CHARGING INFRASTRUCTURE

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Week-06

Lecture-30

Lec 30: Revisiting Isolated DC-DC converters-I

So, hello everyone, welcome to lecture number 30 of this NPTEL lecture on charge infrastructure. In this lecture, we will revisit some of the concepts related to isolated DC-DC converters. So, till now, what have we discussed? We have discussed the basic principle of an EVSE, and in that EVSE, one of the important considerations is the power conversion unit. In the power conversion unit, we have an AC-DC converter followed by an isolated DC-DC converter. Till now, we have seen the single-phase AC-DC converter, its operation, design, small-signal model, closed-loop control, and its CCM and DCM operation for the boost PFC converter, we have also seen the totem pole, which is a derived boost converter-based PFC converter. We have also seen the flyback-based power factor correction converter. Then, we extended our discussion to the three-phase AC-DC converter, its operation, design, small-signal model, and then we performed closed-loop control using the vector control approach. We have seen how we can implement vector control for a three-phase AC-DC converter. We have ensured both converters. While deriving the closed-loop control, we have ensured two control objectives: that the output voltage is regulated at a desired value (obviously, depending on the kind of converter, the minimum achievable voltage should be less than the required desired voltage), and along with regulating the output DC voltage, we have also ensured unity power factor current drawn from the source.

Once we have developed that, the next stage in the power conversion unit is the isolated DC-DC converter. If we see our power conversion unit, it looks like this: we have an AC source, an AC-DC converter, followed by an isolated DC-DC converter, which feeds the battery. Battery. This is a broader or top-level diagram. Now, if you look carefully, we can achieve unity power factor operation and obtain the required DC voltage regulation at the output of the AC-DC converter by appropriately operating the AC-DC converter. However, most AC-DC converters do not involve any isolation. So, that is why we cascade this converter stage with another converter stage, which is the isolated DC-DC converter. This isolated DC-DC converter performs two operations. One is controlling the output voltage and current going into the battery, and along with that, we also ensure galvanic isolation, which will ensure isolation between the battery and the grid, providing protection to the user who is charging their EV battery from the grid.

So that is why we will now focus our discussion on isolated DC-DC converters. Now let us see some of the commonly reported isolated DC-DC converters in the literature. So the first one is nothing but the forward converter. The forward converter is one of the isolated DC-DC converters mostly used for SMPS applications, aiming up to low power levels like 100 to 200W. Another one, which we have also discussed briefly in AC-DC conversion, is the flyback converter. Both are very well suitable for low power applications. However, when we go for higher powers, we have to look for another kind of isolated converter. Because of its operation, we will discuss one or two converters and their operations as we go along. We have another converter, which is nothing but a push-pull based converter.

The push-pull converter is again an isolated converter primarily used for slightly higher power levels up to 500W, not beyond that. Generally, it is not preferred, and we will see why. Then, the fourth power converter is the half-bridge converter, and the next one is the full-bridge converter. Then we have the DAB, called the dual active bridge converter. Now, there are certain variations of these converters, up to this point, up to the half-bridge converter, mostly these are used for low-power applications, while the full-bridge converters are generally used for high-power applications. Since our converters are of high power, we will generally use the full-bridge and dual active bridge converters. In the full-bridge converter, we can have unidirectional power flow, while in the dual bridge converter, we can also have bidirectional power flow. If you look very carefully, there are also derivatives of this because when the full bridge is operated with a special kind of modulation, it is also called the phase-shift full-bridge converter, which is abbreviated as PSFB, one of the commonly used abbreviations for phase-shifted full-bridge converter. In this converter, the structure remains the same; however, the switches are modulated differently, and that's when it gives the name of phase-shifted full-bridge converter. In dual active bridge, you also have some variations, like resonant-based DAB, which is nothing but a dual active bridge having the resonant circuit involved in the operation. This is the commonly used abbreviation for dual active bridge: DAB. Then you also have multi-level DAB for high-voltage operations. Multi-level DABs are also available, and we also have the resonant-based isolated DC-DC converter. In that, the commonly used converters are LLC or CLLC-based converters. So we can write resonant-based converters, in which we have commonly used LLC or CLLC-based converters. Now, if you look at all these converters, they have one thing in common: they all have isolation transformers. for isolation, which is supplied by high-frequency AC voltages.

