacitance and if you connect a inductor in series it will block, it will produce a high impedance for this highly varying transient, so inductor can be a blocking device and capacitor can be a surge device, of course and filters you are using a combination of both but in addition to that there are some other devices also.

(Refer Slide Time: 2:49)



Characteristics of commonly used surge protectors

Metal Oxide Varistors
- Clamping device
- Fast response (<0.5 ns)
- Large energy absorption
- Can safely conduct large currents (few kA for several microsec.)
- Inexpensive
- Large parasitic capacitance (1 to 10 nF)

Spark gaps or gas discharge tubes
- Crowbar device
- Can conduct large currents (several kA)
- Low voltage in arc mode
- Sustained short circuit (follow current)
- Small parasitic capacitance (<2pF)
- Requires large voltage to conduct (>100 V)
- Relatively slow to conduct

So there are metal oxide varistors, and it is a special type of material with special no linear characteristics, inductance and capacitors are linear, are having linear characteristics, their frequency dependent their impedance but they are not dependent upon the magnitude of the current or voltage for their operation, so there are linear devices where metal oxide varistors and spark gaps are no linear devices because their characteristics are affected by the amplitude of the surge.

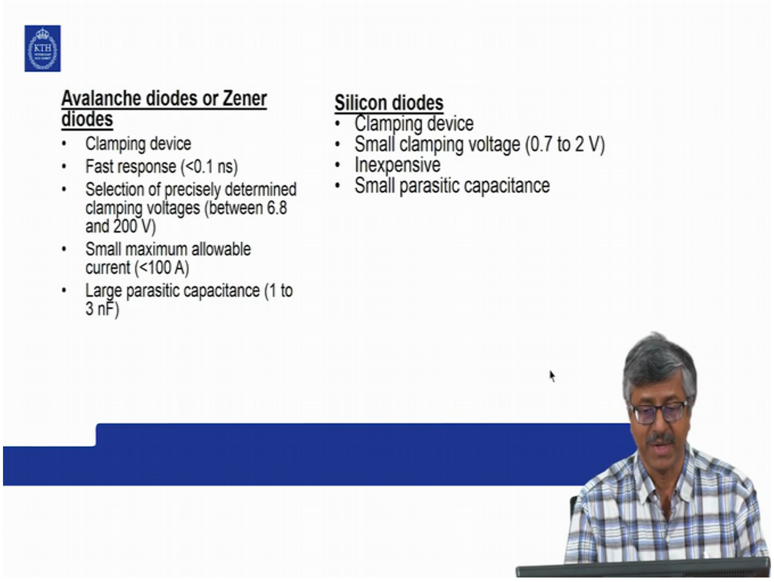
So metal oxide varistors we will describe what it is but some of the basic characteristics of those device are listed out here, so they are often called a clamping device because it clamps, so if you have a surge like this, let us say a clamping device will clamp the voltage to a certain level and we not allowed to increase about that value, now spark gaps or gas discharge tubes is more like a crowbar device, it is like putting a crowbar across two wires and kind of short-circuiting, so it means that when this is operating then suddenly the imburse comes to 0 level or to very low value then after that is only this you will be coming.

So here it will be this that is the residual value, so operation there are very different then this has got very fast response in metal oxide varistors less than 0.5 ns also it can respond and large energy absorption capacity is there, safely conduct large currents, you few kiloampere for several microsecond, it is not very expensive but due to the weight is constructed it has got large parasitic capacitance, offered it is in the form of some sort of a disk, so these large area, surface area like two electrons over here, so this will introduce large parasitic capacitance, so 1 to 10 nF.

Whereas spark gaps can conduct even larger currents, several kiloampere but it will have low voltage in the arc mode, so this is the arc mode and here the voltage is very low, so it means that even after the disappearance of the surge the current will be shunted out and that would serious strain on other equipments, sustained short-circuit that is follow current and small parasitic capacitance it is more like two metal electrodes in a tube, so you have a very less surface area and you have very small parasitic capacitance, however for this to breakdown you required a large voltage to conduct.

Whereas metal oxide varistors can be design even for very small voltages and this is relatively slow to conduct, so this are the differences between metal oxide varistors and gas discharge tubes.

