Design and Simulation of DC-DC converters using open source tools

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Lecture – 06
Startup surge limiting

In this video we shall discuss about a very important point that is startup inrush current limiting. Recall that I have mentioned this earlier to in one of the sessions that at the time of turn on the capacitor charge is 0 there is no energy in the capacitor and when suddenly the input source voltage switches on voltage is applied across the capacitor and for sudden changes in the voltage the capacitor will appear as a short circuit and a very huge current will flow. If by chance that at the point in time of turn on the input source voltage is at 0 then the inrush current is anyway automatically limited.

However, the turn on or switch on of the rectifier capacitor volt circuit will not be synchronized with the input source, such a case the worst case would be when the input source is at its peak VM. So, when the input source is at its peak VM you turn on the circuit capacitor voltage is 0 a huge voltage of VM value is seen across the short circuited path of the source through the diode and the capacitor. This will result in a very huge surge current which may blow off the diodes.

Therefore it is very very important that we provide some protection mechanism which will limit this startup surge current. So, that is the objective of this particular video captures and we shall see how we try to take care of this surge current.

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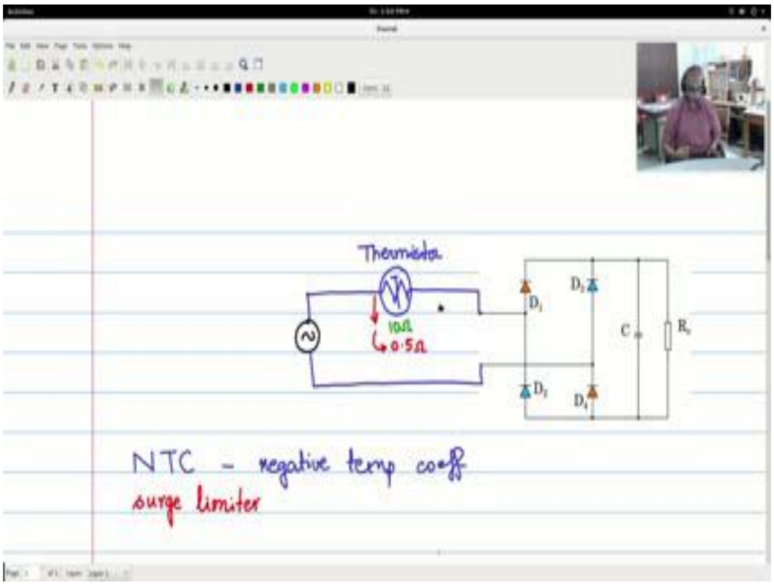

Consider this rectifier circuit here and this is where we connect the source the 230 volt AC. The moment you connect this impedance in this path is very minimal limited only by and the track inductance and the ESR of the capacitors and such of a norm idea it is. So, the inter-surge current at the time and the capacitance voltage is 0 can be pretty large which can glow up these diodes.

So, let us see what we can do to limit this inter surge current at the time of startup. One simple solution is put impedance in series here. So, what we could attempt is to the source we will connect a resistance Rs a series resistance and connect it in this fashion. So, this way this Rs can limit the startup inrush current and the value of the Rs can be chosen such that it is within the rating of the diodes. At the time of startup the voltage here is 0 maximum possible voltage at this node will be 325 which is 230 RMS into 2. So, 325 will come across Rs, so depending upon the rating of these diodes you can appropriately choose the value of Rs.

However this was not a very good solution in the sense that Rs will also dissipate power. The full load current is going to pass through Rs all the time and whatever will be the value of Rs I RMS square into Rs amount of power will keep getting lost in this resistor, so the efficiency of the circuit will come down. So, a simple solution to overcome this problem would be initially Rs can be in the circuit and once the capacitors built up charge Rs can be removed from the circuit that would be a nice solution to have. So, for that what people do is replace this - Rs, by a thermistor. A thermistor is a very special device, so this is a thermistor. This thermistor is called by various names in the market it is a single component, two terminal components available. It is also called NTC for negative temperature coefficient device. That is as the temperature raises a normal resistor a resistance value will increase, in the case of thermistor as the temperature increases the value of the resistance will come down will decrease.

