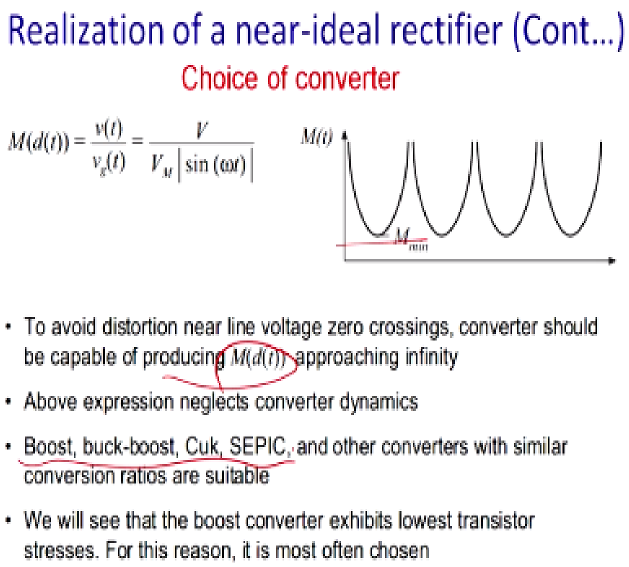
Advance Power Electronics and Control
Prof. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology – Roorkee

Lecture - 16
PWM Power Rectifiers-II

Welcome to our NPTEL courses in power electronics Advance Power Electronics and Control. We shall continue our discussions with a PWM Rectifier 2 where we have left. So we are discussing about that actually modulation index will also change like this. So once actually your input voltage is low you require to boost up, but you require to maintain some kind of modulation index.

(Refer Slide Time: 00:54)



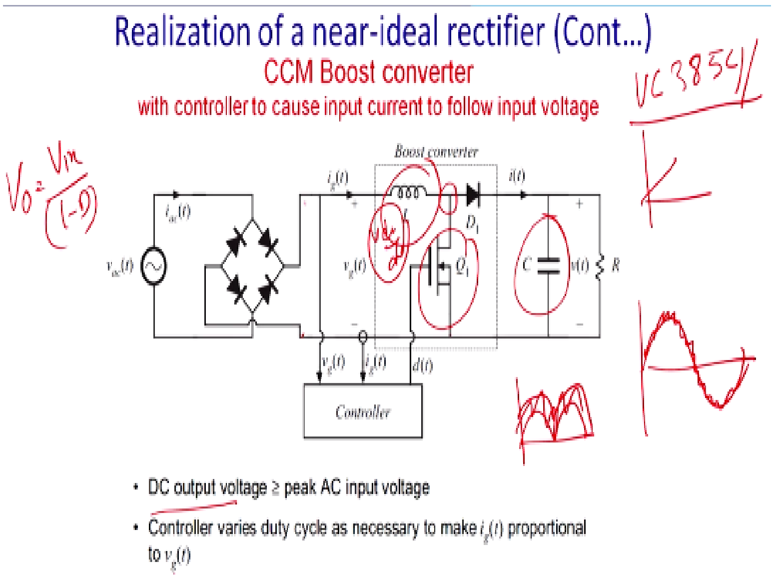
So we require to maintain some kind of minimum modulation index to maintain this thing it should not touch you when actually input voltage is at its peak and we require to do some mechanism that has been listed here that is to avoid distortion near zero crossing the converter should be capable of producing actually this modulation index approaching infinity. So definitely it is not possible, but we should have.

It means that actually the switch should be continuously on close to the zero crossings. The above expression neglects also the converter dynamics so you cannot have this kind of crossing because you require to have a short circuit protection. Short circuit protection will come into the picture and ultimately it will shut it down and what happen boost, buck-boost, Cuk, SEPIC and other DC-to-DC converter with similar conversion ratio are also suitable.

These are essentially non Isolated DC-to-DC converter we also have another type of DC-to-DC converter. We will be discussing DC-to-DC converter later so these are called Isolated DC-to-DC converter that comes with high frequency transformer and incorporated inside and we will see that the boost converter exhibits the lower transistor stresses with a switches and we will discuss the reason for that also.

So let us take typical DC-to-DC converter that is called boost converter what essentially it does you know it boost up the voltage.