(Refer Slide Time: 7:02)



Avalanche diodes or Zener diodes

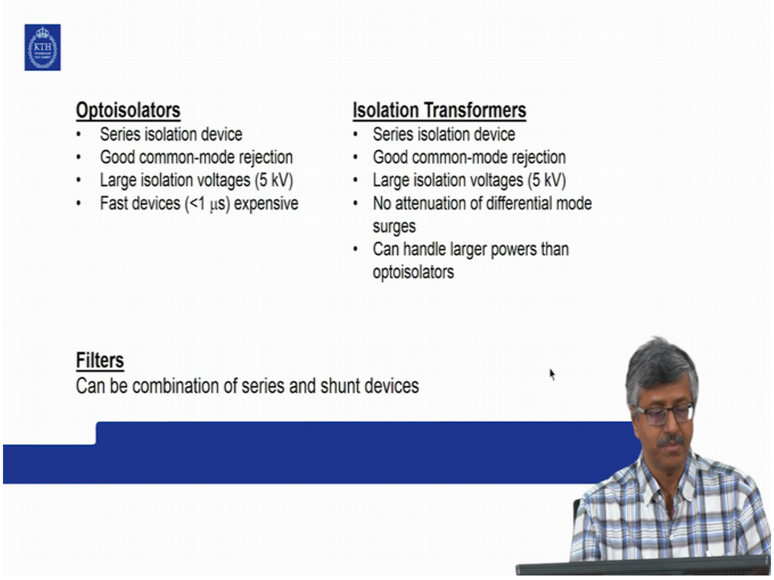
- Clamping device
- Fast response (<0.1 ns)
- Selection of precisely determined clamping voltages (between 6.8 and 200 V)
- Small maximum allowable current (<100 A)
- Large parasitic capacitance (1 to 3 nF)

Silicon diodes

- Clamping device
- Small clamping voltage (0.7 to 2 V)
- Inexpensive
- Small parasitic capacitance

Another devices basically a diode avalanche diodes or zener diodes, so they also are clamping device like metal oxide varistors but much less in power and voltage rating and the parasitic capacitance is large like varistors, silicon diodes is another one clamping device again very low, clamping voltage you can get, it is inexpensive and small parasitic capacitance.

(Refer Slide Time: 7:38)



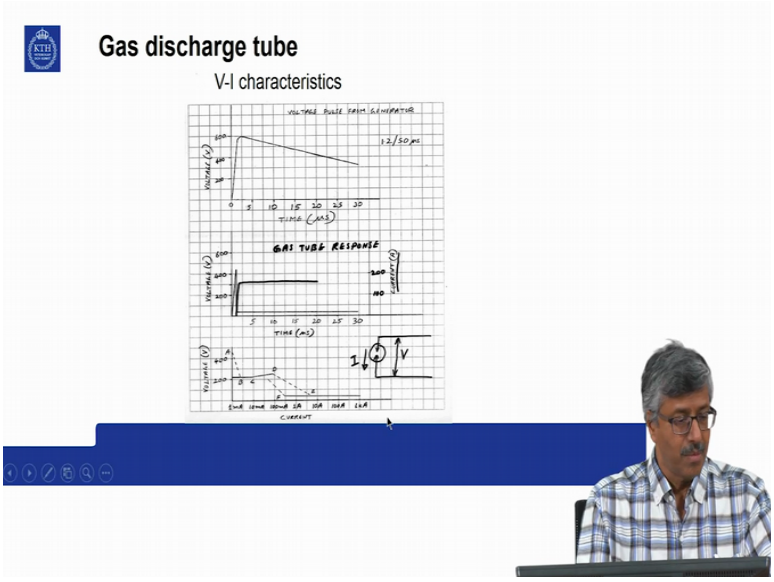
Optoisolators
- Series isolation device
- Good common-mode rejection
- Large isolation voltages (5 kV)
- Fast devices (<1 μs) expensive

Isolation Transformers
- Series isolation device
- Good common-mode rejection
- Large isolation voltages (5 kV)
- No attenuation of differential mode surges
- Can handle larger powers than optoisolators

Filters
Can be combination of series and shunt devices

In addition you have optoisolators for, you know for some signal transmissions and all where optoisolators scan be used and isolation transformers are generally using high-voltage labs and other EMC measurements, so this series isolation devices, so these are not really surge protectors there are more isolation devices rather, filters can be combination of series or shunt devices and you can even introduce small linear devices to a filter.

