Advance Power Electronics and Control
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Lecture – 24
Isolated DC-DC Converters – III

Welcome to our NPTEL lecture on advance power electronics and controls, so we shall continue with our discussion on isolated DC to DC converter we are discussing the forward converter. Let us go to the operation of the forward converter.

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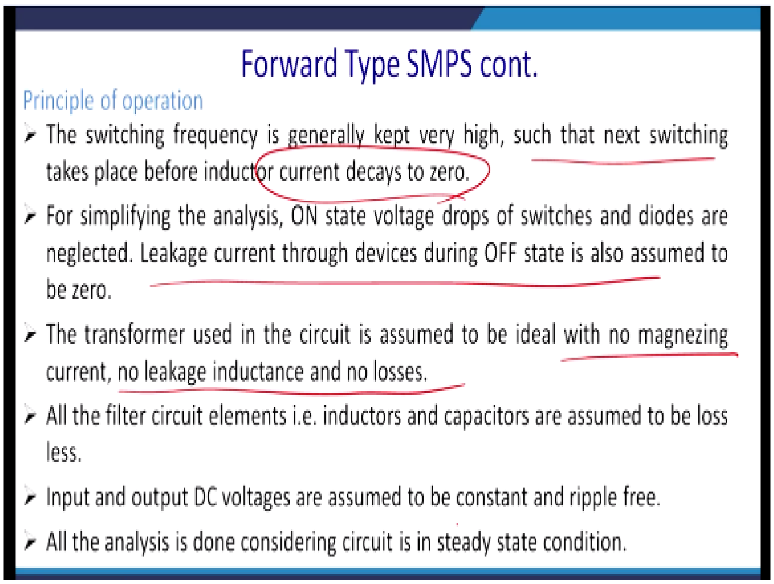

The switching frequency is same as that of the fly back converter is generally kept high and such that the next switching takes place before inductor current decays to 0. We want as a continuous conduction for simplifying analysis we have already discussed that on state. All the condition of ideal is considered that is that drop across that two diodes is assumed to be 0. Switches turn on and turn off our switches is lossless and conduction loss of the switches is also 0.

These are actually the leakage current through the devices in OFF state is assumed to be 0 transformer used in the circuit is assumed to be ideal and coupling is 100% with no magnetizing current no leakage inductance and no losses. All the filters element that mean inductor and a capacitor assumed to be lossless the input and the output DC voltages are assumed to be constant and ripple free. All the analysis is done considering circuit in the steady state condition.

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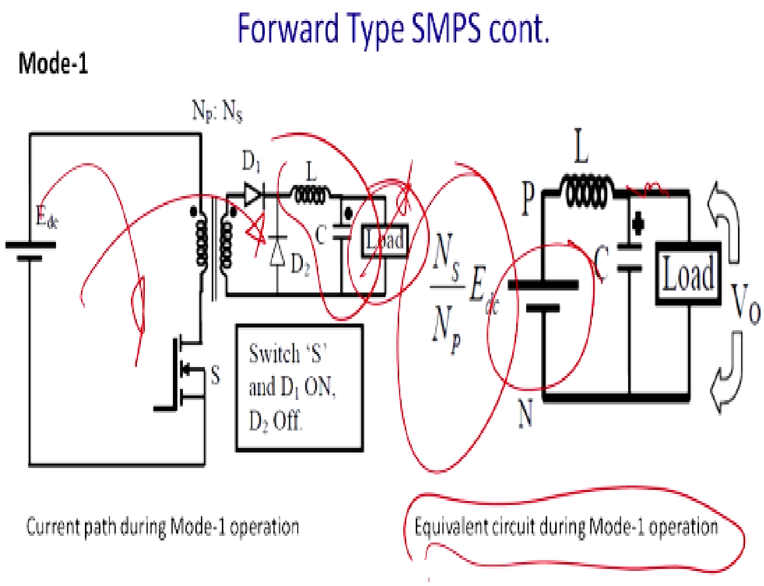

So, see that this is the switch and you have to control this output voltage irrespective of the load. Load may change but output voltage required to be maintained constant so what happen if you couple you know equivalent and this circuit it is been shorted and transformer will transfer power to the primary or secondary and essentially you couple the whole element here and that boils downs to this part of the circuits.

Refer these things in to this part of the circuit is referred to the secondary so you have we know that actually referring the circuit in the primary and secondary on the transformer. We have referred this circuit into the secondary and thus you get NS/NP in to Edc so this is the effective receivers voltage and this part of the filters come into the picture. And of course you can use T filter sometime PI filter also.