(Refer Slide Time: 02:47)



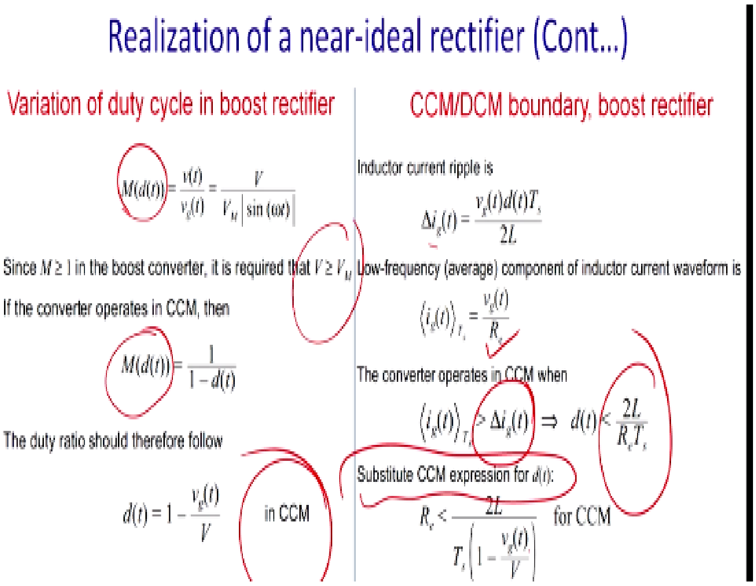
What happen you know when actually switch is on this Q1 is on then essentially this voltage goes zero and current builds up across it. Since current builds up across these so current will ramp on therefore what happen this switch will off. And due to that actually there will be a good amount of stress across the switches we will talk about that stress and ultimately due to the change in current L di/dt will come into the picture. So this voltage + L di/dt will basically the charging the capacitor.

And what happen in this configuration you know this topology is quite easy to use it and you have this kind of thing and this kind of repelled kind of voltage in the input and we generally the control will do something the control will basically put a hysteresis band and we shall restrict that current within the hysteresis band. So ultimately in input side what will happen you will get actually little lot of switching.

And this switching will actually will be mitigated by the switching harmonics and if you can keep this switching frequencies very high then you can get a boosted DC from a AC and power factor and the power quality issues has been solved or address totally. Students are actually requested to visit the datasheet of UC 3854 or 55 and so on. So this datasheet will and application note of that excess instruments will give you basically the total detail.

And walking principle of this DC-to-DC converter thereafter AC-to-DC and DC-to-DC converter where it addresses the power quality issues quite well. The DC output voltage here is actually it is a boost topology it will boost up the voltage essentially you know that in boost topology actually V in 1-D is basically the conversion ratio where D is the duty cycle of the Q1. The output voltage is> peak AC input voltage and the control varies duty cycle necessary makes ig proportional to vg.

(Refer Slide Time: 05:37)



Now variation of the duty cycle in case of the boost rectifier since it comes with the boost topology. So you will find that actually this modulation index is basically the ratio of vt/vg and essentially it is V/V M sin omega t. Since modulation index in case of the boost converter is required to be higher because it is basically if you go back basically you can write actually V M* in V0=M*in. So M is essentially here is 1-1/D.

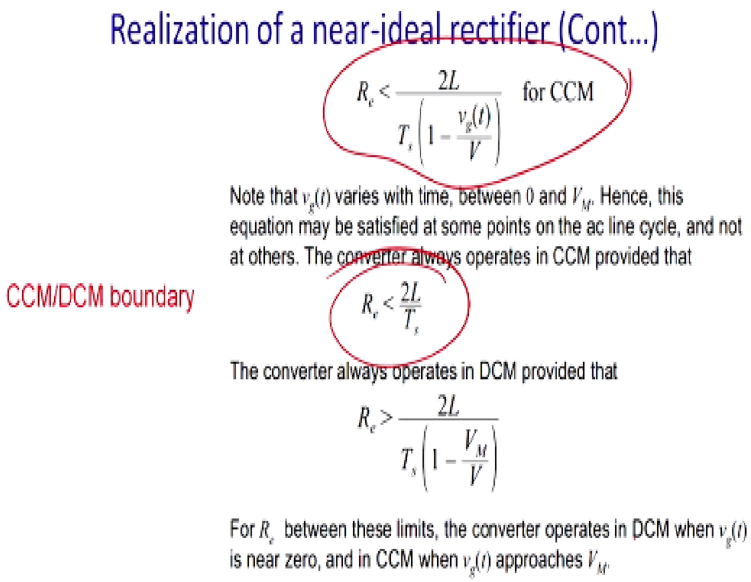
So this value is basically>=1. So in a boost converter it is required that V> V M and if the converter operates in continuous conduction mode. So we will assume that actually load current little heavy then only actually process of this conversion require easier and tends to get improved, but if it consume very low amount of the current that is really a challenge to the designer to design such converter.