So, how does it help in this kind of a circuit? Let us say at the time of startup the core value of the thermistor resistance is 10 ohms. Initially the 10 ohms will limit the startup surge current and the capacitor will get charged and reach a steady state. And as the capacitor reaches steady state the full load current is passing through the thermistor and it is dissipating heat and it will become hot. And once that starts becoming hot the resistance value of thermistor will decrease and it may probably become the order of something point by ohms. The hot value of the thermistors resistance may be 1 by ohms.

Now this is a significant drop. Now this is the very ideal component to have in this kind of a circuit where doing the startup the core value is very high limits the current and during the normal steady operation of the circuit the thermistor which would have become hot imposes a impedance of around 05 ohms. So, this was a pretty good component available it is also called surge limiter. Many manufacturers call them by different names this called surge limiter, thermistor, NTC negative temperature coefficient device; I have something like these some such kind of a name.

Now, we could just live with that, but the problem is that this has a low time constant. The change from cold value to hot value can take hundreds of milli seconds depending upon the size of the thermistor. You can find thermistors ranging from 1 to 2 amp at the lower end up to 50 amps or 60 amps at the higher end.

Now, imagine a situation where the bridge is working, reach the stable state, the thermistor is hot, and now the power goes suddenly. The moment the power goes suddenly the thermistor will not immediately regain its old value, it will take some time. And before that let us say the power comes back again. In such case the thermistor will not protect because thermistor has not yet regained its old value and you will have huge startup surge current which may at that time load the diodes. So, this is one disadvantage of the thermistor which you may have to live with or look for another solution. Another solution is probably we could use a relay.

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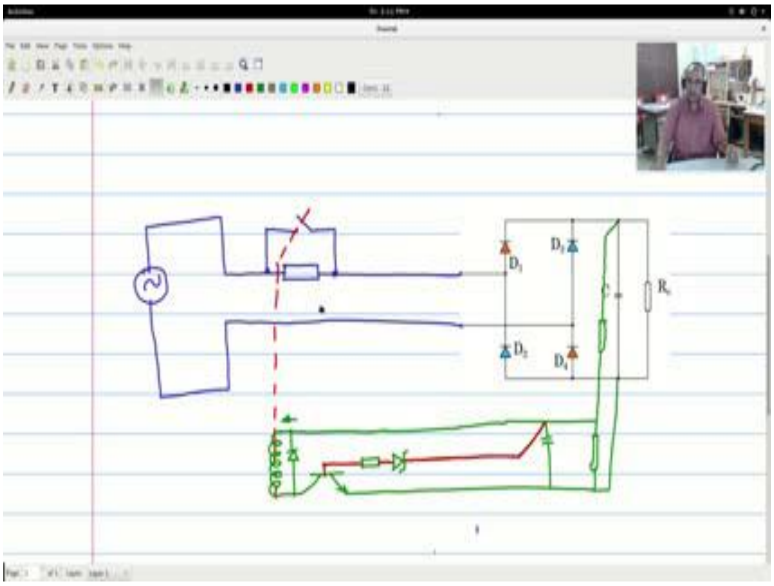

In this case we shall introduce light before the resistance as shown; the input source is connected in this fashion. Now what we do is connect a relay switch across this. Now this relay has to be energised, so energisation of the relay will be by means of a coil. So, moment when there is some current flow in the coil the relay will be energised and it will turn on it flows and bypass the resistance. The operation is pretty simple here. So, you have the source, the source is connected through the resistance to the bridge rectifier capacitor filter.