(Refer Slide Time: 8:32)



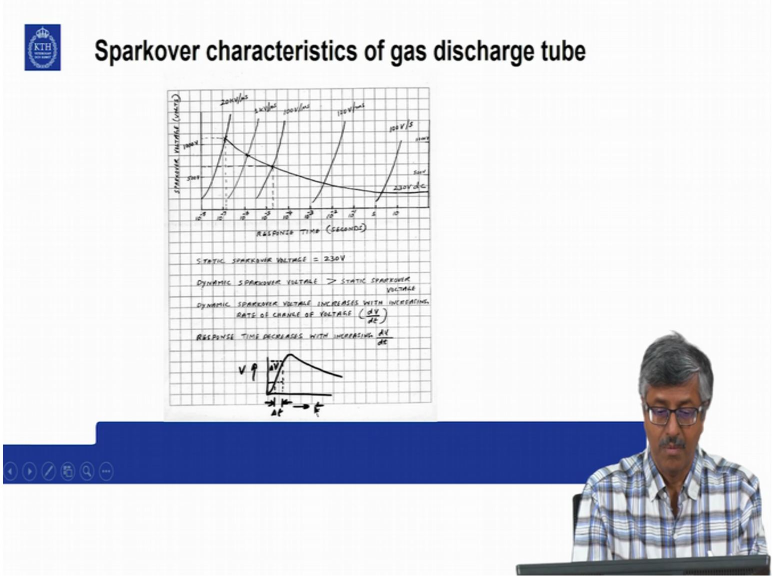
Gas discharge tube

V-I characteristics

Let us look at the V-I characteristics of gas discharge tubes, so the picture here shows that, so this is the basic surge let us take the 1.2 μs rise time by 50 μs for time come, this the voltage and this is the time, now is the voltage reaches certain level suddenly gas discharge tube will conduct, it goes down and reach the breakdown or arc sustaining value, so this is the arc voltage and at this point a current will be initiated and that current rises up and it is shown over here.

So this current is quite large, then for the gas discharge tube to turn of either this current has two below certain threshold value for it to goes up, so this is the voltage current characteristics of a gas discharge tube, what is the here and it is a representation of the same effect as per some other choice of axis that is voltage and current.

(Refer Slide Time: 10:18)



Sparkover characteristics of gas discharge tube

STATIC SPARKOVER VOLTAGE = 230V

DYNAMIC SPARKOVER VOLTAGE > STATIC SPARKOVER VOLTAGE

DYNAMIC SPARKOVER VOLTAGE INCREASES WITH INCREASING RATE OF CHANGE OF VOLTAGE $\left(\frac{dV}{dt}\right)$

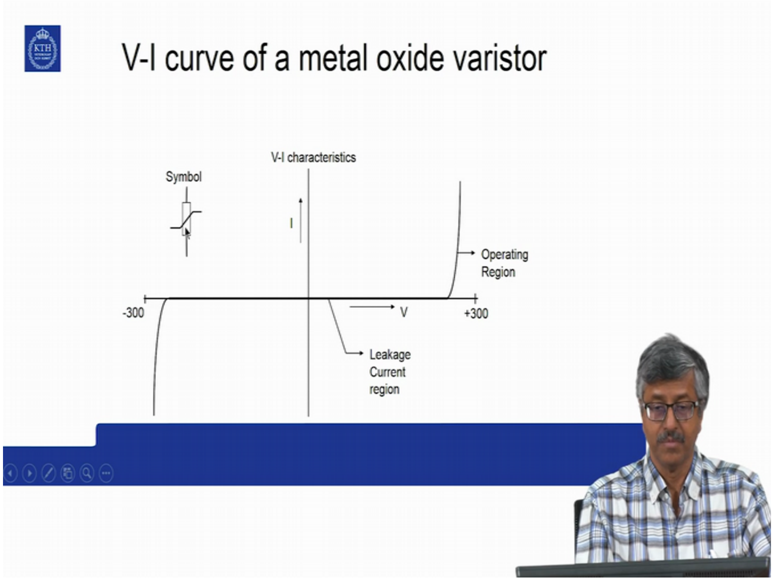
RESPONSE TIME DECREASES WITH INCREASING $\frac{dV}{dt}$

Sparkover characteristics of gas discharge tube, the time of operation were gas discharge tube varies with the rate of rise of the transient, so it is not constant time required for the operation, similarly the level at which the tube conducts is also different that depends upon the rate of rise, so gas discharge tube are often ceramic and metallic tubes in the presence of inner gas or summer gas like that, so this is the response time in seconds, so this is 10 seconds and this is 10 power -8 seconds and this is it of rise of the voltage and sparkover characteristic is like that.