So we assume that it is a continuous conduction mode and we have 1-dt and the duty ratio should be therefore follow this=1-vg/V in case of the continuous conduction mode. Similarly, inductor current ripple will be given by del ig= VM squares. So low frequency average component of the inductor current is given by this that is basically vg/Re. So converter operates in CCM when ig t Ts> than actually this del ig t and ultimately the corresponding dt which actually makes the converter in the continuous conduction mode is this ratio.

So we have to make the duty cycle such that it is <2L/Re Ts where L is a inductance of this boost converter Re is the effective or resistance connected to the load and Ts is the actually time create of the switching. So we can substitute here and substituting that we can get Re is basically Re< this expression that is 2L Ts 1- vg t/V and this system will operate in the continuous conduction mode and analysis is quite easy in a continuous conduction mode.

Once it becomes discontinuous conduction mode that becomes a very difficult to maintain THT. So this is design and required to operate this converter into the continuous conduction mode.

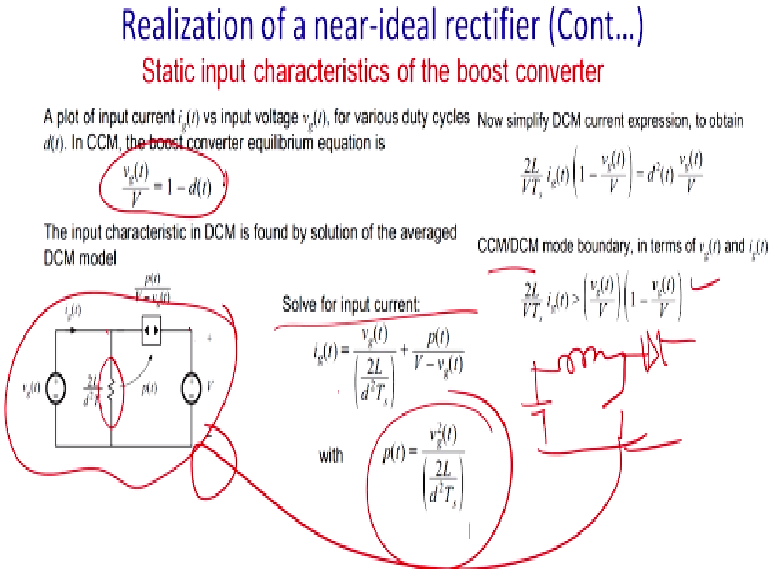
(Refer Slide Time: 08:49)



So realization of the near-ideal rectifier. So for this reason this is a condition where you can may contain continuous. So please not that vg varies with the time between 0 to V M. Hence the equations actually equation may satisfied at some point on the ac line and not at others. So since this value is changing the converter always operates in CCM mode provided that this condition has been satisfied.

Because you know this you cannot take any guarantee over it who is higher and who is lower. The converter always operate in DCM provided that if Re is> than this Re is between the limits of the converter DCM and CCM nearly to the zero and it generally makes the transition CCM to DCM.

(Refer Slide Time: 10:06)



