Advance Power Electronics and Control
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Lecture – 23
Isolated DC-DC Converters-II

Welcome to our NPTEL lectures on advance power electronics and the control. Today we will have a second class on isolated DC to DC converter. So you know we were discussing about the fly back converter that is a simplest converter in many aspects we have talked about few aspects that is quite actually required for DC to DC converter and essentially isolated DC to DC converter comes out with a isolation by a magnetics on the transformer.

So we required to reset the flux in every cycle otherwise the transformer core is saturate and no energy will fly primary to the secondary.

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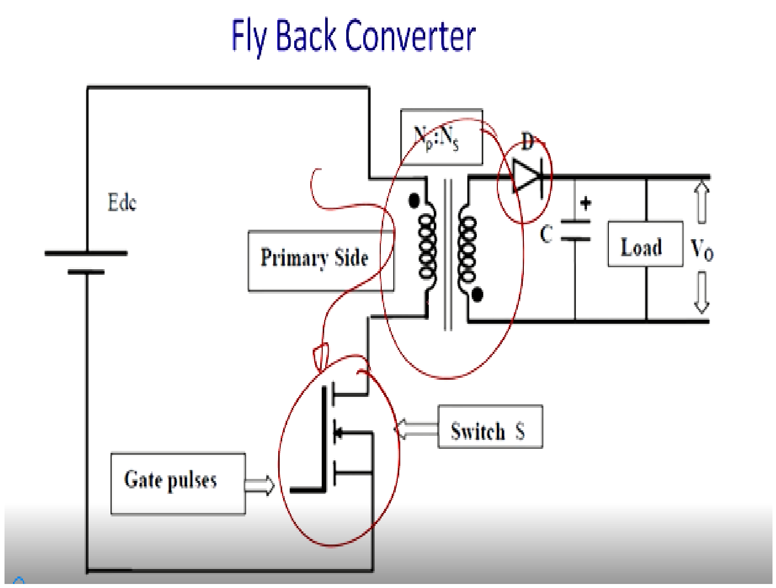

And for this it t has a unique feature it is a special kind of transformer and you can see that dot convection is opposite to the conventional transformer which we have studied yet. So when the switch is closed then what happens the current flow through this path and this diode is reversed biased I will just come a little later . Then what happened energy is what happened you know actually this inductor will actually energize and no current flow to the secondary.

And it is called inductor transformer, it has a small layer gap and it will be the energy will be stored into this area. Once which is closed you required to have our resetting winding which was not shown in the figure for sake of the simplicity then polarity of this device gets reversed previously polarity was this one switches off polarity will be this then you required to have a diode.

And then eventually you will fly back primary to the secondary. For this it is called the fly back converter. So one of the advantages that is simplicity it and it is a one switch operation it is quite compact size of the transformer is quite less because its but since it stores the energy in the air gap so it cannot handle a huge amount of the power and another big disadvantage are big stress will be on the switches because you require to reset the flux.

And for this you have a resetting winding and we will see that what are the voltage stress comes out to across the switches. So let us see that wave form of it.

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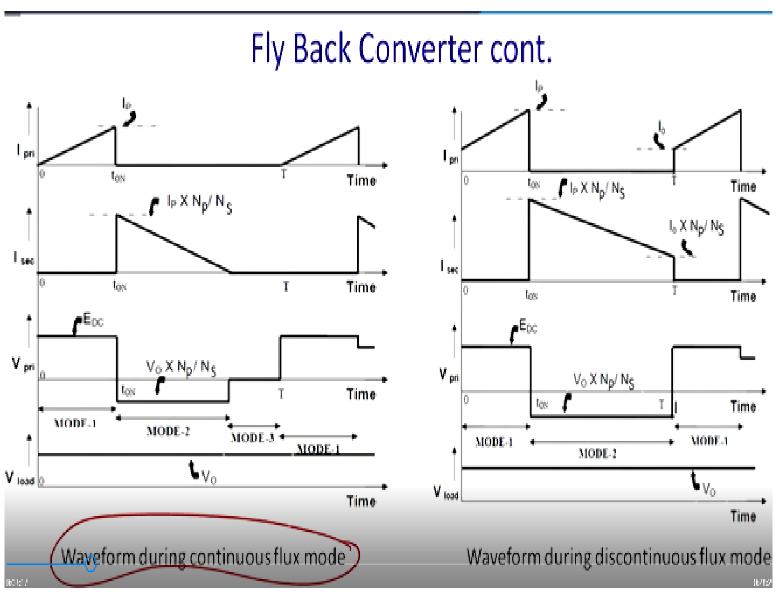

And consider that this is a continuous mode of operation when we want to have a continuous mode of operation and analysis is easy your discontinuous mode of operation which we have seen into the non-isolated DC to DC converter and analysis is quite complicated and also if you for the transformer point of view it has a unique problem in that non-isolated in case of the isolated DC to DC converter.

This is the I primary and this is I secondary so and this is the value of the reflections and once actually this is a pre-primary and this is a pre EDC and what happened you know when it is switches off then polarity of it get reversed and that is proportional to basically V0*NP/NS and that will last till that actual conduction period of the secondary current once and this is basically this is the place where actually you got a discontinuous conduction mode.

And you have this current wave form and this is a continuous connection mode and you can see that this is a wave current wave form and thereafter it is a voltage wave form thereafter it is a voltage wave form of the primary and current has been dragged the whole time so that you get a reset of the flux . So volt area curve of this and this should be equal so why do you can see here you know actually.