So far near DC sparkover you need a long time for gas discharge tube is subjected to this DC voltage, so if it is a slowly rising waveform, it will take less time but it is at higher voltage, similarly 100 moles per mile second only a fraction of a microsecond is required as response time but a response happens at much higher voltage, similarly it goes so starting sparkover voltage is 230 V and dynamic sparkover voltage is greater than statics sparkover voltage.

Dynamic sparkover voltage increases with increasing rate of change of voltage that is DV by DT, the response time decreases with increasing DV by DT, so this are the references you can get from this picture.

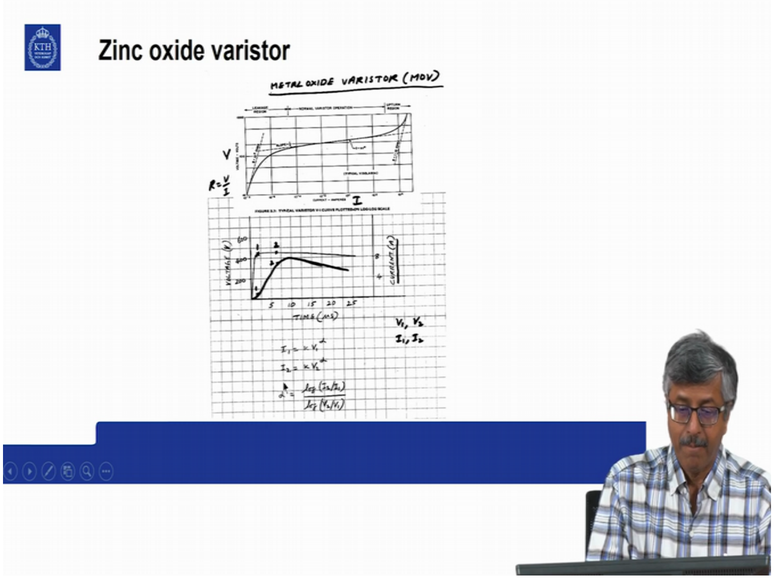
(Refer Slide Time: 12:46)



V-I curve of a metal oxide varistor

V-I curve of a metal oxide varistor, so this is the no linear, this is the operating region and some leakage current region and this the symbol of the varistor.

(Refer Slide Time: 13:12)



Zinc oxide varistor

METAL OXIDE VARISTOR (MOV)

$R = \frac{V}{I}$

V_1, V_2

I_1, I_2

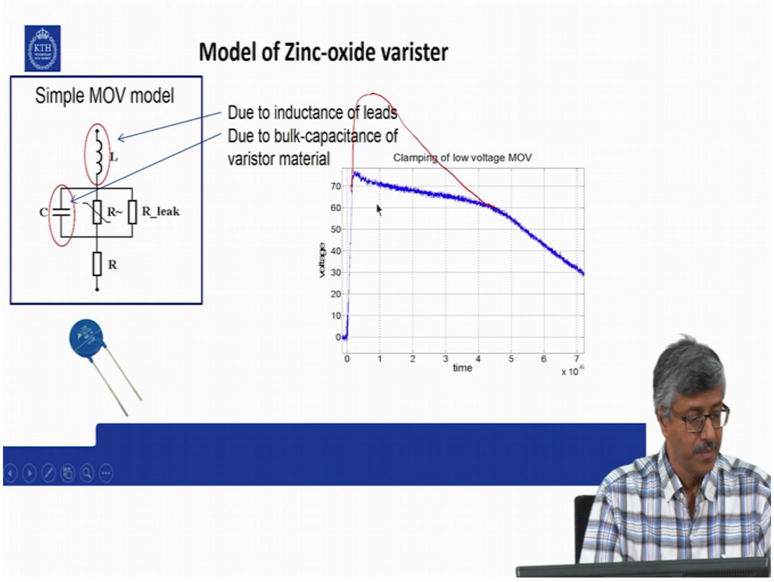
$I_1 = k V_1^{\alpha}$

$I_2 = k V_2^{\alpha}$

$\alpha = \frac{\log(I_2/I_1)}{\log(V_2/V_1)}$

So we can have a current versus voltage waveform for this also, so in time domain you can represent it like this, say for example this is suppose your surge is going up like this then varistor is operating, so it is clamping at this value and this is the current through the varistor, so you can take two operating points, 1 and 2, so I1 is KV 1 to the power of alpha and I2 is KV2 to the power of alpha, that alpha is log of I2 by I1 divided by log of V2 by V1.