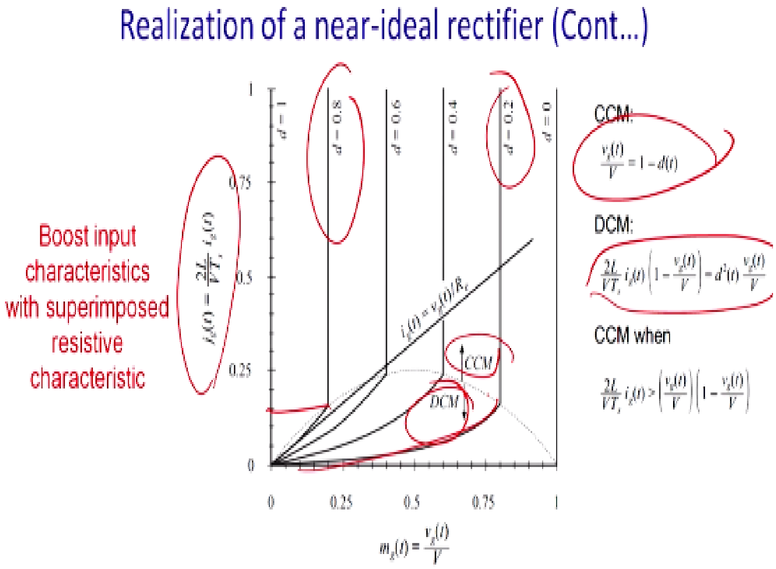
Now static input characteristics of the boost converter. So we can model this boost converter as this. So we have a switch with an inductor so that can be model at 2L/ d square Ts. Ultimately this will be the switching on and the switching off, this will be the power and this is actually the pt/V-vg is the current flowing through the system. Now you see that what happen here.

The static input characteristics of the boost converter you just have a boost convector that is basically for sake of recall is this and how you will get this. See ultimately when you shot it so ultimately you got an inductance. So this has been lumped here and current flowing into it also basically to this point-this point. So this is a power - this voltages. So thus actually in CCM the boost converter equilibrium this is basically the normal boost converter duty cycles is you can equate this actually 2L/VTs*ig t 1-vg t/V=d square vgt/V.

Students are requested to go follow the book like Ericson and others to find a detailed derivation of it due to lack of time actually. We cannot go to all derivations part of it the CCM and DCM mode of the boundary in terms of vg to ig can be actually 2L VTs *ig should be>

vg/V*1-vg/V. From there you know so we can solve for the input current so input current becomes vg t/2L dt square Ts+ pt V-gt. From there actually we come to the overall expressions of it that is pt=vg square t 2L/dt square Ts.

(Refer Slide Time: 12:41)



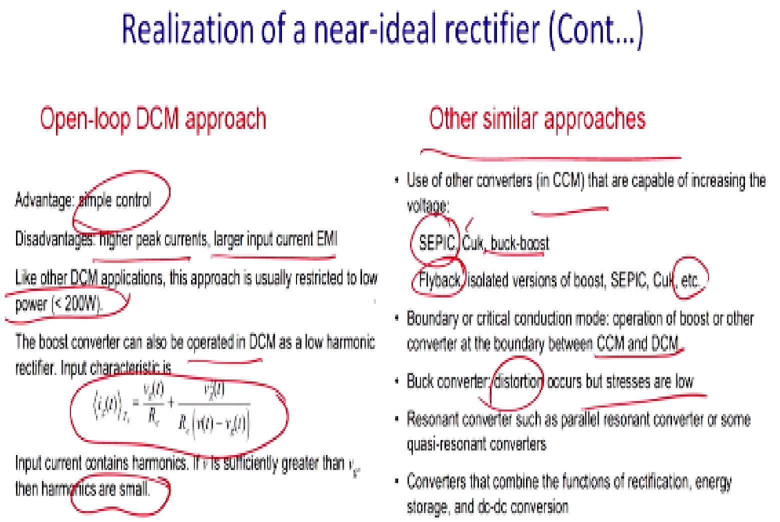
So what we can conclude from this actually data that is if it is CCM you have very simpler equations. And that is what if you have done the courses of the power electronics and you have studied the DC-to-DC converter. You are aware of the fact that actually the boost converter actually conversions is actually 1-D. So while it is in a discontinuous conduction mode you can find that 2L VTs ig 1-vg/Vt this is nothing actually, but this expression=dt square vg/V so this will govern the equations.

And you will find actually this is the expressions of the this is the expressions for the duty cycle and this is the expressions of the load current you can find that basically this is the zone where it is actually you can find that this currents are discontinuous to a conduction mode and till this time it will go to the continuous conduction mode. If duty cycle is quite high as high as 0.8.

So it will come out from the actually when it is< 0.25 of the duty cycle so it will come out from the discontinuous conduction mode and if it is duty cycle is quite low so it will continue to be discontinuous conduction mode for the larger duration of the time and thus operation becomes difficult. So let us consider that you know open loop DCM approach and with the other approaches.