Some kind of filter maybe used to get a better results because you have a here 40 degree K you can increase that DK further.

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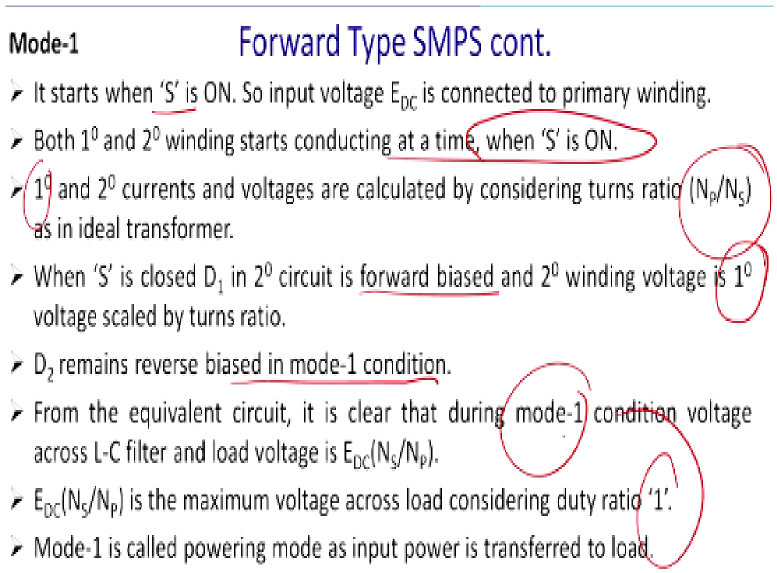

It starts when switch S is on so the input voltage e DC it is connected to the primary winding both primary and the secondary winding starts conducting at the same time when switch S is on. Primary and secondary currents and voltage are calculated by considering the strands ratio NP/NS as an ideal transformer when S is closed. D1 in secondary circuit is forward biased and secondary winding voltage is scaled down by the ratio of NP/NS.

That D2 remains reverse bias in this mode so because you know energy is flowing for primary to secondary and from this equivalent circuit it is clear that during the mode 1 condition voltage across the LC and the load voltage is eDC NS/Paso, it is just like a step down transformer. This is step down transformer so eNP/NS is the maximum voltage across the load considering due to ratio = 1 so you will get less than the voltage than this fellow.

The mode 1 is called the powering mode as an input power is transferred to the source to the load and next comes to the 2nd.

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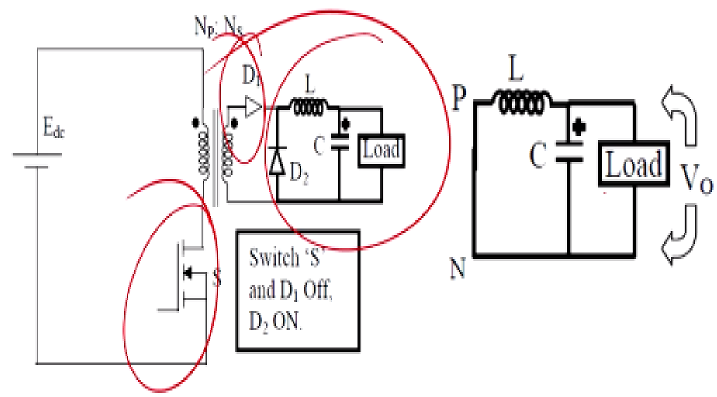
Mode-2 **Forward Type SMPS cont.**



Current path during Mode-2 operation Equivalent circuit during Mode-2 operation

When this switch is off and thus D1 is off ultimately this portion of the circuits plays and it we are assume that D2 is ideal that it can be shorted so you get this part of the circuit to be actually constituted and the filling to the load. So, this is the oscillations of the network.

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Mode-2 **Forward Type SMPS cont.**

- When 'S' is turned OFF, 1^0 and 2^0 winding currents of transformer becomes zero.
- But 2^0 side filter inductor maintains continuous current through free wheeling diode D_2.
- D_1 is reverse biased during this mode and input is isolated from output.
- Inductor current flows through parallel combination of load and output capacitor.
- During this mode, there is no power flow from source to load but output voltage is maintained constant due to large capacitor C.
- As charged inductor and capacitor is used in circuit, it provides continuity in load voltage. But in this mode, as there is no input voltage involvement, capacitor voltage and inductor current starts decreasing.
- Therefore to maintain continuity in output voltage 'S' is turned ON again.

So, when S is turnoff primary and the secondary winding current other transformer becomes 0 but secondary site filter inductor maintains continuous current through freewheeling diode D2. D1 is reverse biased so thus this bucking operation comes in to the picture apart from the trans ratio bucking D1 is reverse biased during this mode and input is isolated from output. The inductor current flows through the parallel combination of the load and the output capacitor.