As long as the relay is off which is so, because we would not have energised this coil the current from the source passes through the resistance and back. Moment the capacitor voltage is built up let us say after 2 cycles we would like to close this switch. At that time energise this relay so this switch will be closed and now the resistance is bypassed current will flow through that relay and normal operation begins.

Now, the issue is how do we energise this? We could probably take from this capacitance, we tap the DC from this capacitance and then appropriately we need to this relay. So, how do we do that? Let me just give one typical sample circuit. Now let us say I put a resistance divider and capacitance like this so let me consider this as the common point for the relay circuit, then this is something like your attenuator. So, let us say I put a resistor here. If you look at this circuit, this circuit actually is not complete but the concept is like this we draw the power from output capacitor itself. As the capacitor voltage builds up this act like load and then charges up this capacitor this capacitor with DC and it will pump current into the coil so that the coil gets energised. But then the energising current that is needed for turning on this switch is decided by this resistor and by this resistor and these resistors.

You could also make this relay to work like in a switch mode type of configuration. I will show that also which would be a still better circuit. Now create it like a switch, I will erase this part, I will also erase a part here and now put a npn transistor and I need to try this transistor on, and now in a zener and then, we shall take from there and this we will join that, now we need a diode here for freewheel. Our case is bit complicated, but not so complicated. I will explain this.

Now, consider this portion of the circuit which is shown here in red that is the base drive for a transistor. Now start from the beginning; the supply is turned on, capacitor voltage is 0, this switch is off, the current flows through this resistor and charges of the capacitor. Now as the capacitor is charging up this potential is raising. As this potential is raising it will reach a point when this potential will be higher than this zener drop plus VBE plus 07. Once this goes beyond VZ plus 0.7 this will cut in and the base drive will flow through this transistor. Once a base drive flows through this transistor there will be a current flow through the coil of the relay in this direction. So the relay will turn on, which mean this will turn on and the current will now flow through the relay by passing the resistor.

Now let us say the power switch is off, the capacitor discharges, it discharges very quickly through the load because this is a higher current this is a very small current maybe 1 or 2 percent of the total load current to energise the relay, and this potential will keep dropping. Once this potential goes low this potential goes below VZ plus 0.7 this transistor will go to the off state. Once this transistor goes to the off state even if there is any inductive current this will freewheel in this fashion. You can just put a diode it is sufficient because the relay coils have very larger resistances at the order of 10 to 12 ohms.

So that will dissipate and when the power comes immediately the resistor is in action and after sometime the relay will come back into action once again . So, this is how the relay can help in limiting the surge current.

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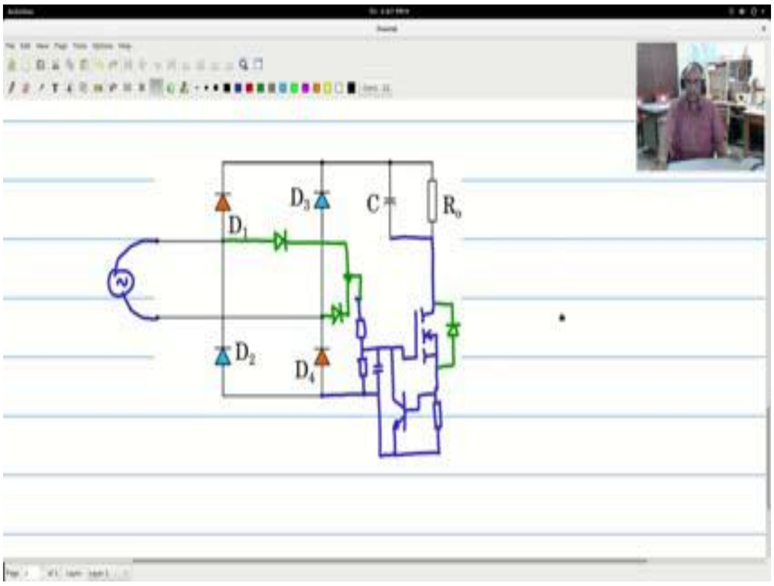