DCM makes actually system less bulky why basically this failure of the inductor is going to be less in case of the DCM.

(Refer Slide Time: 14:53)



So and is control is quite simple you have only voltage control, but disadvantage is that so your duty cycle is quite low. So for this reason what happen higher peak current a larger EMI, EMC this problem will pop in. Like other DCM application this approach is usually restricted to the low power applications and mostly your mobile charger and the laptop chargers are having this features.

And that is quite nasty with respect to this actually EMI EMC because of the high peaks because current has to be low because your mobile charger you are basically reducing your voltage to 5 volts from actually 310 volt peak voltages. The boost converter though it is a buck operation anyway. So boost operation can be find in application mostly you know actually there is mostly in UPS.

Most of the UPS will say that is Power Factor Corrected UPS. So in that Power Factor Corrected UPS we incorporate this boost topology. So after this boost topology will followed by a half bridge inverter that will feed your actually your power to the actually the inverter. So there is a different kind of inverter comes into the pictures. If it is actually online UPS what happen there you actually get it by this method.

Otherwise if there is offline UPS offline UPS generally supply when power goes out and also there is a Line-Interactive UPS that also correct the sags. So if you have actually online UPS generally it required to be Power Factor Corrected and it shifts out quite well and also many adjustable drives nowadays actually ACs and other applications are coming out with the inverter driven applications like it should have adjustable speed drive.

There also we will have this kind of applications, but mostly since ACs voltage most of the household uses 1.5 ton ACs so voltage around 1.8 something like 1.8 kilowatt or something like that. So there what you will find you know actually since the loading is quite high it will go to the continuous conduction mode. So these are the few applications nowadays because gradually we have actually we have a washing machine that can be also inverter fed and she is also inverter fed so all can we have a inverter fed drive.

And thus what happen we require to rectify it and we require a PWM converted place in between to actually give you a process DC to the rectifier and thus a process AC in the output and also you do not throw any garbage in terms of the power quality to the utility. So let us come back again this application part of it. So boost converter can be operated in the same as low as the harmonic rectifier and its input characteristics is given by this.

So that is is ig Ts=vg/Re+ vg square Re vt-vg. So what happens here a discontinuous conduction mode you cannot get rid of the problem of the THD. Input current contains harmonics if v is sufficiently> vg then harmonic will be small. So that is all about it so, but it is not the case generally we have a harmonic issues in the case of discontinuous conduction mode.

So similar type of approaches can have you know in CCM mode and we can have a different kind of topologies this is basically the SEPIC topology, Cuk topology pronunciation is Cuk and buck boost. Cuk is also a kind of buck-boost and also 2 switch buck-boost topology or any other buck-boost topology and thereafter we may have a isolated conversion that is flyback thereafter forward thereafter push pull we can have so many things in case of this conversion process.

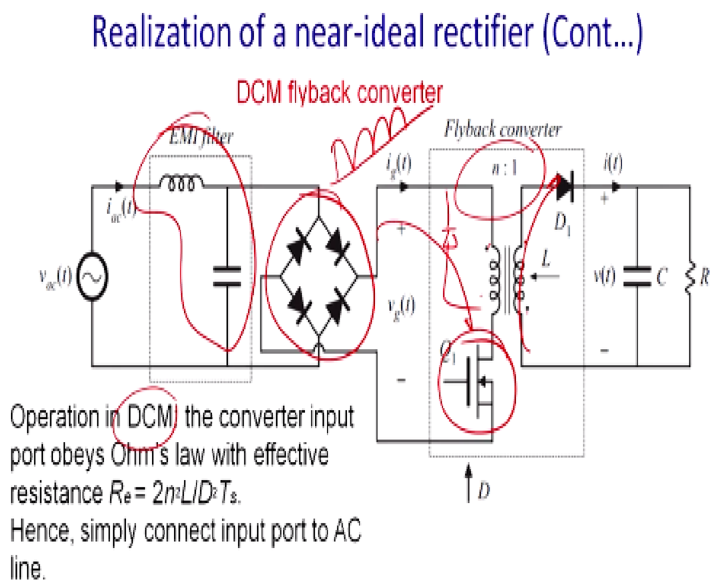
And boundary or critical condition mode of operation of boost or other converters at boundary between CCM and DCM. Buck converter has an advantage, but it makes the distortion occurs, but stresses across the switch will be lower. Another application can be resonant converter so that is applicable for the zero voltage or zero current switching. So it comes with the actually inductor and capacitor banks which we have a natural frequency of oscillation.