(Refer Slide Time: 14:23)



Model of Zinc-oxide varister

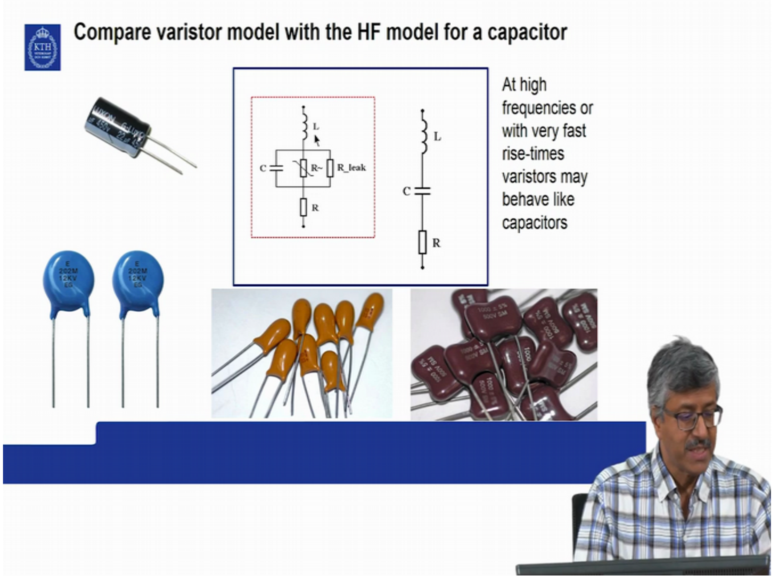
Simple MOV model

Due to inductance of leads

Due to bulk-capacitance of varistor material

Metal oxide varistors can be modelled, so suppose this is the ideal no linear part of the varistor due to the leads of the varistor, you have inductance and bulk capacitance also it was varistor and that is this bulk capacitance and bulk leakage resistance R leak, so this is the clamping voltage, the actual voltage would have been like this, it would have been going like this and coming like that or something like this, so it is getting clamped introduced.

(Refer Slide Time: 15:26)

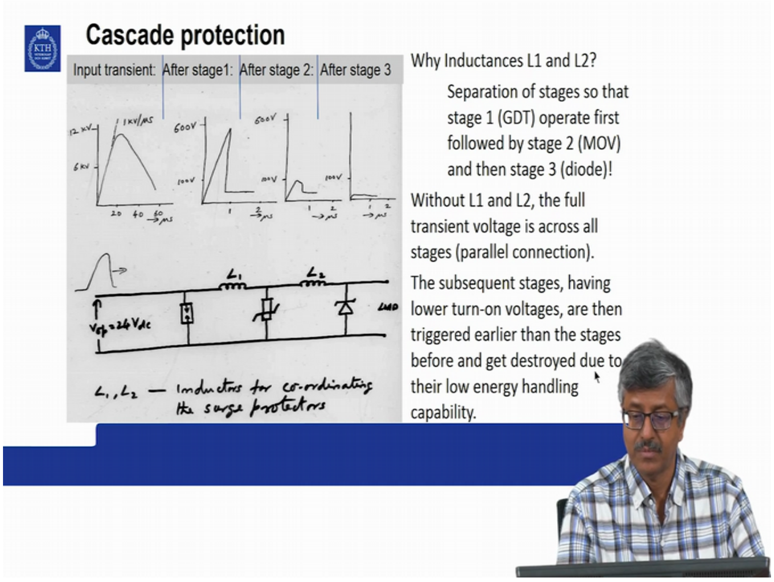


Compare varistor model with the HF model for a capacitor

At high frequencies or with very fast rise-times varistors may behave like capacitors

Now the varistor model and the high-frequency model of a capacitor are quite similar even though there are some differences, so at high-frequencies with very fast rise times varistors may behave like capacitors also because of that, because this no linear at memory where with large voltage to be impressed across it but during high-frequencies lot of voltage drop can happen in the inductor itself.

(Refer Slide Time: 16:14)



Cascade protection

Input transient: After stage1: After stage 2: After stage 3

Why Inductances L1 and L2?