Volt area curve=matches continuous conduction mode to stress across switch you will find less and similarly similar stress continues and this is the constant DC output voltage.

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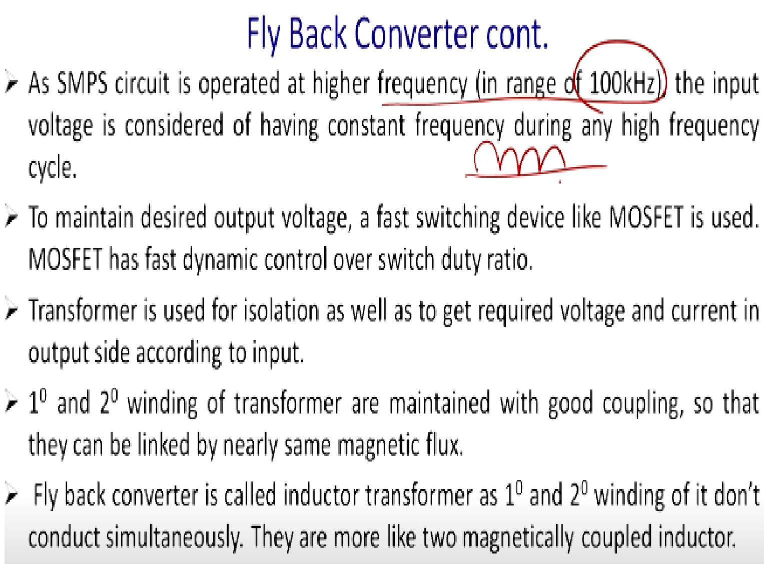

As the SMPS circuit is operated a very high switching frequency and the range of the 100 kilo hertz generally MOSFET is implied the input voltage is considered to be constant because you may have a ripple DC of 50 hertz or 60 hertz and compared to the 100 kilo hertz we can take it as a constant . Any to maintain the desired output voltage a fast switching device like MOSFET is used and MOSFET has fast dynamic control over the switch duty ratio.

Transformer is used for isolation as well as to get require voltage and the current in the output side of the output side according to the input. Transformer 1 that is basically the primary and transformer 2 that is basically the secondary winding of a transformer and maintained with the good coupling so that they can be linked by nearly same magnetic flux and we say that coupling is almost 0.95 and that kind of you know value .

Fly back converter is called inductor transformer because there will be a smaller air gap and energy will restore into it as 1% and the primary winding and the secondary winding does not conduct instantaneously they are more like a 2 magnetically coupled inductor.

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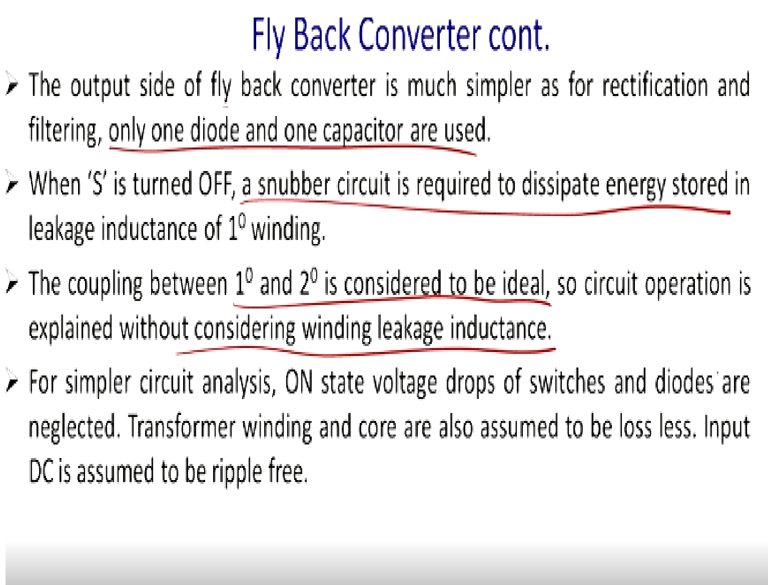

The output side of the fly back converter is must simplest as for rectification and filtering only 1 diode and 1 capacitor is use for its compactness. So we will find actually the site of the filter is quite less but since we are using a such a high frequency so size of the filter drastically reduced when the switch S is turned off a snubber circuit is required to dissipate the stored energy and a leakage of the first inductor or the first winding.

Coupling between 1 and 2 is considered to be ideal for this analysis but coupling can be as high as 0.9 so the circuit operation is explained without considering the leakage reactance. For simpler circuit analysis ON state voltage drop of the switch and diodes are neglected and transformer of winding core loss are also assumed to be loss less so that we can use that actually input power=output power condition. The input DC is assumed to be ripple free.