Another method of surge limiting is by using MOSFET’s. This is the regular rectifier capacitor filter circuit I have broken open this point, so this portion of the wire has been removed, so actually these two are joined together here. Now I would like to introduce impedance here. So, the impedance here is in the form of a MOSFET. Let me draw the MOSFET circuit here like this and we have a resistance division here another capacitance like this. For now let us say it is getting connected to this point, we have the source connected here. Let us say the source is turned on, capacitor voltage is 0. The source will go through and charge up this capacitance, the gate drive for the MOSFET increases.

So, the MOSFET cross the gate voltage crosses a threshold, the MOSFET starts entering into the linear region this resistance starts decreasing. So, when it is in the linear region we will see that the capacitor also gets charged, thereby limiting the surge current. And then as this further gets charged to 12 volts or 15 volts if this potential division is such that this will ultimately in the steady state come to 15 volts. This will be fully on in which case it will be the regular capacitor filter circuit.

When the source switches off the capacitor is a largest capacitor is a very small capacitor. So, there can be a significant amount of charge that will get dumped in here and this will not turn off, that is because there is a body diode present here. Every MOSFET has a body diode, which means that when these switches off this capacitor can have some charge flow like this and back here which means this will get charged and this will not turn off. So, we would like to decouple the output capacitor and the gate drive capacitor so that each can independently have its own type constant as per design.

Therefore, we will not make the connection here. We will remove that connection and we will make a direct connection to the input like this. Now this way the capacitor and this are decoupled. Now see the operation is exactly same as before only thing is that this and this are decoupled. Now, let us see the operation when you turn on the source will flow through like this charge of the capacitance and back again. Actually these two green diodes and the bottom diodes form a full bridge, these two will be signal diodes they will not be carrying power only the gate drive current.

So, as this is getting charged this is trying to turn this on this goes through the linear region tries to limit the current through this, and then after it reaches stable state this would be at 15 volts and this would be fully on. Now, when this goes off and the source goes off the capacitor will not be able to discharge, because these diodes are present into this. Of course, this will be charged through the load that is ok and that is allowed and that is desirable, but this capacitor should not come back and charge up this and that is prevented because of these two and these two decoupled full bridges. So, this way this MOSFET can behave like a linear resistor dynamically changing and limit the surge.

One more level of continuous protection that can be given in this type of circuit, for example I erase this portion look carefully I will now use a different colour, no I will use the blue colour itself. Now let us say I have a resistance like this and I have a transistor MOSFET and the transistor is connected like this and looks complicated but not so. Now, you see what happens. The normal operation is that let me remove this (Refer Time: 25:35) S. The normal operation is as discussed earlier now this extra thing has been put normal operation would be that it goes through like this the current flow is through the MOSFET like this and then back through (Refer Time: 25:54).

Now, when the current through this goes beyond a particular value, there is going to be a drop across this resistance. Now this resistance coming directly across the base emitter junction of this npn transistor. Once this drop this resistor can be so chosen that once this drop crosses 0.6 this tries to cut in. So, once this tries to cut in this impedance drops which means this capacitor will discharge through this and this voltage will come down. Once this voltage comes down MOSFET comes out of saturation goes into the linear region and tries to limit the current flow here.

So, this is a kind of a continuous self protection circuit very interesting this will never blow and this is what is called as the self protection circuit using the BJT. So, this is one of a very robust surge current limiting circuit that can be used along with the rectifier full bridge.