Separation of stages so that stage 1 (GDT) operate first followed by stage 2 (MOV) and then stage 3 (diode)!

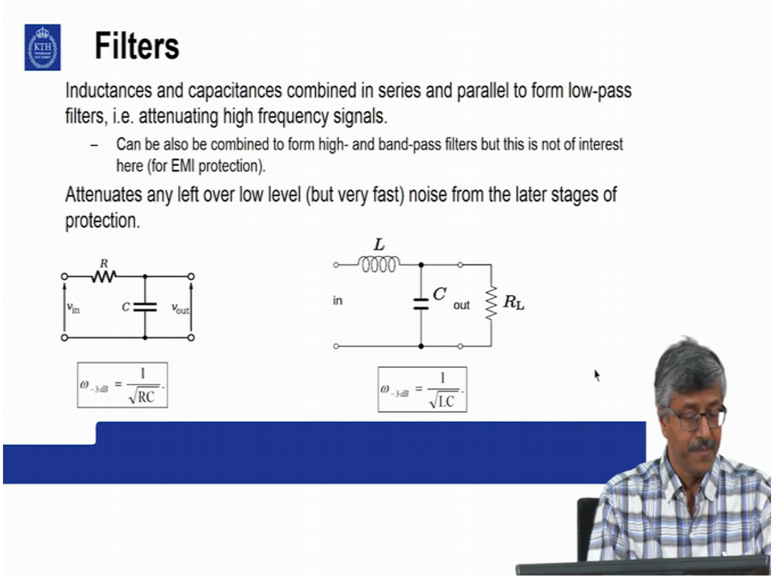
Without L1 and L2, the full transient voltage is across all stages (parallel connection).

The subsequent stages, having lower turn-on voltages, are then triggered earlier than the stages before and get destroyed due to their low energy handling capability.

So we will show one example of that, now here cascade protection often you use several stages for protection so that at each stage you are reducing the transient from the previous stage, for example if this is your input transient you have a spark gap then after this stage 1, the current is the voltage transient is of this form, the clamping by spark gap when you have a MOV, so that is clamping the voltage then after that you have a divert clamping the voltage, so you get very low values over here, so in between you have inductance for coordinating the surge protectors.

So you require this because when a surge is coming you want first this to operate right, you are spark gap to operate, so that maximum energy is bypassed, if it failed to operate and the surge is coming directly onto this diode already equipment can happen, so that is the reason why to make sure that this is operating first, you have this inductance.

(Refer Slide Time: 18:15)



Filters

Inductances and capacitances combined in series and parallel to form low-pass filters, i.e. attenuating high frequency signals.

- Can be also be combined to form high- and band-pass filters but this is not of interest here (for EMI protection).

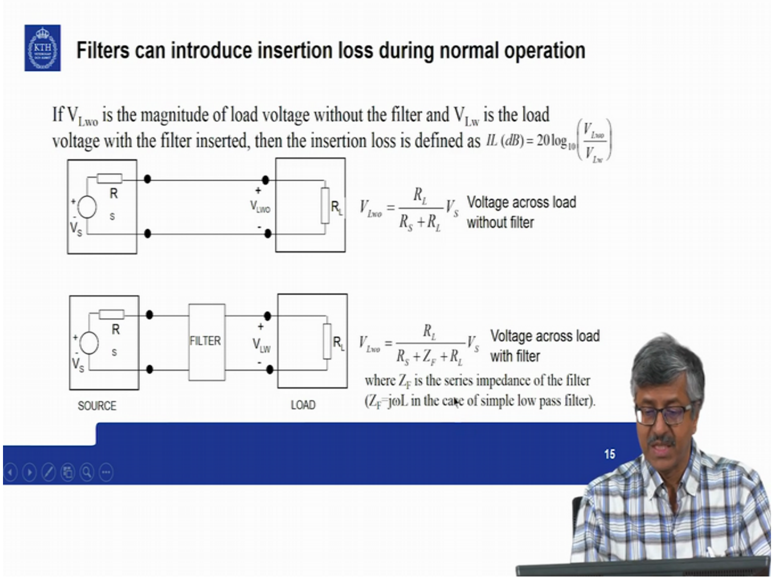
Attenuates any left over low level (but very fast) noise from the later stages of protection.

$$\omega_{-3dB} = \frac{1}{\sqrt{RC}}.$$

$$\omega_{-3dB} = \frac{1}{\sqrt{LC}}.$$

Now filters as I said before often inductance and capacitors can be combined in series and parallel to for low pass filters that is attenuating high-frequency signals, so filters can be used to attenuates any leftover low-level but very fast noise from the last stages of protection, so passive filters frequency selective devices, so you can just we will higher frequencies from the repairing current after the surger stage and cleanup the signal in the output, so in RC network is shown here as a filter and LC network is shown here as a filter.