During this mode there is no power flow from the source to the load but output voltage is maintained constant due to large capacitor a charged inductor and the capacitor is used in the circuit. It provides continuity in the load voltage but in this mode there is no input power involvement capacitor voltage and the inductor current start decreasing while feeding the load Therefore to maintain continuity in the output voltage AC is turned on again.

Mode 2 to maintain the load voltage within a desired tolerance band the filter inductor and the filter capacitor value should be chosen sufficiently large.

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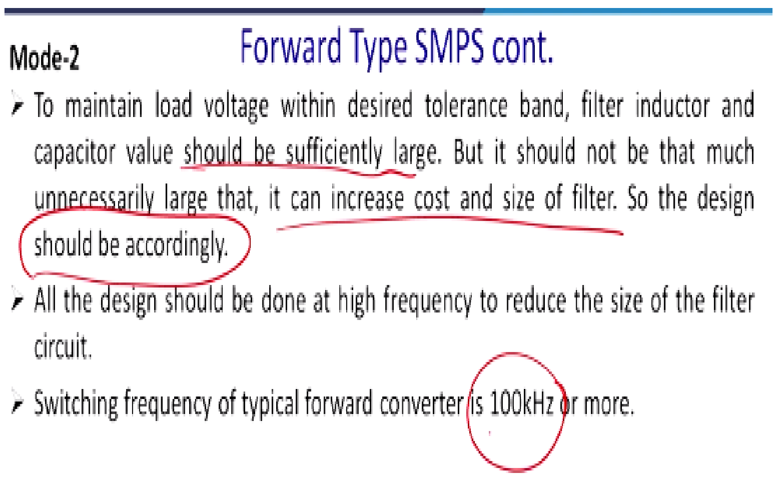

But it should not be that much big or bulky that it will be costlier bulkier weightier everything that can increase the cost size of the filter. So, design has to put a proper step to design this isolated DC to DC this type of 7.40 to DC to DC converter. All the design should be and high frequency to reduce the size of the filter circuits generally we can go up to a level of 1 kilowatt with that and switching frequencies. Typically of this converter we can choose MOSFET to have 100kilohertz switching frequency.

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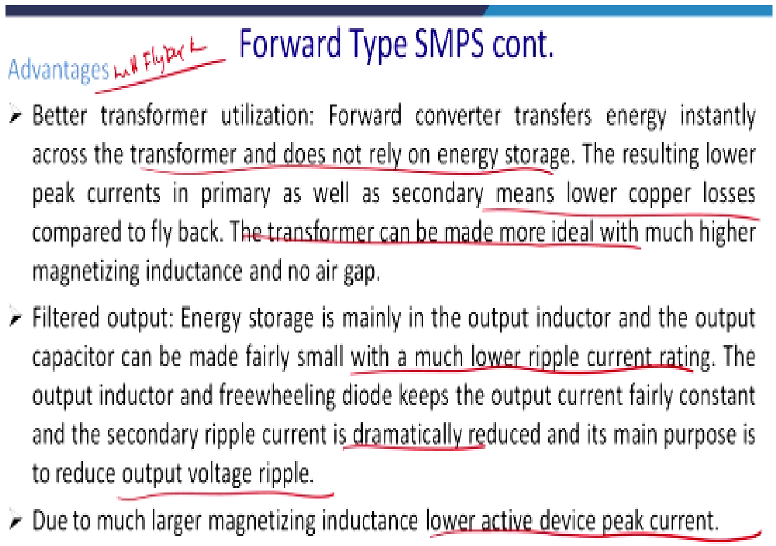

Now what is the advantage of this forward converter type SMPS over fly back advantage with respect to fly back when a transformer utilizations forward converter transformer transfers energy instantaneously across the transfer across the transformer and does not actually stored the energy. The resulting lower peak current in the primary as well as the secondary means lower copper losses compared to the fly back.

The transformer can be made more ideal with much higher magnetizing inductance and no air gap. Filtered output energy stored is mainly in the output inductor and the output capacitor can be made fairly small with a much lower ripple current rating. The output inductor and freewheeling diode keeps the output current fairy constant and the secondary ripple current is dramatically reduced and it is when process is to reduce the output voltage stable.

That is the one whole purpose of it due to much larger magnetizing inductance load active so that actually the current is less picky than this fly back converter. So, this is a one of the advantage of this forward converter disadvantage you have a more component counts.

