Advance Power Electronics and Control
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Lecture – 22
Isolated DC-DC Converters and Choppers

Okay welcome to our lectures on the advance power electronics and control today we shall discuss about the remaining part of the chopper there after we shall switch over to the isolated DC to DC to DC converters. So let us come to the point where we have left that is basically class E chopper.

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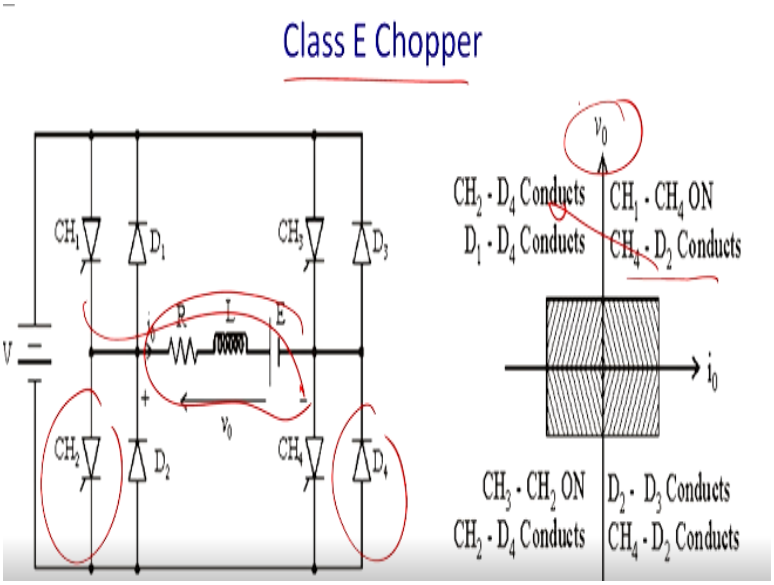

It is actually all the mode of operations for it is possible. So first quadrant mostly so first squadron mostly CH1 and CH2 is on while it is actually current flow in these directions and CH2 and DH2 conducts. So when it is actually regenerative braking then just this will have an interchange this nomenclature will have a inter change that is CH2 n D4 will conduct so CH2 and D4 will conduct and you will get a regenerative braking.

And since the voltage is positive and you essentially get a forward voltage mode and motor will be actually operating in the same directions and it is that motoring and then the regenerative braking. Same way if you wish to operate D3 conducts D2 D3 conducts and then for the

regenerative mode then for this actually CH4 and D2 conducts then essentially your voltage will be reversed.

And you will be operating in actually reverse motoring mode because your current is positive but your voltage is negative. And it is just opposite to it where you have a regenerative braking and it is possible to our regenerative braking and also in the reverse direction. So you will find CH2 CH3 will conduct this will be conducting so current will have a changes directions and CH2 and D4 will conduct.

So here please note that in this mode and this motor essentially you see that one of the changes here you can point it out very easily what are the things it will conduct. So here if current flows this direction of course you have to operate CH1 and CH4 so this will be operating and since current in unit directional so then the next case of course CH4 and D2 will conduct for octane and current will be always positive.

And now in this genre you can find that CH2 and CH3 on same way so this will be on and CH2 and D4 will conduct here CH4 and D2 here it is CH2 and D4 just actually the mirror image of this operation same way here and here you will find that basically CH4 D2 conducts here you will find that CH2 D4 conducts and also the diode will have an interchange because D1 and D4 will conduct in this operation.

Because voltage is positive and in this case since voltage is negative D2 D3 will conduct. But here this will fast on will be when D on will be operated by CH24 but first D2 and D3 will conduct in reverse mode there after followed by CH4 and D2. So this is the 4 quadrant operation of the chopper.

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Class E Chopper cont.

- Class E chopper is a 4 quadrant chopper.
- When CH_1, CH_4 are ON, output current i_0 flows in positive direction through CH_1, CH_4. So output voltage V_0=V. This gives 1st quadrant operation.
- When both CH_1 and CH_4 are OFF, output current i_0 flows in same direction through load, D_2, D_3 due to inductive load. So output V_0=-V. Hence chopper operates in 4th quadrant.
- When CH_2 and CH_3 are triggered load current i_0 flows in opposite direction and as well output voltage becomes V_0=-V.
- As both V_0 and i_0 are negative, chopper operates in 3rd quadrant.
- When CH_2, CH_3 are OFF, load current flows in same direction as before through load, D_1, D_4 due to inductive load. So output voltage V_0=V.
- Since V_0 is positive and i_0 is negative, chopper operates in 2nd quadrant.