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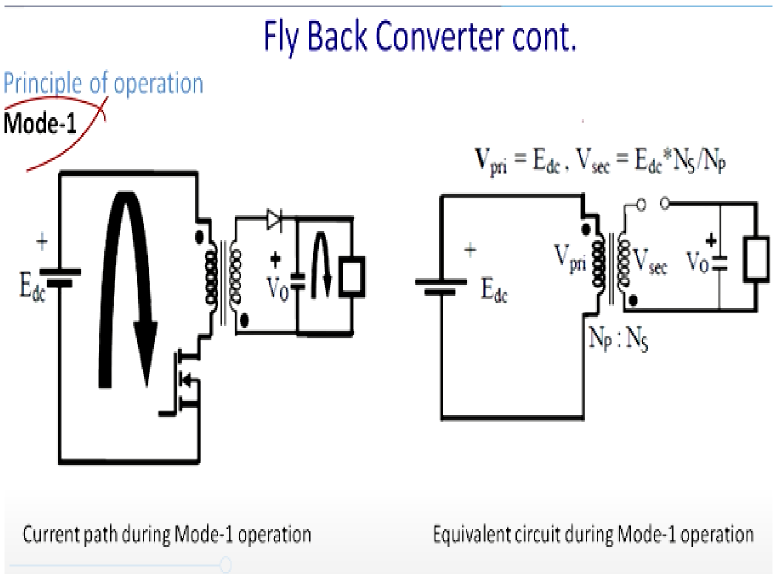

So this is our assumption based on our assumption we are going for this analysis . So mode 1 when switch is on so what happened when switch is on effectively sell he becomes this so current will flow through it and this is NP/NS .So since diode is reverse bias no power flows into a secondary. Since this polarity and due to the dot convention you will have this polarity so this diode will have a reverse biased.

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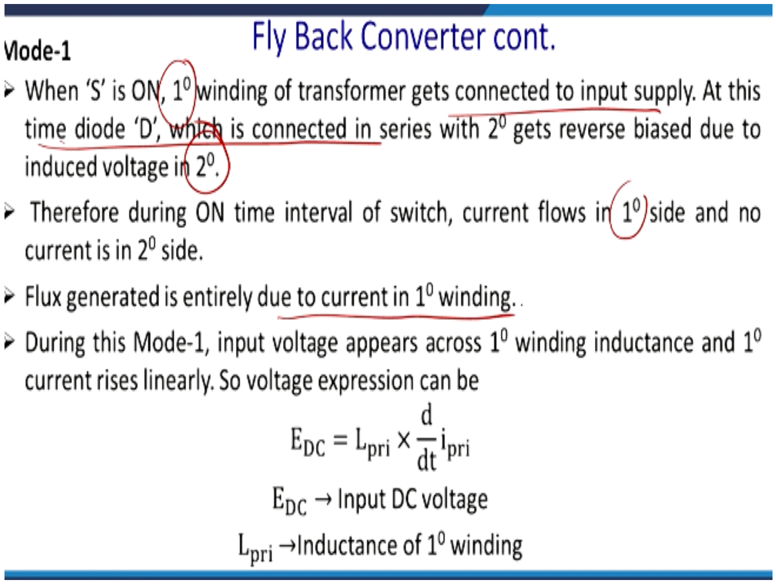

Next when switch S ON I ON 1st winding of the transformer get connected to the input supply as it is the time of the diode which is connected in series with the secondary gets reversed biased due to the induced voltage in winding 2 or the secondary. Therefore during turn on interval of the switch current flow in winding one side and no current flows to the second winding flux generated is entirely due to the current in the first winding.

During this mode input voltage appear across first winding and inductance first winding current increases linearly so the voltage expressions can be given EDC=L d/dt where EDC is the input DC voltage and L is the primary inductance.

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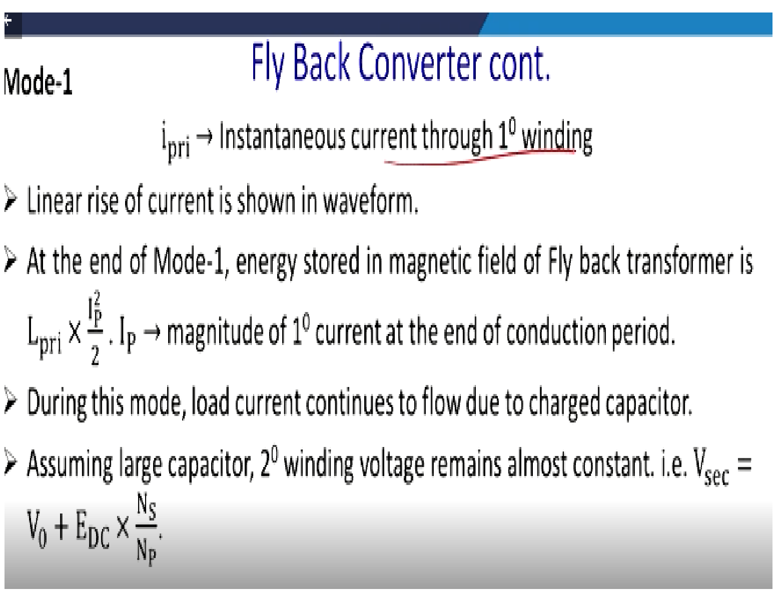

This is primary instantaneous current through the winding 1. Linear rise of that current is shown in the wave form and since L=l d/dt at the end of mode 1 energy stored in the magnetic field of the fly back transformer is L pri Ip square/2*IP the magnitude of first wining current at the end of the conduction period has been shown. During this mode load current continues to flow due to discharge of the capacitor and assume that this is a continuous conduction mode.

Assuming the large value of the capacitor in winding 2 the voltage almost remains constant you know actually on period of the switch. So you get essentially the V secondary=V0+EDC NS/NP.