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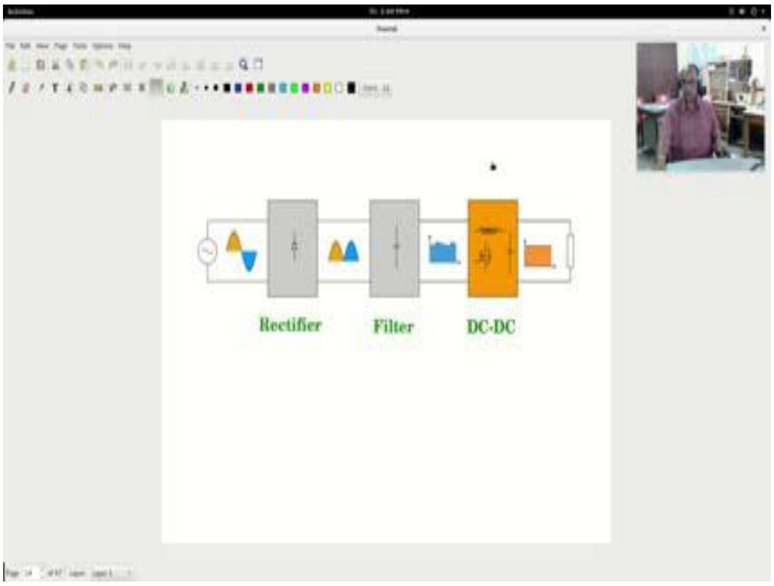

So, with this I will close this topic of rectifier and C filter. Let me get back to the overview slide. You see that we began with this description of the system overview we had discussed on bird’s eye view of the entire DC-DC convertor system. Till now we have discussed about the rectifier and filter we now know how to get a DC at this point from a 230 volt or AC input source. So, from now on all our discussions will be focussed on the DC-DC convertor alone and we assume that at this point we have a reliable DC obtained either from battery or from the rectifier filter combination.

I have also put few practical exercise tasks for you on the Google drive which you can download. Recall that we made an example of the rectifier filter in GEDS schematic, I have put that schematic also, I have put two other schematics too let me show them to you; in this folder.

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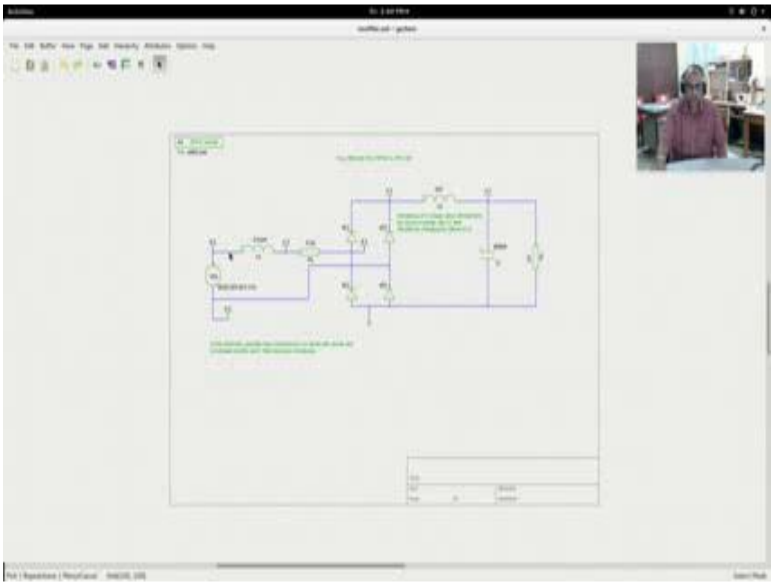

One other schematic is like this, you see here I have included two non-idealities; one is the track inductance from the source to the centre of the bridge on the AC side another is the track inductance from the rectifier to the C filter part. So, we include this and now we simulate and see what the effects on the various wave forms are. If you notice this inductance value if we keep on increasing, it will become the rectifier LC filter circuit, this one interesting thing that you should try.

Another exercise which I have included is this. I have put two resistors here and trying to restart the characteristics of this and characteristic of this so that all diodes will not have the same ideal characteristic. This is a practical scenario just observe the currents and the voltages for this too and play with these values apart from playing with these values. And this will give you a feel for what to expect in a real circuit on the oscilloscope.