So gradually let us brief on what we have discussed class E chopper is a 4 quadrant chopper CH1 and CH4 are on then output current flows in the positive direction through CH1 and CH4 . So the output voltage is positive and =V0 and it gives a first quadrant motoring operation when CH1 and CH4 are off the output current I0 flows to the same direction to the load current D2 and D3 due to the inductive load.

And current to assume to be the continuous so the output voltage becomes negative hence chopper operates in the 4th quadrant when CH2 and CH3 are triggered there after then the load current i0 flows in opposite direction and the output voltage also become negative and motor will start operating in a reverse direction. So both V0 and i0 are negative chopper operating third quadrant.

And there after when CH2 and CH3 are off and load kind flows in the same direction as before through the load and D1 and D4 due to the inductive loading earning and hi constant current high value of the current because of the may be the high track and we assume that current to be continuous not necessary constant. So output voltage be can V0 and so it is basically the 4 quadrant operation. So since V0 is positive and i0 is negative again chopper will come to that second quadrant.

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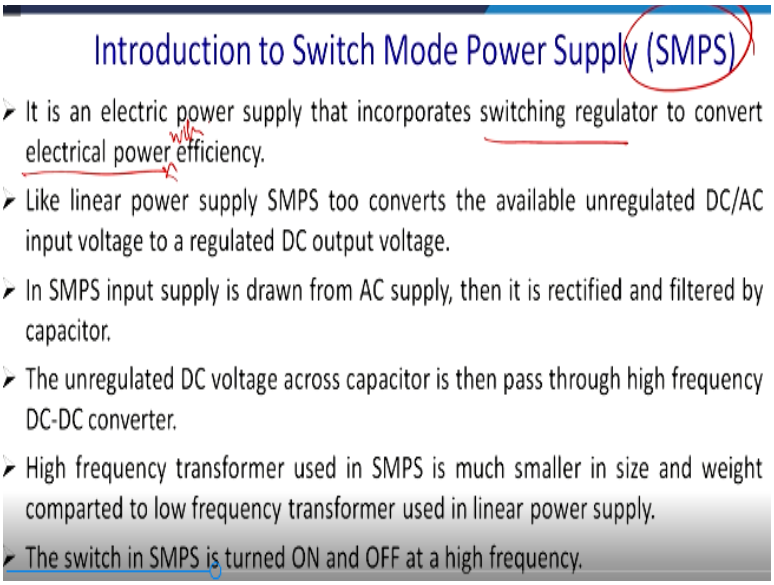

Now let us come to the new topic that is very important for more present perspectives this is again as DC to DC converter and this DC to DC converter requires there is a little bit change of this DC to DC converter what we have discussed it. So we all are aware of this term SMPS switch mode power supply and switch mode power supply this name is familiar with our history goes with the desktop.

So we say that switch mode power supply is operating already this is a faulty or whatever it may be SMPS so there is a actually a point of using the SMPS. SMPS essentially as synonymously used as isolated DC to DC converter so why isolation we have to flow power from input to the output and that load may be very sensitive like your desktop like your laptop like your mobile.

And you want that disturbances also surges or any other disturbances okay input side should not cripple or damage your highly sensitive load are you got a load side protections and for this what you want you know in between there will be a flux linkage on galvanic isolation and due to that you get a more controlled power or more purified power more safe power at the output and that is a one of the best advantage of SMPS.

And SMPS you know this magnetics comes into the pictures are not bulky because you know it uses the high frequency and the size of the core is reduced and you may have a compact packaging also which who can refer you can refer to those actual charger of iPhone it is quite

compact so it uses the same kind of circuit. So it is an electric power that incorporates switching regulator to convert the electric power with high efficiency.