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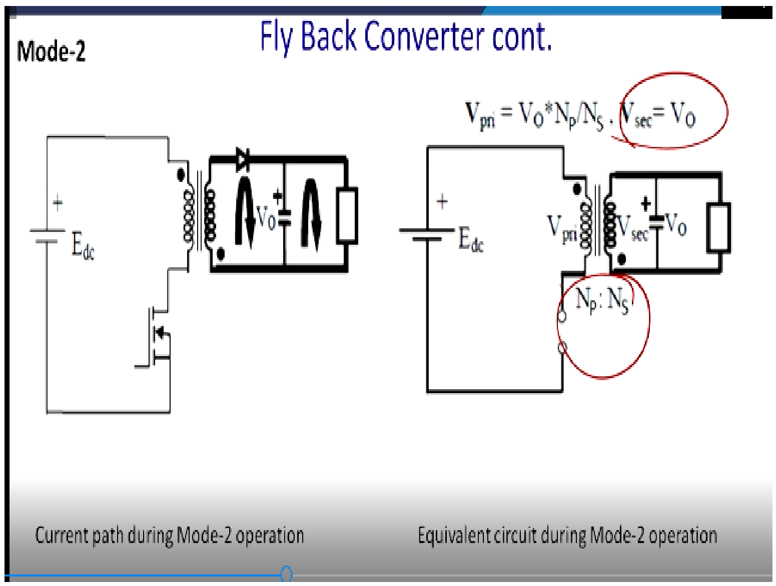

This is a condition of mode 2 when switch is off and but what happened then basically primary voltage will be V0*Np/NS so this will be the actually the primary voltage. So ultimately there we have a voltage stress across a switch that is proportional to V0 NP/NS.

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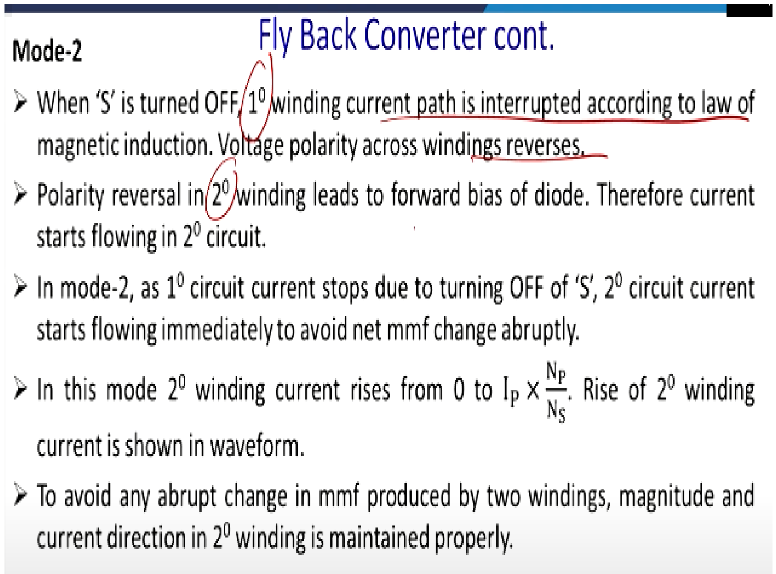

When switch is off winding 1 or the primary winding current part is interrupted according to the law of the magnetic induction and actually it has been switch has been put off the voltage polarity across this primary winding actually reverses. Polarity reversal in secondary winding leads to forward bias of diode and therefore current starts flowing into the secondary circuit and it is going to charge the capacitor which was initially decreasing and the feeding the load.

The mode 2 as circuit 1 current stops due to the turning off the switch S the second circuit current starts flowing immediately to avoid net mmf change abruptly. In this mode secondary winding current actually arises from 0 to IP*NP/NS rise to actually rise off the secondary winding current shown in the wave form which has been here. So this will be the value this has been actually rice in the wave form of the secondary.

So initially this value will be IP*NS NP/NS, so this will be the value. To avoid any abrupt change of mmf produced by 2 windings the magnitude of the current direction in winding 2 is maintained properly by the help of this diode.

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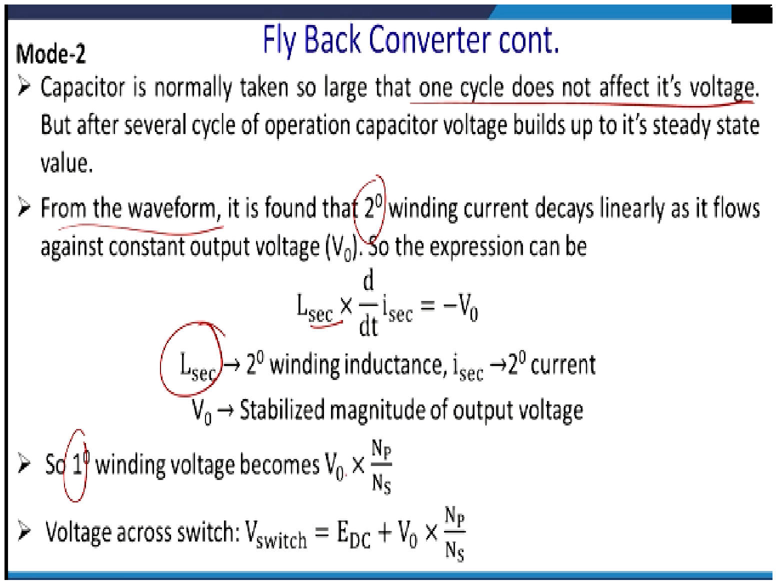

And capacitor is normally has to be designed so large that one cycle does turn affects its voltage so it should be able to actually deliver power for the 10 cycles in such a way actually it has been designed. But after several cycler operation capacitor voltage builds up to its steady state value so we required to build we require to take the voltage boost up the voltage in steps. Wave form it has been found that the secondary winding current decays linearly.