(Refer Slide Time: 19:29)



Filters can introduce insertion loss during normal operation

If V_{Lwo} is the magnitude of load voltage without the filter and V_{Lw} is the load voltage with the filter inserted, then the insertion loss is defined as $IL\,(dB) = 20\log_{10}\left(\frac{V_{Lwo}}{V_{Lw}}\right)$

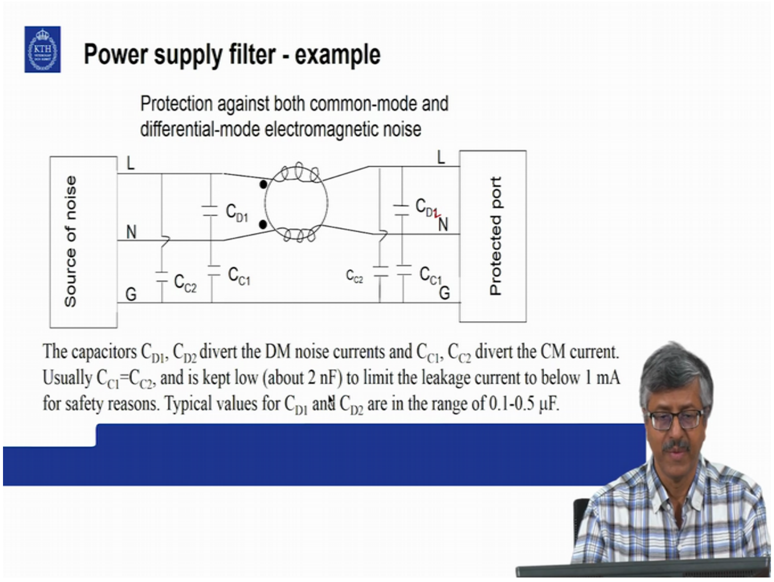
$$V_{Lwo} = \frac{R_L}{R_S + R_L} V_S$$ Voltage across load without filter

$$V_{Lwo} = \frac{R_L}{R_S + Z_F + R_L} V_S$$ Voltage across load with filter

where Z_F is the series impedance of the filter (Z_F=jωL in the case of simple low pass filter).

One drawback of filter is that it can introduce insertion loss even during the normal operation, for example if this the magnitude of the load voltage without filter and VLW is the load voltage with filter inserted, then the insertion loss is defined as 20 log VLW or by VLW that is given by this and with the filter, with the impedance of ZF the voltage across load with filter is given by this, so is the series impedance of the filter.

(Refer Slide Time: 20:26)



Power supply filter - example

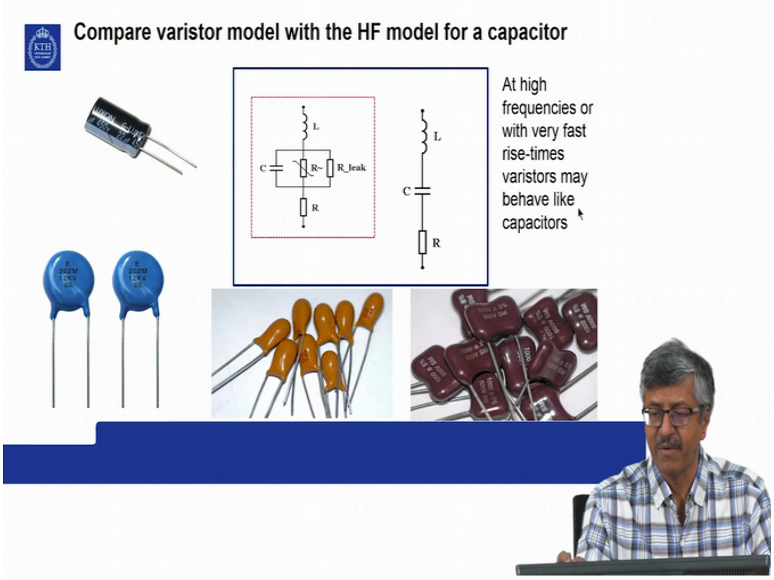
Protection against both common-mode and differential-mode electromagnetic noise

The capacitors C_{D1}, C_{D2} divert the DM noise currents and C_{C1}, C_{C2} divert the CM current. Usually C_{C1}=C_{C2}, and is kept low (about 2 nF) to limit the leakage current to below 1 mA for safety reasons. Typical values for C_{D1} and C_{D2} are in the range of 0.1-0.5 µF.