We can convert power and also with a huge change in an input and the output variation. Let us see you are using a mobile charger and you have taken to the countries where it actually supply voltage 110 volt it is an 220 volt in India. So you should be able to use that so their SMPS fights its application like your laptop which are using in India it is not like that you would not be able to use the same laptop charger in USA.

Because please understand that all of us most of the laptops are now manufactured in Taiwan and it has been actually totally exported to the various countries so this has a compatibility is available with your laptop charger. Like linear power supply SMPS too converts the available unregulated DC to AC input voltage to a regulated DC voltages. Most of the cases, your plugin so you get a rectification.

So far this you got a unregulated DC stage and you may your voltage may actually sack soil surge anything can happen but you get a regulated DC at your output voltage. The SMPS input supplier is drawn from the AC supply then it is rectified and filtered by the capacitor and you have seen the challenges. Nowadays, actually modern way of rectification is a PWM rectification which we have already discussed.

The unregulated DC supply across the capacitor then past the high frequency DC to DC converter because in between you have a high frequency magnetics high frequency transformer used in SMPS is small in size since you know that actually V=BANF there will be a cost and generally if it is sinusoidal it will be 4.44. So if you can increase the frequency so the same voltage reckoning for these value.

Essentially it is a B and the area B is the flux density and area of the A is the area of the core. So B will be depending on the material you can choose a different material and thus value of the A will decrease. The high frequency transformer used in SMPS is much smaller in size due to that

and weight compared to the low frequencies actually transformer used in linear power supply generally we have most of the use most of you have done

Basically used it for your BTB project all you will be using it so we use actually IC regulator 7805 that gives you regulated 5 volt and essentially what you do your solution is quite bulky what you do essentially you actually rectify you have you use a very bulky transformer of 0 to 12 + -12 actually 220 volt to 12 volt or 9 volt from there actually you get it rectified by a bridge rectifier that you put a filter and then you put this 7805.

That is series IC regulator so that is a way of doing it and you can you have if you have used it you can imagine that how actually bulky is your solution and instead of that actually same thing is has been done by your laptop your mobile charger and how compact it is. So high frequency transformer so the switch in SMPS is turn on and turn off at high frequency and that is a challenge you know.

So for this reason what happened we generally preferred MOSFET as a suitable design and most of your below 100 kilowatts these are all MOSFETs sorry below 100 watts these are all MOSFETs.

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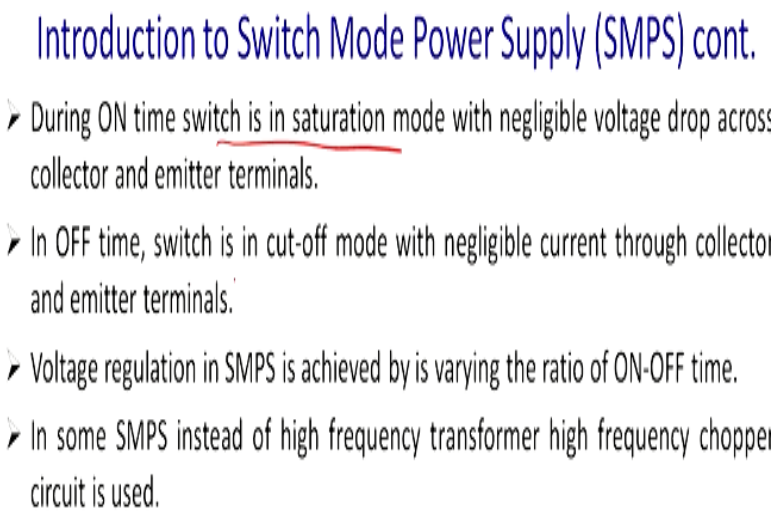

During the ON time switch on time the switch is actually in a saturation mode so that you have a low conduction losses or that negligible voltage drop across a collector and the emitter or the in case of the IGBT or the drain and source in case of the MOSFETs. So if you require to go a little bit of higher power rating then you get to use the IGBT. The OFF time of the switch is in cut off mode and with a negligible current through the collectors and emitters or drain and source and thus turn of losses is basically at the when it is switch off.