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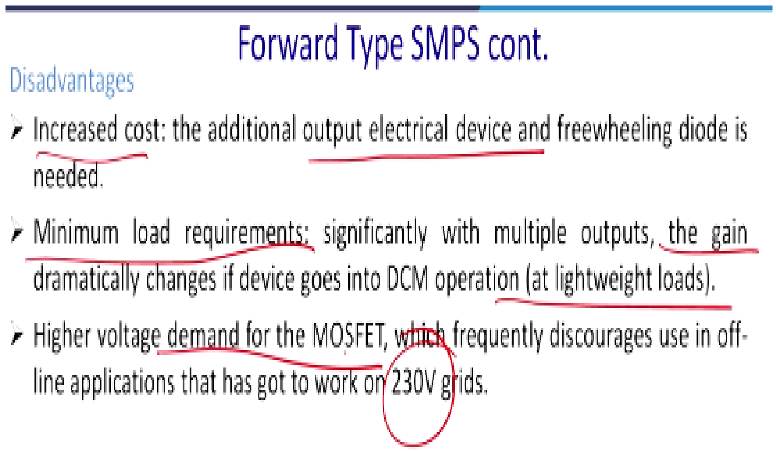

It increases costs the additional output electrical device and the freewheeling diode is needed please note that since you are operating at a very high switching frequency this diode required to be a very fast recovery diode and for this reason. It has it had to the considerable cost to the bill of material minimum load requirement. That is also a feature you cannot keep your load open circuited it significantly with the multiple outputs.

The gain dramatically changes if the devices go to DCM operation at light loads higher voltage demand for MOSFET which frequently discourages the use of line applications. That has got to work on 230 volt grids. So, these are few things we have to keep in mind.

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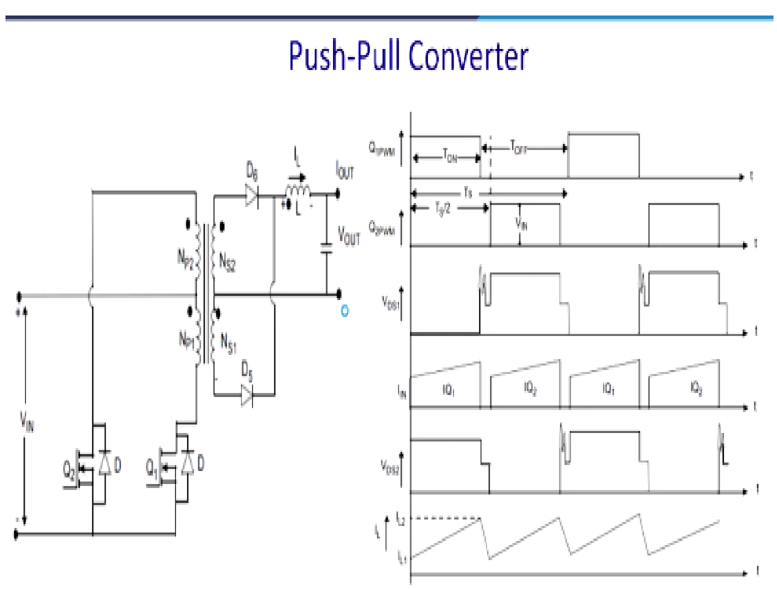

Now let us go back to the another converter essentially you couple one of the disadvantage of this actually isolated DC to DC converter which we have discussed is that we require to reset the flux and to reset the flux we have a constraint of the duty cycle and ultimately what happened then you have to feed power from the store energy in fly back switches or no power flows ultimately energy slice back and thus power handling capabilities is less.

And we cannot increase the duty cycle beyond 50% because then what happened resetting of the flux is a very big pen otherwise the magnetics will saturate same in case of the forward converter if you increase the duty cycle beyond some limits so resetting the flux is also a challenge. So, for this reason we require 2 because we have always told you that actually we have solved few problems in forward converter.

Because stressors across the switches here you know it is quite low because you do not have once actually previously what is to happen once. Once it is switch off so since there is no voltage across it so it is just blocking the voltage of VDC. It is not blocking the voltage VDC NP/NS * V0 so stress across the switch got reduced. But resetting have the winding has to be ensured by smaller duty cycle.

And thus power rating of the devices becomes lower so these are the few challenges which we wanted to remove in case of the push pull converter where we can actually think of that one push pull in for in actually one forward converter forward mode and another forward converter when operate which has been actually put together in parallel to give the more power. Essentially it will have a more power rating and you can see that.