And it flows it against the constant output voltage v0 so actually you can see L secondary *di/dt=-V0 so where L secondary is basically the inductance of the secondary winding and I secondary is the current in the secondary winding and V0 is thus stabilized magnitude voltage which is the output voltage you want to achieve. So first winding voltage at that time once actually the diode is conducting.

So that voltage stress across the switch that is basically the reflected voltage on the secondary is V0*NP/NS and across the switch will be EDC+V0*NP/NS. Let us take an example you know then only you will understand it better. So you are bucking let us say your laptop charger 310 volt that is basically EDC and to V0=20 volts for sake of simplicity or make it 300 volt and this ratio NP/NS can be approximated to be 10 rest you can actually manage with the duty cycle.

So what happened you know you can see that so what will be the amount of the voltage V0 NP/NS V0 is basically 20 +20*10 so this voltage become 200 volt so this voltage is 200 volts+300 volts stress across a switch will be 500 volt this is the one of the biggest disadvantage of the fly back converter. So it has to actually take huge voltage stress across the switch.

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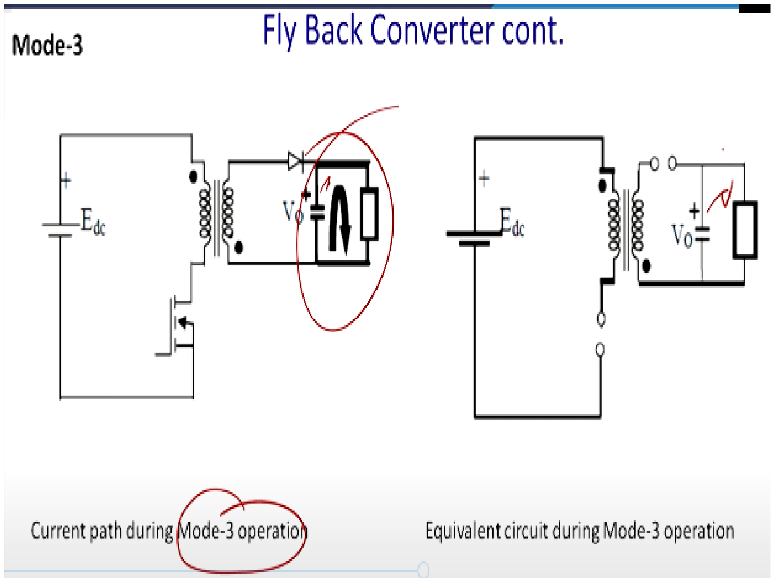

Now current path during this half period so this is a third mode of operation and when actually current has decayed in case of that in case of discontinuous conduction mode and what happened you know actually this capacitors essentially is the feeding this load. So let us analysis this part of the circuit so this will be feeding the load and switch is off because it is in a discontinuous conduction mode.

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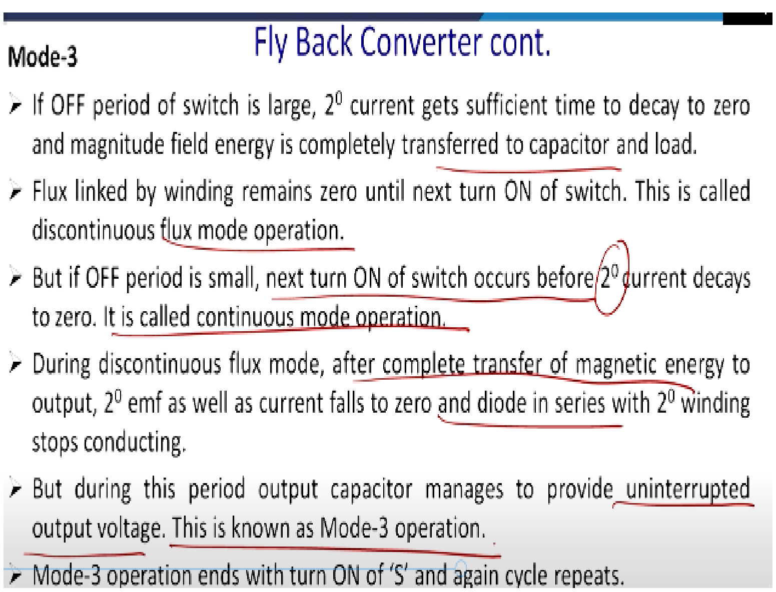

So if OFF period of switch is large secondary currents get sufficient time to decay time to get to 0 and magnitude of the field energy is completely transferred to the capacitor and the load . Flux linked by the winding remains 0 until next turn ON the switch is also off this is called discontinuous flux mode of operation. So this switch is off and this switch I also off because it is a discontinuous conduction mode and capacitor essentially feeding the load.

But if OFF period is small then next turn on switch occurs before the secondary current decays to 0. Then it is called continuous conduction mode during discontinuous flux mode this is one of the actually features off the control point of view after complete transfer of the magnetic energy to the output secondary EMS as well as less current falls to 0 diode in series with the winding stop conducting.

Because there is no energy storage into the source but during this period the capacitor managers to provide uninterrupted output voltage and this is known as the mode 3 of operation. So while writing a state stress model of a discontinuous mode of conduction we have a three set of transfer form three set of actually set of equations and it has to be linked and while linking you know there is a challenge and we will find that there will be a 0 in right hand side of the (()) (18:56).