So there is almost open circuit condition prevails and when it is switch on short circuit condition prevails. The voltage regulation in the same place its achieved by varying the ratio of T on and T off. Same way we have seen that plug boost and plug boost converter and Cuk converter. So some SMPS instead of using high frequency transformer. Use high frequency chopper is used for the higher priority.

Generally, it uses GTO but of course you have to be operated around sub kilo hertz frequency. So maximum you can go as high as actually a 1 kilo hertz and your power rating can be much higher you know around 100 kilowatt. So let us come to the linear IC regulator you have most of users used this.

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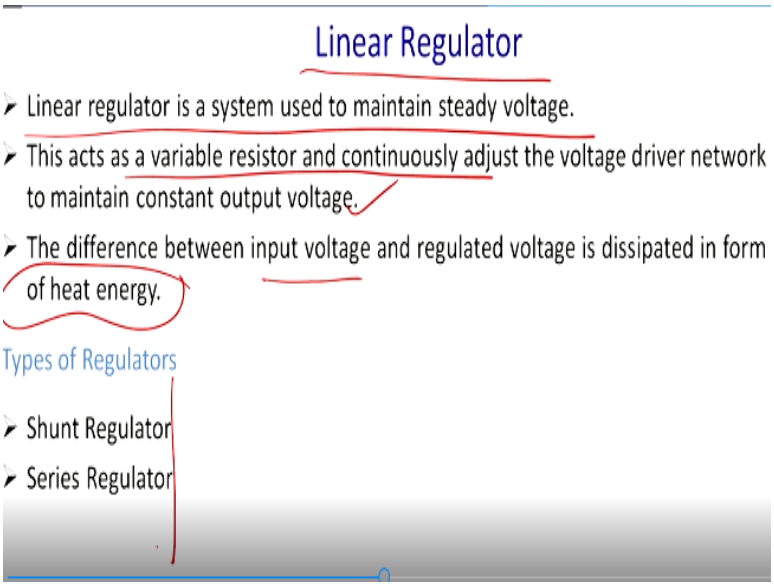

Actually I was naming 7805 7812 that is 12 volt regulated IC and mostly where actually input and output are very close we will be using this kind of IC. So let us see the principle operation of

this IC regulator. Mostly these are quite actually these are used for the for the great driver circuits of this converters. The linear regulator system is used to maintain the steady voltage these facts is a desirable resistors continuously adjust.

And a voltage driver network to maintain that cost and voltage but you have to ensure that this input and output voltage are quite close to each other to have high efficiency the difference between the input voltage and the regulated voltage is dissipated as a heat. So if it is a huge difference the huge chunk of the energy is being dissipated as a heat. So that will be inefficient solution moreover actually will provide a sink to the actually dissipate the heat. So there are two type of regulator 1 is shunt regulator another is series regulator.

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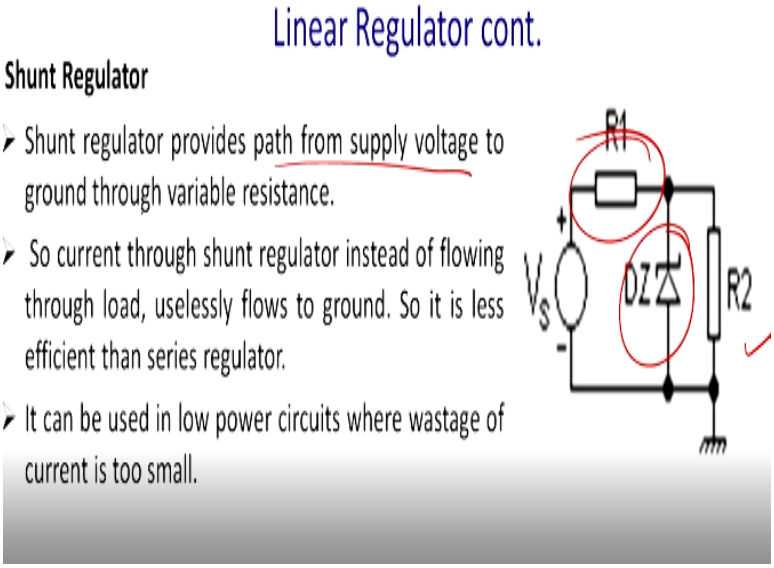

So shunt regulator is essentially who can simplify like this there is a you have studied in the analogue electronics. So that is you got a current control resistance and this a Zener it will have a sharp cut off voltage and you will get a regulated voltage here. So Shunt regulator provides a path for the supply of the voltage but there will be a constant power dissipation across this R1 path supply the voltage to the ground through the variable resistance.