Another example of a filter is a power supply, this gives protection against both common mode and differential mode electromagnetic noise, so one example is shown here, so L line neutral and ground, so you have a choke over here, let us say this the protected port, you have capacitance across all the lines, now CD1 and CD2 and this is CD2 and CC1 and CC2, CC1 and CC2, so this divert common mode, CD1 and CD2 divert the DM mode current that is differential mode.

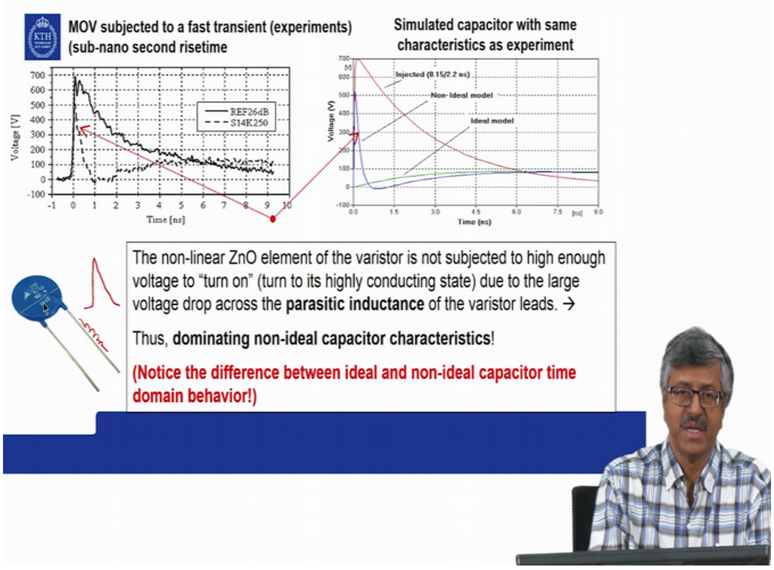
Whereas the other one CC1 divert common mode currents and usually CC1 equal to CC2 and is kept very low about 2 nF to limit the leakage current to below 1 mA for safety reasons and typical values of CD1 and CD2 are in the range of 0.1-0.5 µF, so this is only one example you can find several such examples in literature or at filter manufacturers website, so it would be interesting to look at them and see their designs.

(Refer Slide Time: 22:52)



Compare varistor model with the HF model for a capacitor

At high frequencies or with very fast rise-times varistors may behave like capacitors



MOV subjected to a fast transient (experiments) (sub-nano second risetime

Simulated capacitor with same characteristics as experiment

The non-linear ZnO element of the varistor is not subjected to high enough voltage to "turn on" (turn to its highly conducting state) due to the large voltage drop across the **parasitic inductance** of the varistor leads. →

Thus, **dominating non-ideal capacitor characteristics**!

(Notice the difference between ideal and non-ideal capacitor time domain behavior!)

Now previously I mention here that at high-frequencies or with very fast transcends rise time varistors may behave like capacitors, so that example is shown here, this is MOV subjected to fast transient experiments, some nanosecond rise time and this is one experimental data and this is something simulated capacitor with same characteristics as experiment, the non-linear zinc oxide element of the varistor is not subjected to high enough voltage to turn on due to the large voltage drop across the parasitic inductance, so what it shows is that when varistor is connected and if you have very long leads and if it is subjected to extremely high, extremely fast rise time voltages.

Then the drop across this inductance, so this may be like a inductor, so the inductive drop under extremely fast rise times, will drop the voltage in such a way that is varistor will not be clamped, so you do not get the benefit of the varistor if you have very long leads, so that effect is shown over here, so this is the non ideal model and this is the ideal model and this is the injected current, so that is why you have often have surface amount of varistors to eliminate this type of a problem, so that the full voltage is coming across the varistor elements and the full non-linear characteristics of varistor is playing into picture otherwise varistor may just act like a high-frequency capacitor nothing more than that, so that ends this part of the chapter.