And it is called minimal order system so controlling this kind of entity quite challenging the mode two operation ends with the turn on of S and then the cycles repeats. So this happens only in a light load condition.

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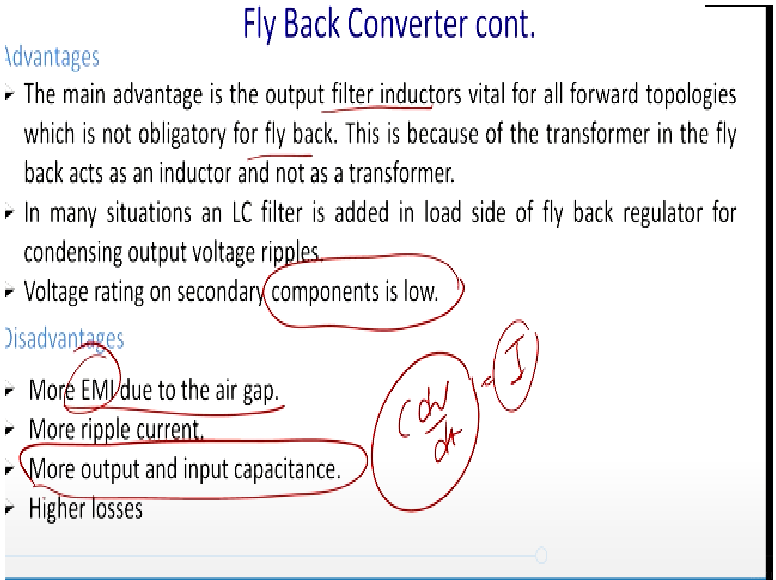

So let us come to the advantage and disadvantage of the fly back and few words about actually third mode. Third mode essentially problem lies that if you have a voltage error and you look at to correct it really control system will correct it now opposite direction then you will find that voltage sac will increase and thereafter it will actually correct. Discontinuous mode of conduction or discontinuous mode of conduction is challenging.

Very challenging from the control point of view what this we want that actually that is to operate this fly back converter to be operating continuous conduction mode let us see that advantage of the fly back converter. The main advantage of this of the output filter and the output filter is vital for the forward topologies. It is come to the forward topologies a little later and which is not obligatory for the fly back.

It is not essential this is because the transformer in the fly backs acts as an inductor and not as a transformer so it will store the energy while its current flows through the switches and the inductor and that will actually go back once switch is off. In many situation an LC filter is added in the lower side of the fly back regulator for condensing the output voltage ripple. So but since voltage is quite low.

And you have a high switching frequency the size of this filters will be pretty much compact and the voltage rating of a secondary component is quite low. Because there no secondary is being stepped down to the application level. So ratings of the diode and other devices will be quite low but there will be high stress across the switch. Since there is an air gap and energy is stored into the air gap so there will be a problem of high EMI.

Because since always what happens you know where there is a change of impedance in this case it is a reluctance L reluctance and the core reluctance there is always waves gets reflected and thus flux will have a reflections in the boundary of the L reluctance and the core reluctance and since it is on and off at a 100 kilohertz frequency so that gives rise to the EMI. So it will have a high EMI.

More ripple current you have seen that current is picky in primary and the secondary and you will see that to bring down these ripples dv dt=I so to bring down this ripple the value of the capacitor required to be increased. Last but not least high losses across the switches because switch is operating all the rating switch has to undergo a voltage stress + EDC to -EDC something like that.

So 2 EDC voltage drop will be there while turning on and turning off so there is a huge loss and also you are required to take the switches of the quite higher rating to sustain it.

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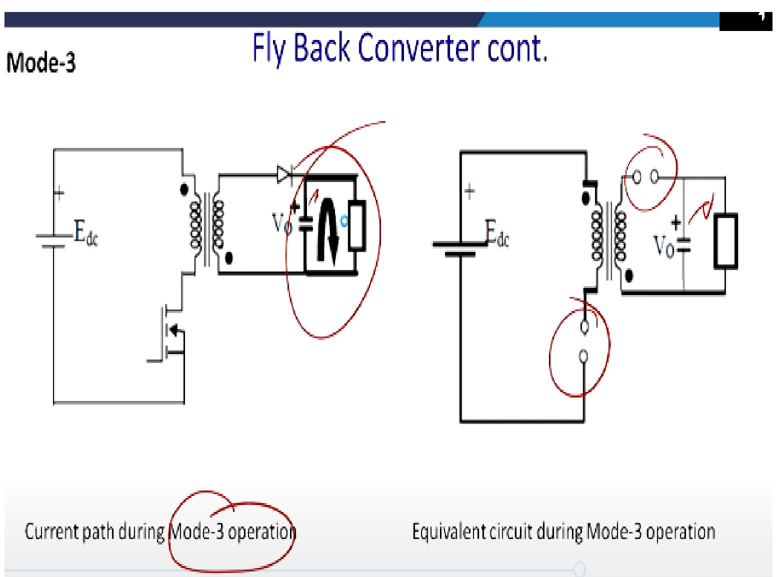

Now next topology we will discuss is the forward SMPS here this is a high frequency transformer and it is almost same but you can see the dot . Dot is placed as per the core conventional transformer but their component count increases if you go back to the circuit there is just required only one single diode. So only one single diode but you will find that component ground secondary has been increased.