So the current through the shunt regulator instead of the flowing through the load uselessly flow to the ground so it is less efficient than the series regulator and it can be used for the low power circuit where wastage of the current is too small and generally it is used for the gate driver or

actually or biasing of the transistors in signal level. Now let us come to the second point that is this is a series IC regulator.

See that and what happened that these IC regulator actually will have feedback anyway there are more common and efficient solutions actually what I was talking a little bit ago 7805 seven 0/80 0 table these are all series regulator. It works by providing a path from supply voltage to the load through the variable resistance. Power dissipated by regulating the device equal to the product of the power supply output current and the voltage drop of the regulating devices.

So actually if you variable resistance then voltage will change if voltage is changed and 1 current will flow and then actually we have to regulate this voltage we will come the next circuit I will see that how does it operate and it is operated by a feedback. So for the better efficiency and reduce the stress across the devices regulator should be design to minimize the voltage drop.

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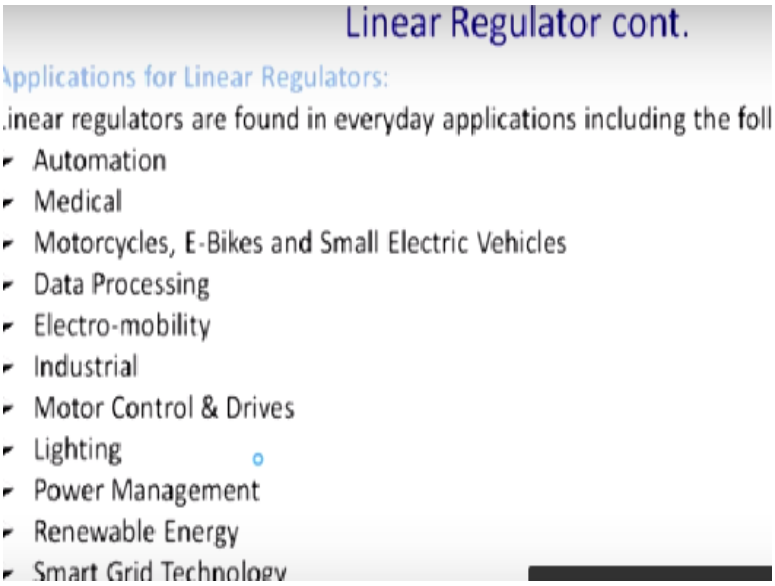

So we can find this actually IC regulator everywhere for the low power applications in case of the automation like you know you use mostly a multi we use basically a processor or the or this actually microcontroller and you know the simplest microcontroller you might be using for the BTB projects and all. So that is that can we use for the automation so you can use it for this medical operations so you require a very regulated power supply.

And they are actually you do not want that actually the switching. Switching willing actually gives you the Mi MC and that is not actually possible to use so and that could be hazardous to the patient so in that kind of applications we are monitoring any voltage or current. Voltage or pulse rate or something or amplifying. So there kind of these applications actually this IC regulator is preferred motorcycle E bikes and the small electric vehicles.

So they are also where voltage difference is not very large because you have a 12-volt supply and also you have an almost 12-volt consumption. So there you can use you can use for the data processing electro mobility and other drives and you can use for the lighting and the smart grid technology.