That help us to switch either when current is current across the switch is zero or the voltage across the switch is zero and that leads to the zero voltage or the zero current switching same way the switch can be off when voltage across or current through the devices is zero. So same way we can have a zero turn of losses. So resonant converter such parallel resonant converter or some quasi-resonant converter can also be used for this purpose.

We shall discuss in detail about it subsequent applications. Converter that combine the function of rectification and also sometimes the energy storage and DC-to-DC conversion mostly this application is a flyback where actually we have a special kind of transformer generally transformer does not store energy. We have a special kind of transformer that is called inductor transformer not only it will convert it will also store energy and it will flyback when it is required in the negative half cycle.

So that is also some other approaches can be followed in case of the PWM Rectifier.

(Refer Slide Time: 21:47)



f

Now let us see one example where actually the power flies and it stores the energy and see that this is a very common usage of below 100 watt AC-to-DC conversion does all your laptop charger, your mobile charger essentially of this kind of topology. So this is the EMI filter as I told you it may operate into a discontinuous conduction mode and thus we have a huge problem EMI EMC.

Since you are using a mobile so if it also actually interfaces or your communication of course your sound quality of the mobile will deteriorate. So we require to suppress the conducted emission as well as the remitted, but we cannot do much about this actually radiated emission, but we can reduce something about the conducted emission by putting the EMI filter. So this is the rectification and ultimately we got the DC.

Please mind that there is no capacitor so that we get a double frequency ripple in the output and this is the MOSFET most of the cases because power rating of this device are quite low and see the dot convention of this actually the topology. You can find that it is dot here then dot is here. Generally, in case of the normal transformer we have a dot here where actually current try to flow here actually it will oppose and current will go out, but here dot is actually this position.

So ultimately when switch is on current flow current will flow and thus this inductor required thus this actually the transformer require a special property and it required to actually store the energy. So due to that actually when it will be off some percent is omitted there will be diode actually to suppress the stress across the switch and what happened then there will be resetting winding so that is a over simplified circuit.

So then actually current will flow back to the secondary. So you can choose the turn ratio by anything because you have to have a huge drop in voltage for the mobile or the laptop charger and thereafter you know you can also change it by the duty cycle. So thus the operating in a discontinuous conduction mode the converter obeys the Ohm's law and the effective resistance is 2 n square L where L is a leakage inductance not the EMI filters leakage inductance of this actually the inductor/D T square Ts.

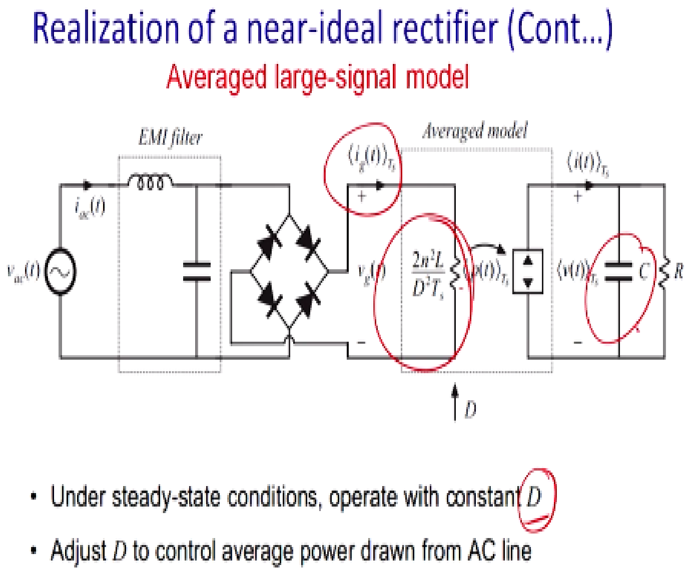
Hence simply connect the input port to the AC line the power will be converted. So this is the here you know you can see that what happen we have violated 2 things. This has a storage element so we are saying that normal converter should not storage element input should be=output, but here input is stored for very small fraction of time and thereafter it will be transferred to the output.