So you require 2 diodes D1 and D2 and you know it is something like a buck topology you know so this is so it bucks that voltages and it is isolated essentially it is a isolated buck topology something like that most from the cases this voltage is less than the EDC at what essential you get unregulated DC to regulated DC with an isolation. Since it does not store in energy so it can handle around 2 to 3 times higher power then this actually the SMPS.

So let us see that how does it operate so we shall consider that same IL this is the load voltage which is assumed to be constant.

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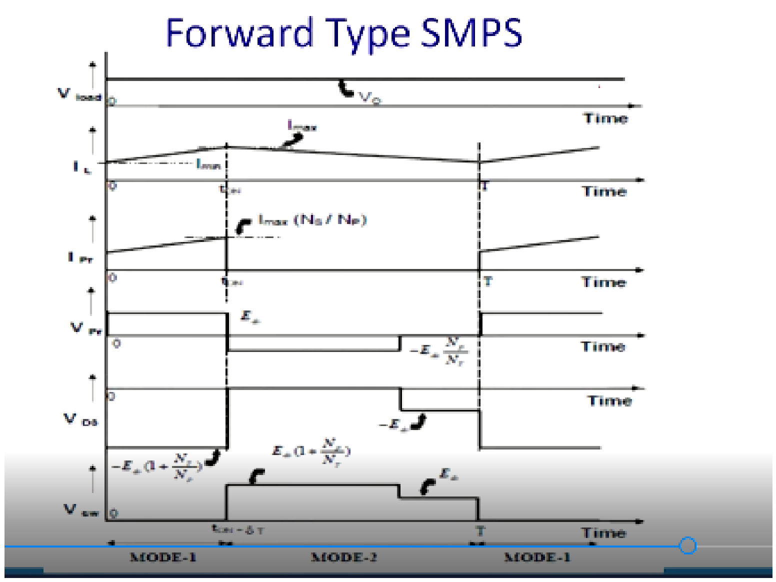

This is the inductor current and which is actually assumed to be continuous and this is a primary current and it will go to actually IMAX NS/NP and this is the primary voltage applied in the transformer once switch is on once switch is off it will change this polarity and then value will be = output voltage*NP/NS where EDC is the output voltage of this DC to DC converter. And this is the voltage stress across the switch DS and this is the pattern of this CW.

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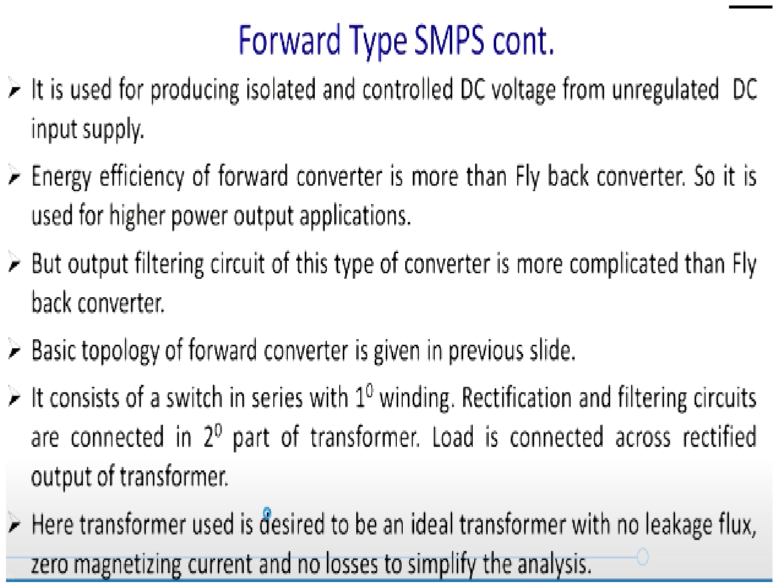

Now see that how does it operate we shall come it is used for producing isolated and controlled DC to control DC voltage from unregulated DC voltage. Energy efficiency of the forward converter is more than fly back converter there is a less losses and second one is this compact since energy is not stored unlike in case of the fly back converter . Si it is used for the higher power application than the fly back converter.

But output filtering circuit of this type of converter is more complicated than the fly back converter . So we can see that there is a diode 2 diodes and the AC filter basic topology of this converter is given in the previous slides it consisting of switch in series with the first winding and other rectifications and the filtering circuits is connected into the secondary or the primary secondary of the transformer.

Load is connected across rectified output of the transformer. Here transformer used is desired to be an ideal transformer with no leakage flux 0 magnetizing current and no losses to simplify the analysis.

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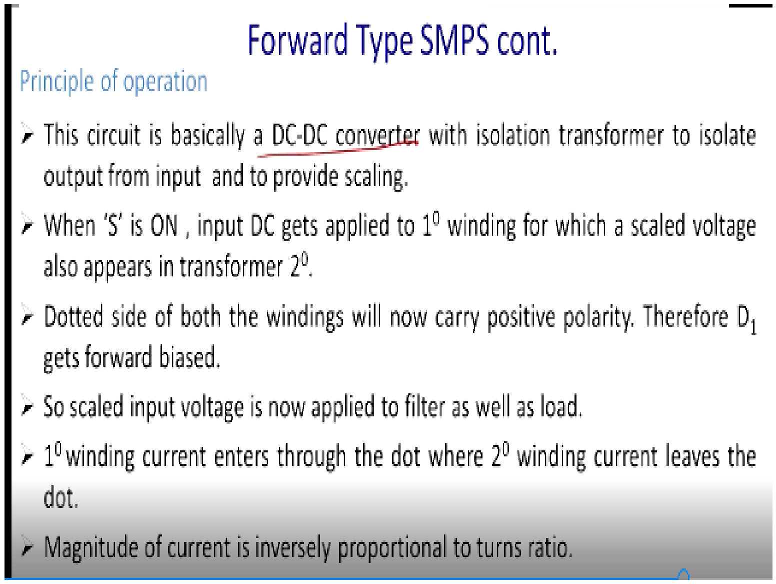