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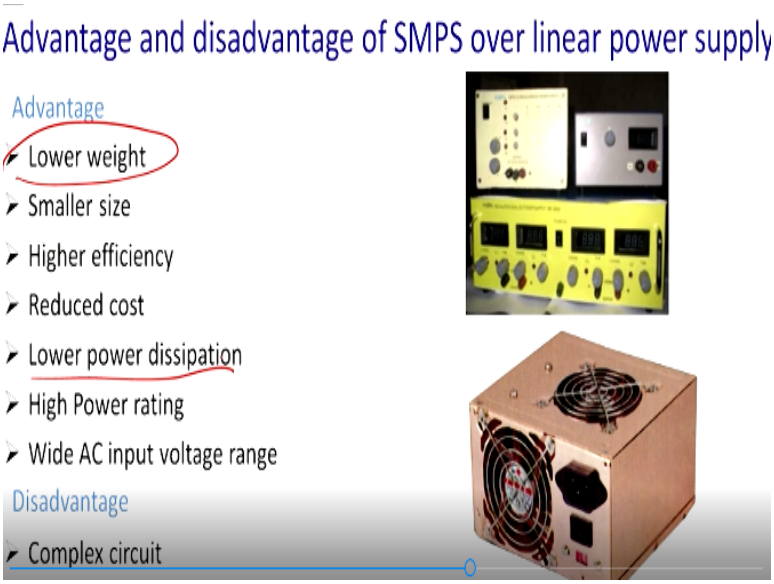

Now let us come to the SMPS so you can use those things but if this actually mostly you use those things for because you actually verify the concept without the prototype but in actual practical application where power rating become high then we have to replace this IC regulator by SMPS. One of the advantage of the SMPS of the it will have a lower weight with the power rating and the smaller in size higher in efficiency reduce cost and lower power dissipations and high power rating it is possible to go for the SMPS with a megawatt level.

Because you may have a offshore wind power plant and you would want to transmit that power to the HVDC link and that is also possible by a DC to DC converter. Wide AC input variation

range which as I was talking you know same laptop charger can we use to in India and the USA but disadvantageous is that design is a challenge you know. So there is a potential for the future engineer like you actually and there is a huge scope of and the huge job market for it.

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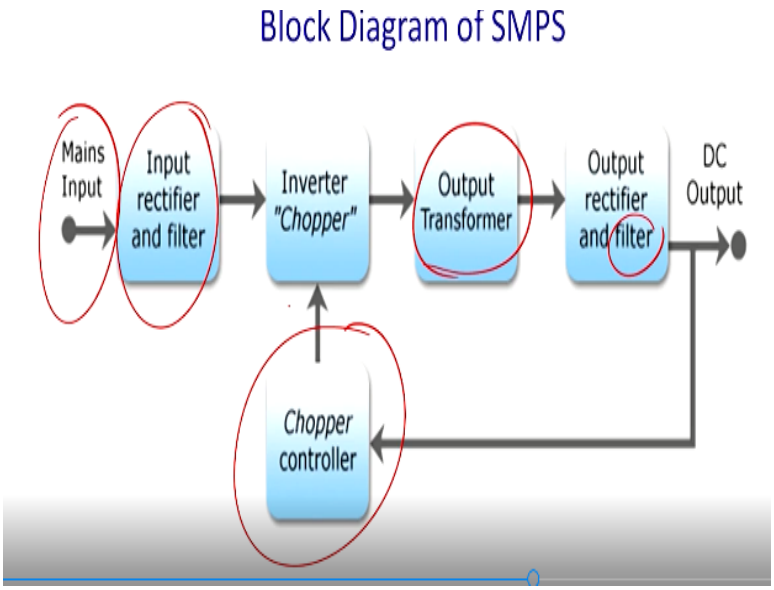

So essentially this is a block diagram of SMPS you got an inputs it may be actually regulated unregulated DC or AC. In case of this if you are using a solar panel kind of thing then it is a unregulated DC because its input voltage will change. Input voltage and current voltage will change according to the duration and the temperature. And this is a Mains input then they are really rectifier so if it is basically Ac input.

Then you have a inverter chopper will see to it actually how does it work so and it will be high frequency thereafter you have a transformer that is basically y high frequency transformer then you have filters to filter out the ripples and makes it DC and this filter and before that there will be rectifier and generally we use a different kind of rectification that is called a synchronous rectification D on the MOSFET is quite low instead of the diode drop.

So we can go for the lower losses by switching also and there is a DC output and you will be controlling the switching in such a way that you can get a regulated output voltage in this point and you know there if there is a step down and step up operation you can play with the

transformers trans ratio. So that is the one of the biggest advantage of it so if you are actually bucking up voltage like 20 times 30 times.