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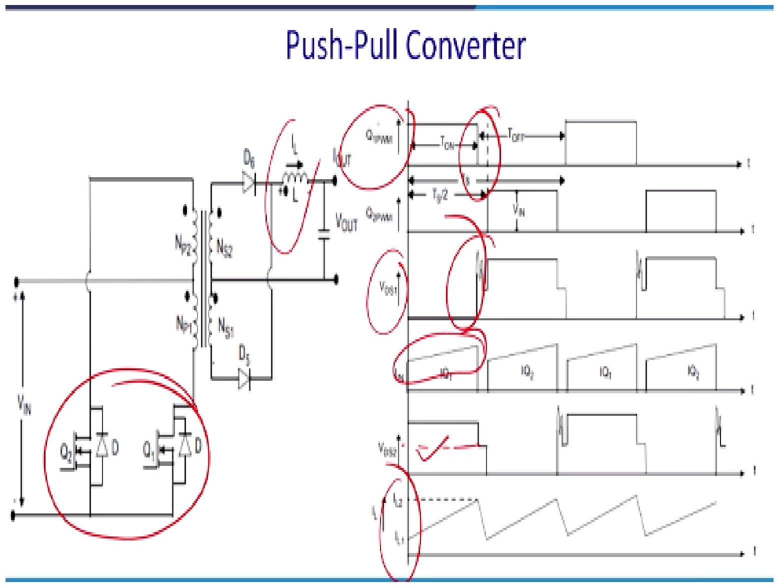

This component count is also increased it has the 2 switches but we will see that what are the actually the voltage is across the switch. And accordingly we will see the devices now you see that these are the pulses of switch 1 this and this is the pulses of switch 2 and that required to be separated by small time duration. And once actually since there is an inductance in the circuit so there would be a spikes.

So, this voltage is the VDC 1 and this is the voltage stress across the switch q1and it will be blocking that voltage still it is conducting then it will be a voltage of V in + the stands ratio of NP /NS. So, they will have to block once this actually q2 is off so voltage will come down to the level of BN and then once it is retriggered it will come down to the 0 same way we can have a replica of it which had not been shown so this is the D2.

So, we assume that this switch is blocking that voltage since it start conducting initially so this value is VN and thereafter and it is basically MP1 * S1 * V0 so this much of the volt is stress it has to block then it is been triggered and same cycle continues. So, this is the current you make continuous conduction mode for duty ratio for this devices and q1 is the current through the devices.

And this is the current the inductor IL which will assure we have assumed that it has a quite steady load and current is continuous.

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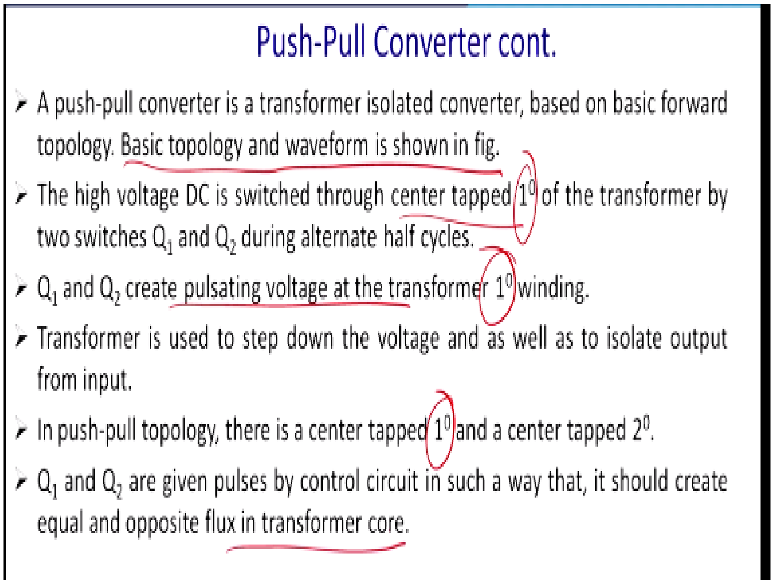

Push Pull converter is isolated transformer isolated converter is a transformer isolated converter based on basic forward converter topology it is been super imposed by the 2 basic topologies of the wave form shown in the figure in previous slides. The high voltage DC is switched on to the centre tapped of primary by a transformer by switch q1 and q2 in an alternate cycle. Q1 and Q2 create pulsating voltage as a transformer winding.

Primary transformer is used to step down the voltage as well as the isolated output input in push pull topology there is a central tapped of primary and the central tap secondary. Q1 and Q2 are given a pulses by the control circuit in such a way that it should create equal and opposite flux on a transformer so you need not have to wait of the resetting winding to actually reset the fluxes of the transformer.