And this circuits is basically a DC to DC converter with isolation transformer to isolate output from the input and to provide a scaling proportional to this trans ratio . When S is ON input DC gets applied to primary winding for which it is scaled to voltage also appear into the transformer 2. Si it will be transferred according to the trans ratio . Dotted side of both of the winding will now carry the positive polarity.

So therefore please refer back to the figure so this diode is D1 so D1 will be forward biased. So scaled input voltages is now are applied to the filter and subsequently will be applied to the load. The First winding enters the current to the dot where the secondary winding leaves the dot . The magnitude of the current is inversely proportional into the turns ratio.

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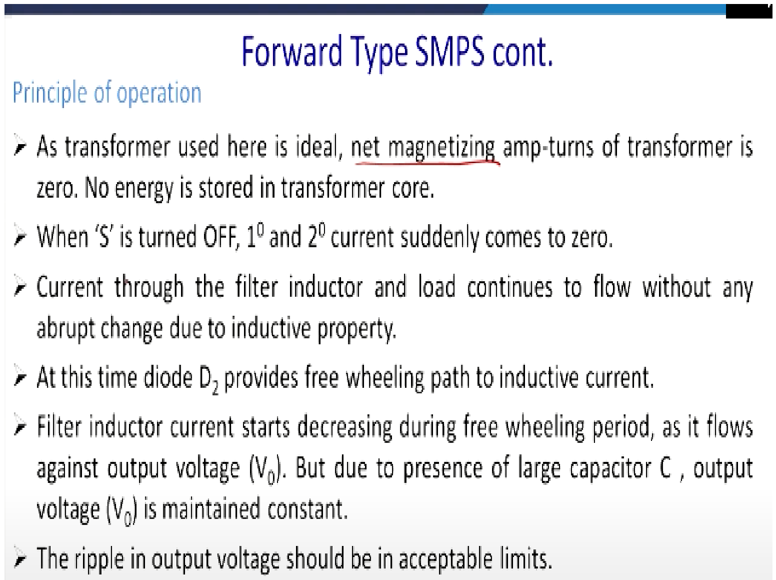

As transformer used here is ideal the net magnetic magnetizing ampere tuns of the transformer is 0 and no energy is stored into the transformer. When switch is turned OFF that S is off primary and the secondary current suddenly becomes 0 that leads to the stress across the switch. Current to the filter inductor and the load continues to flow without any abrupt change due to that inductive property.

At this time diode D2 provides freewheeling path to inductive current filter inductor current starts decreasing during the free willing period as it flows against the output voltage but due to the presence of the large capacitor output voltage almost remained constant the ripple in the output voltage should be in acceptable limit as given by the designer. So they will say that actually ripple is 5% or 6% like that. Accordingly, you will choose the value of the capacitor.

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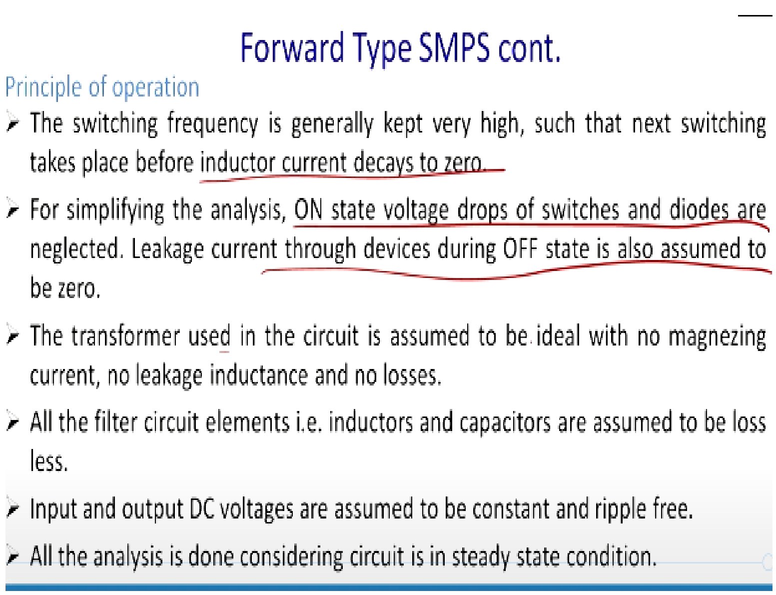

The switching frequency is generally very high so that the next switching takes place before the inductor current goes to 0. While simplifying the analysis ON state voltage drops of switches and diodes are neglected. Leakage current to the devices during OFF state is also assumed to be 0. The transformer used in the circuit is assumed to be ideal with no magnetizing current no leakage inductance earn no losses.

As all the filter current elements inductor capacitor are assumed to be lossless. So efficiency of the system is quite high and analysis become simpler. Input and output of the DC voltage I assumed to be constant and the ripple free all the analysis is done considering that circuit is in steady state condition. Thank you for your attention, I shall continue with the next part of the fly back forward converter. Thank you.