Then actually one of the disadvantage of the continuous conduct of the non-isolated DC to DC converter is that duty cycle will be quite low. So you know feel bucking to 300 to 5 bolt that is actually kind of a bucking you will get in case of your laptop a mobile charger mobile because if you have a you are feeding to the actually through a diode based rectifier the peak voltage of the DC is around 300 volt and since it is takes a very negligible amount of the current.

So actually you get almost a 300 volt and you are actually getting a regulated 5 volt. So if you use a non-insulated DC to DC converter so actually K actually what essentially you will get is basically 5/300 and you will be forced to operate in a discontinuous conduction mode and what we have studied all the analysis and this ratio is also flawed then. Because we are derived it for the continuous conduction mode.

But here you got an advantage here so you can also play with the trans ratio you can actually buck you can bucket by this transformer here and also you know you can have 2200 volt by 110 volt and you need not go to USA because if you are charging your mobile also in the trend that also has a 110 volt supply.

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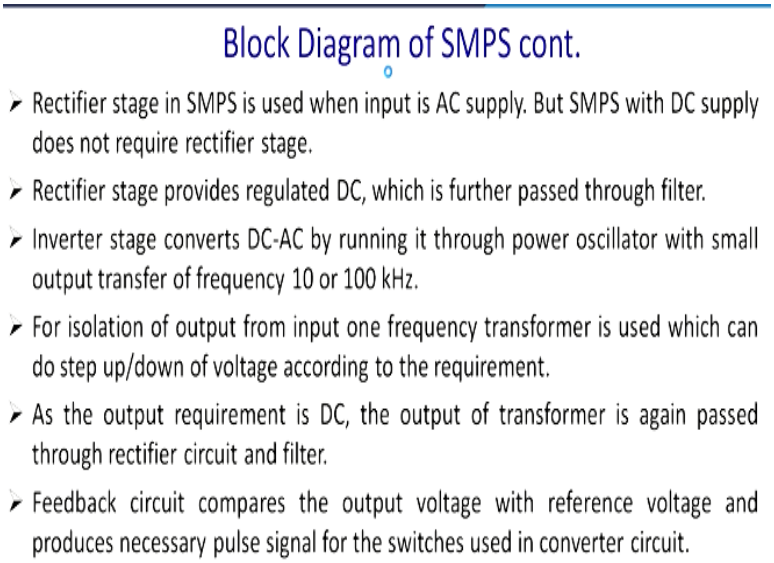

So it is a quite important aspect and its control is quite challenging and thus people like you has an advantage to walk on it. The rectifier stages MPS is used when input is AC supply but SMPS with the DC supply does not require a rectifier stage. So you can have a huge variation of your input rectifier stage provides a regulator DC which further process to the filter in what does stage converts DC to AC.

By running through it the power oscillators with a small with small output transformer frequency ranging from 10 to hundred kilohertz. And the power rating is actually just reverse so it can go to 1 kilohertz to 1 kilowatt to 100 watt. For isolation the output from the input 1 frequency of transformer is used which can step up or step down voltage according to the requirement. So as the output requirement is DC.

The voltage of the trial the output transformer is again pass to that rectifier circuits and filter and it gives you the refills almost a ripple free DC. Feedback circuit compares the output voltage they will be outer we have discussed that thing in a buck and boost converter analysis. Feedback circuits compares the output voltage with the reference voltage and produces a necessarily small signals for the switching used for the control of the converter.