So, there is no chance of the saturation of the transformer and you can take the duty cycle quite high level so let us talk about the first mode of operation it starts with the turning on of the q 1.

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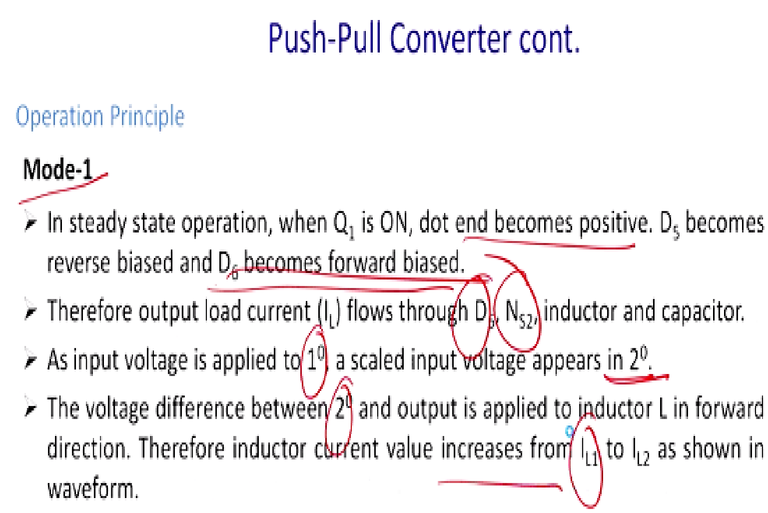

This is a mode 1 in the steady state operation when q1 is on the dot end becomes positive and D5 reverse biased and D6 becomes forward biased. Please refer to the figure then only you can understand it better. So, Q 1 is on so current will flow like this and ultimately this is the case of the figure so D6 becomes forward biased. Therefore the output load current IL flows through D6 and N S2 inductor.

And the capacitor the input voltage is applied to the primary is scaled input voltage appeared into the secondary. So, divided by N2/NS the voltage difference between secondary and the output voltage applied to the inductor L in forward direction. Therefore inductor current value increases from L1 min to L1 max subsequent time as shown in the wave form.

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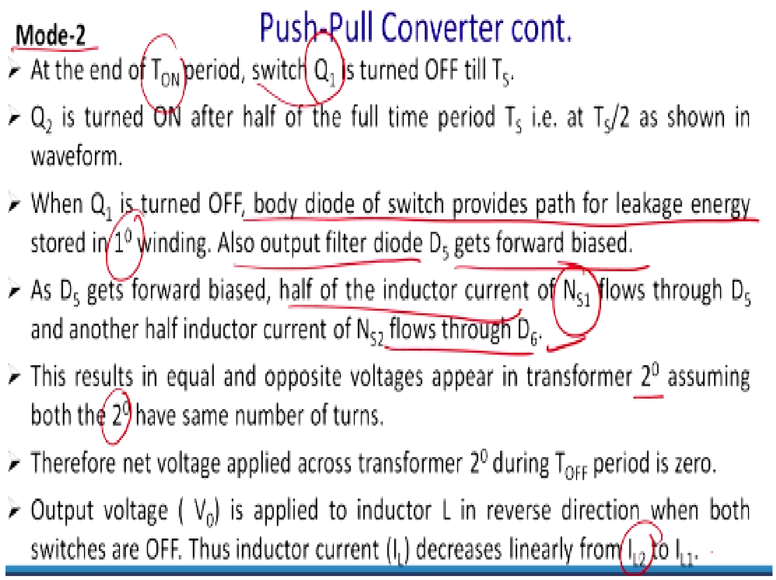

Now there will be a small pause between the conduction of Q1 and Q2 otherwise slice shot will occur so this small process has been neglected at the end of that t1 period Q1 is switched off till time Ts Q 2 is turn on after the half of the full time period Ts that mean at Ts /2 as shown in the wave form. When Q1 is off body diode of the switch provides the path for the leakage energy to be flown and if you use instead of the MOSFET for the other device.

You have to give anti-parallel path for the diet and the stored in winding 1 also the output filtered the D5 gets forward biased as D5 get forward biased half of the inductor current of the NS1 flows through the D5 and another half of the inductor current of NS2 flows through D6. This result in equal and opposite voltage appears in secondary assuming both the secondary have the same number of turns.

Therefore, net voltage applied across the transformer secondary during T off period is 0 output voltage V0 is applied to the inductor L reverses the direction when both the switches off. Thus inductor current IL decreases linearly from L 2 to L1 so it will come back to the thing.