And these are basic advantages since this power flies so what this is called Flyback

Converter. So realization of the actually non ideal rectifier let us see that how we can model this isolated DC-to-DC transformer. Some we require isolation for the highly sensitive device. Of course you know if your mobile phone is worth of 30,000 if you can afford or 50,000 so you do not want that actually to simple spikes in the inputs your mobile gets damaged.

So for this reason this gives a galvanic isolation from the surges and other volt stresses and for this reason actually this isolation has been preferred for your costly sensitive low voltage devices. So let me come to the actually the modeling part of this flyback converter. So same way what we have done the ig is flowing and here you know we will change this transformer and switch to the equivalent resistant Re that value is given by this.

(Refer Slide Time: 26:46)

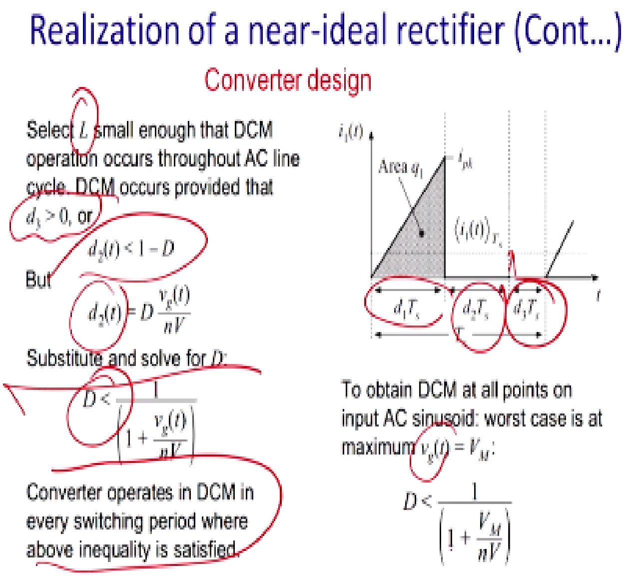


So it is 2 n square L D T square Ts and power will flow to the secondary that is Ts and that will be given by V* it that will be=R. Please understand that capacitor is placed here to actually smooth out the ripple in case of the DC where there is no actually input here bulky capacitor in the AC side or the ripple DC side. Under steady state conditions operate with the constant D.

So if you have a constant load, but it will change why because you know I was telling you that these are mobile charging applications. These are mobile charging applications there are different mode of charging. Initially when mobile actually almost zero percent charge so it will charge in a first charging mode so current through will be high. Since it is a chemical process you know actually automatically charging will be slower.

And then we will go for the different mode of charging. So if we assume that load it may be actually you are driving the LED for the lighting purpose. So then you require a constant load and ultimately you got a constant D may be. So adjust D to control average power drawn from the AC line. So if you wish to change this R then something will change otherwise everything can be fixed.

(Refer Slide Time: 28:21)



Now there is some issues here the converted design. So that is a huge topic of DC-to-DC converter, but we have to consider it. So we have told you that to make it in a discontinuous conduction mode we should select L a small value so that the same operates and occurs through the line and the same occur. Again in case of that it is a buck operation as I told you and since D2 you know that actually D v gt/Nv.

From there we can solve the value of D and ultimately we will find it out 1/1+vg/Nv. So converter operates a discontinuous conduction mode every switching period where above inequality is been satisfied. So we can see that when switch is on current will actually picky that is a problem EMI EMC so current will actually picks up this is basically the average current so this is dotted line.

So ultimately this switch in this switch will be on inductor will be building the current through it. Thereafter this will flyback into the secondary or the time period of dt* Ts through this actually the direct action with the setting winding. This has been not discussed here for actually simplicity and the time of operation. Thereafter you know current through this actually that setting winding decayed and till that this d3* Ts there is no current into the circuit and for them that leads to the discontinuous operation.

When is a continuous conduction mode actually this should be=0 and this to obtain the DCM at all the points at the AC input sinusoidal the worst case voltage vg that should be Vm and inequity is been satisfied. So this is quite applicable in the application specific case. I shall continue to our discussion in our next class because for take a simple example you can use your laptop in USA where supply volt is 110 and also in India that is 220 volts.

So how this application fit to this requirement. We shall continue to our discussion I hope that actually students are finding this crystalline practical examples are quite interesting feel free to feedback once you are attending the class in emails. Thank you very much for your kind attention.