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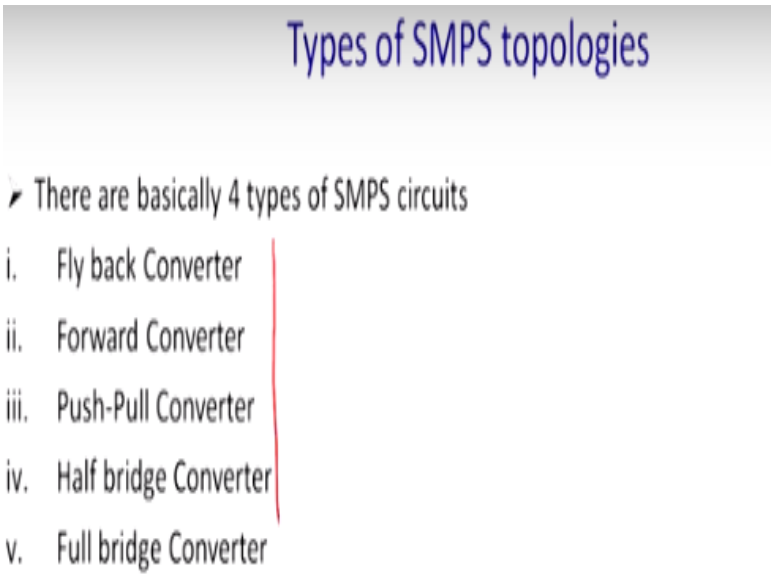

Now this we have named 5 topologies of the isolated dissipated second converter and these are essentially ascending order of the power. So fly back can be operated maximum around 250 watt

it is a challenge to have a fly back to be designed mode than 250 watt. So there after till around 2 kilowatt. So all your laptop charger SMPS of your desktop your mobile charger essentially falls into this category of fly back converter.

Now forward converter it will have a ranges of around 2 kilowatt and which you have which might be using mostly of your power supply DC power supply in your labs or have a little high current requirement like LED drivers or you have the for the lightings and all those issues you may use the forward converter and if you actually of course you know getting the forward converter over till 2 kilowatt It is also a challenge.

Because you know till now you can use MOSFETS now we required and basically switching frequency it can go as high as a 100 kilo hertz for hard to switching and there is also a concept called soft switching that is ZVS that is 0 voltage ad 0 current switching then you can go as I has you know 500 kilohertz may be. Depending on this parameter of the MOSFETs otherwise actually we restrict it to 100 kilo watts.

Because actually can this switching losses will predominates and so we have to choose higher rating MOSFETS here and this can be maximum we can operate in a range of the 20 kilohertz we shall see that why it has been restricted and there is a push pull converter so you can go out as high yes 5 kilo watt and you can extend that range to the 10 kilo watt and thus you required to use IGBTs and maximum frequency can we you know in the range of 10 kilo hertz.

And of course there is no harm we in push pull water operating for this 250 watts and you can choose a switching frequency of 100 kilohertz. So generally we do not do that so we have this kind of break up because this is simply a circuit and get really the number of switches get increased. Because this solution is a 1 switch solutions this solution is also 1 switch solutions but magnetics will be higher

We shall see that actually we should have a higher magnetic component here. Push pull is essentially the 2 switch solution and half bridge is also 2 switch solutions and there after full bridge is a 4 switch solution. Now there are few issues involved of the DC to DC converter since

in between you have a transformer. So if you once you are basically a chopping this and thus actually current will flow from this to this in case of the normal transfer operation.

You know fly back will be a different will come later so what will happen you know you will be when you were chopping if you have this kind of voltages and we are applying to the this is a voltage and we are applying the same to the transformer so then what will happen to the flux this is the integration of this voltage. So it will ramp on until this point thereafter it will be like this thereafter on this point and so on.

It will go up and after some point of time actually it will reach the phi m so ultimately this transformer will be saturating no out no actually no voltage will be linked to the secondary. So one of the requirement of this all magnetics based solution you require to reset the flux in every cycle and you have to you have to apply somewhere positive voltage then in some way you will reset it to the negative voltage

So that actually residual flux in this transformer becomes 0 this is the challenge here of this all these DC to DC converter. We will see that and due to that switch we will have a high voltage stress so you want to have this kind of voltage applied then you have to then you cannot continue to apply negative voltage for the same duration of the time what do we essentially you do a higher voltage.

And you try to reset this voltage flux this flux this integration of this time voltage come and then what happened the stress across the switch becomes higher and it should have an also the reverse blocking capability. So this is the one of the challenge you will see that as how you will reset the flux. Sooner you try to reset the flux then it will give you a high stress across the switching. Anyway we have another 3 4 drawbacks of the SMPS.

And we have to address it and we will find it out how it can be done for this is an design of this actually isolated DC to DC converter little challenging. Thank you so much for your attention. Thank you.