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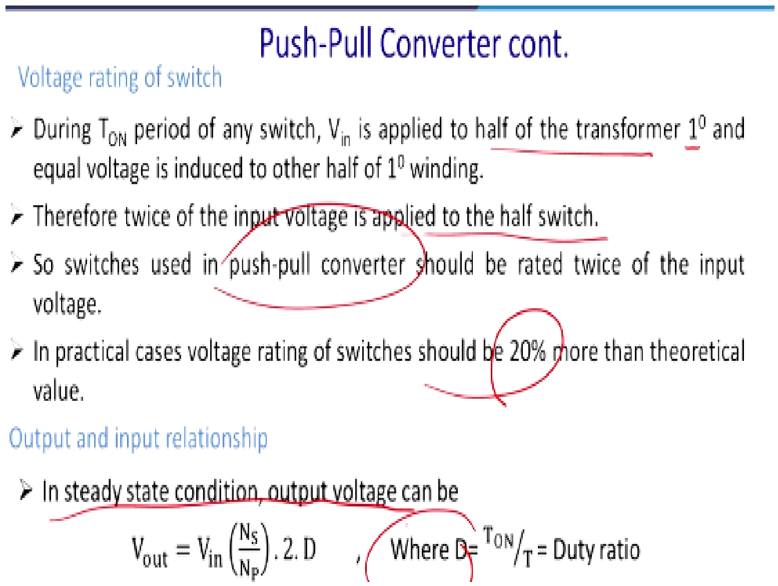

And now voltage rating of the switch during T on period any of the switch that Vin is applied half of the transformer of primary and equal voltage is included to the other part of the primary winding. Therefore twice of the input voltage is applied to the half of the switch so switch used in push pull converter should be rated twice of the input voltage as there is not much actually advantage of it.

In practical cases this voltage rating of the switches should be this percent more than the theoretical value for actually taking the factor of safety. So, we have the output input relationship across the switches in the steady state condition the output voltage can be V out = V in NS/NP * 2D where T = T on/T where is the duty ratio.

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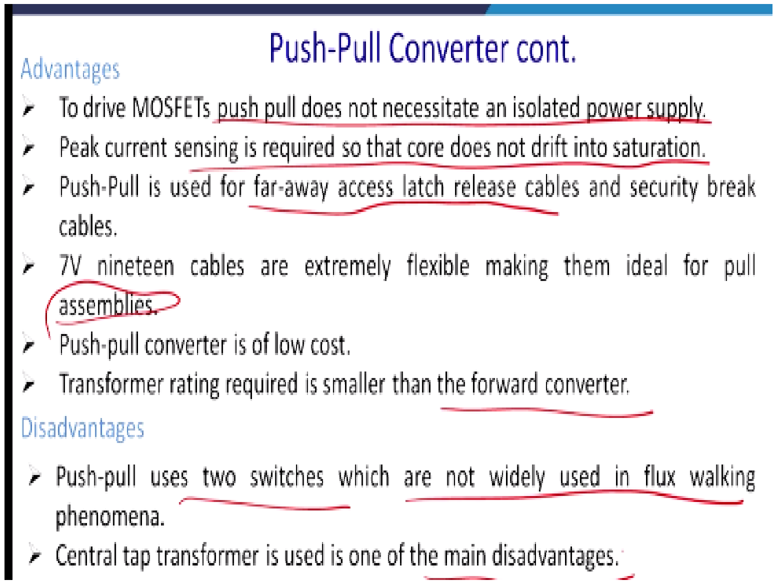

Now what are the advantage of this type of push pull converter one resetting of the flux is easy you need not have to we have not shown we require a compensating winding or the resetting winding in case of the fly back converter as well as the forward converter for resetting the flux and thus voltage stress that gives a voltage stress across the devices so for this reason here we have we it is automatically resets the flux in every cycle.

And if it is a little adjustment it is required we can do by little change in that duty cycle but that kind of facilities is not available in case of the fly back converter and thus you have been restricted to actually use your duty cycle less than 0.5 so and hence power transfer primary to a secondary is quite lower to drive MOSFET push pull does not necessary isolate power supply that is one of the biggest advantage of it.

So, you can take the supply you can actually same supply which you are taking as a input of the DC there you can actually scale it down by may be a small scale scaling resistance and you can give the same power to the actually to the MOSFET driver chip. Peak current and sinks is required so that core does not drip in to the saturation. Push pull is used for far away access latch releases cable and security break cables.

7 Volt 19 cables are extremely flexible and make them ideal for the assembling of this push pull converter. Push pull converter is of low cost thought it uses multiple switches but you will find

the rating of the switches is quite low and it can take more power than the forward and the fly back converter. Transformer rating required is smaller than the forward converter. But only thing you would have to keep in mind you required extra switch.

Push pull converter uses 2 switches which are not widely used in the flux walking phenomena. That means flux balancing can be done central tap transformer is used in one of the disadvantage of the push pull converter because generally we do not manufacture central tap converter. So, now let us we have solved few problems. You know while in a first class other DC to DC converter.

I said that there are 3 4 challenges in DC to DC convertor isolated DC first challenge is resetting of the flux and in fly back you manage with the resetting winding and thus you pay the price having huge stress across the switch and also you restrict the duty cycle less than 50% and thus what happened. You transfer less power from the primary to secondary but it is 1 switch phenomena.

Forward converter nowhere better actually since it will transfer the power from instead of the storing. So, site of the basically electrical parameter gets better because forward converter is more picky forward converters are less picky. Sorry, than the fly back converter so AM I MCS and all those other issues are there where forward converter basically defeats the fly back converter and in push pull convertor since 2 switch typology it resets the flux in their pre cycles.

And stresses across the switch is the stubble of this DC bus voltage and you can trust and you do not have any limitations of the duty cycle so instead of.

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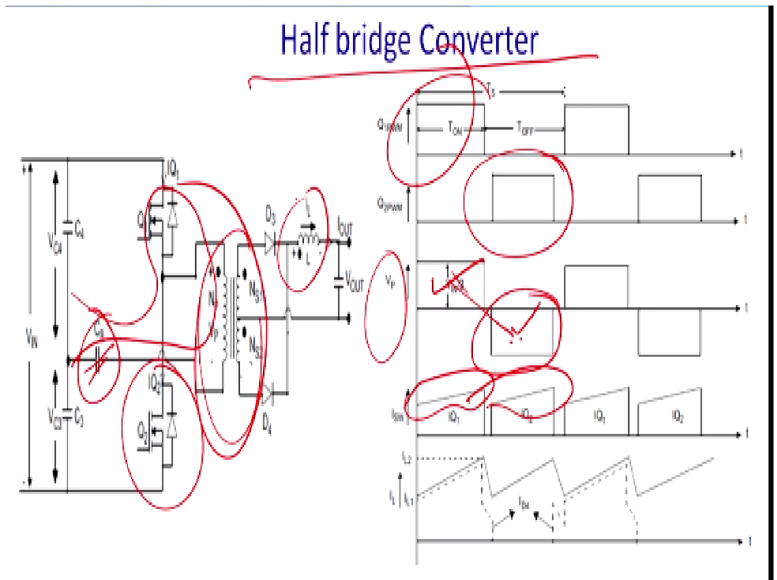

So, instead of actually this push pull converter one of the disadvantage of the push pull converter that it use the central trap transformer and thus it is with required extra winding and it is bulky and costly and there we go for another topology since it uses the 2 switches it is the half bridge converter. Half bridge converter uses 2 switches you have to give a DC blocking capacitor what happens generally this q 1 and q2 may have a small difference of the time period.

It may be as low has 1% deviation or 2% deviation but 1% or the 2% deviations in to this switching may lead to the saturation of the transfer. So, DC blocking transformer required to get DC blocking capacitor required to keep so that what happened this actually this core does not get saturates and we shall see that stress across the switches and all those issues here and we will find it is better off than the push pull convertor.

So, this is the pulses and for the switch q1 and this is a pulses of switch q2 you can see that this is a primary voltage across this transformer and it is VP and which is half of the voltage of the DC link voltage. Since actually q1 is triggered current is flowing through this and ultimately this point is blocking the half of the voltage. So, voltage rating of the switch is just by 2. Similarly once actually you got negative cycles so you got a positive voltage cycles.

And negative voltage cycles when actually q2 is triggered automatically flux gets adjusted unlike all the distributers you can whatever we have discussed till now we have not balanced the flux in that way by switching way and here you have a chance to balance the flux balancing by really applying the negative voltage across this transformer and you are setting the flux in every cycle and so on.

And this is the current across the switch once it is triggered we assume that current is continuous conduction mode. And thus q1 is actually current q1 is actually going on. Then after once q2 is triggered then i q2 is going on and so on. And you have the inductor current that is L1 and L2 and it will be a super impose of L1 and L2 and that gives you this kind of ripple current so this is the explanation of the half bridge convertor.

And it has a huge power handling capability power and since it uses 2 switches voltage stress of this switches is half of the receiver's voltage and all those advantages can be coupled in to the system and it can handle the power in the range of hundreds of watts. So, this is the half bridge convertor. We shall discuss about the half bridge convertor in our next discussions. Thank you for your attention. Thank you.