That means we convert the DC quantity into a high-frequency AC, and that will be used to supply across the primary winding of this transformer. Now, one thing I mean you can ask a simple question: previously, if we look, we have an AC source. Why can't we provide isolation here? Why do we need an isolated DC converter? Now, you are The question is also valid: why can't we have the isolation directly at the AC? That means by putting the low-frequency transformer—the transformer working at 50Hz—why can't we put the 50-hertz transformer here and then we can just use a simple non-isolated DC-DC converter? But the problem here is one important thing, which is we know that our transformer works on the principle of Faraday's law of electromagnetic induction, and we know that the voltage is nothing but we can write the voltage induced as $N\frac{d\varphi}{dt}$.

So, we can say from this formula Our voltage is nothing but $N\Delta$ change in the flux, and this delta change in time, and that we can say delta T is nothing but it is inversely proportional to frequency. So, we can say it is nothing but inversely proportional to the frequency of the supply voltage or the voltage which is used to excite the winding. And this we can further write as V equals we can write N. In terms of flux density, ΔB into the area of the core over which the windings are bound, that means I am talking about the core. If there is a transformer here and if I am winding primary and secondary windings over here, applying V_p voltage from here, Apply V_p voltage from here and get some V_s voltage on the secondary winding. And this what I am talking about is the area of this cross-sectional area of this core. Cross-sectional area means if you cut this core, we will find the core to be looking like, you know, if we draw the 3D of this one, it looks like this. It looks like this. And we are talking about this area, this area of cross-section of the core.

So, we can write the flux to be ΔB, which is a flux density, flux density into area of the core multiplied by frequency of excitation of this from the primary winding or you can say the V_p, the frequency of excitation of this voltage V_p. in this one if you look very carefully in this case if let's see if the applied voltage is constant and our number of turns on the transformer windings are constant and our ΔBvalue is also you know if you look any core it has the bh curve if you look any core it has the B-H curve which looks like this going here then coming there, so it is nothing but it isB_{max} and this is I mean sorry this look like and this is my B_{min}. So, after this one the flux density goes beyond this then the core gets saturated, so we must have the flux density swing should be from B_{max} to B_{min} or maximum to be this below that it is also possible. So, let's say it is going from B_{max} to B_{min}. So that is also kind of constant we have assumed.

So now if you look very carefully, our area of the core is inversely proportional to the frequency of excitation from one of the winding of the transformer. Now that is very critical because if we see at this point, if we put our transformer directly at this point, Then what happens is that our transformer is seeing the primary voltage is having the 50Hz excitation frequency. That's when we have to calculate our AC, which ensure that ΔB is between B_{max} and B_{min}. And accordingly, our area of the core will go very higher value.

On the other hand, if we take this isolated DC-DC converter this isolated DC-DC converter converts the DC to a high frequency AC and that AC will be imposed or is used to excite the primary winding of the transformer since that is having the high frequency component so our area of the core gets reduced so we can say that if my frequency of excitation increases my area of core decreases and since my area of code decreases the weight and volume of the transformer reduced which is used for isolation and that's when we can get the very high power dense or very small isolated dc dc converter which can provide the isolation and can actually help to get the required voltage and current at this output so that is the reason why generally instead of keeping the transformer directly after the grid i mean which which is nothing but a low frequency transform instead of that people go for this configuration where they connect the grid to the ac-dc converter and then after ac dc converter they have the isolated dc dc converter because in isolated dc dc converter we have a high frequency transformer and because of going for high frequency transformer that means the transformer which sees high frequency excitation the area of the core which is needed is reduced and that's when we get our the volume of the core and volume of the transformer get reduced and that's when we can get the very small size isolated transformer and thus we can get very small size isolated DC-DC converter.

So, this is why they use the isolated DC-DC converter having the high frequency transformer embedded in it. So let us take one by one the operation of isolated DC-DC converter. Some of the converter flyback converter we have discussed some of its operation. Maybe we will skip that. We understand full bridge converter operation.

The half bridge converter operation is nearly the same. And we will see the phase shift full bridge converter, our dual active bridge converter operation, push-pull and forward converter operation. So, let us go and discuss those things.

So, first and forward converter is nothing but a for isolated converter is nothing but we will discuss which is a forward converter. Now, if you look in the forward converter what we have is we have the transformer which is bounded on a core with two windings the primary winding and secondary winding have we Np number of turns and Ns number of turns and turns ratio is nothing but $1/n$.

It uses one switch which is S1 switch and it uses two diodes D1 and D2 and then inductance and capacitance connected to the load output and it has the input voltage applied across it. Since it is a DC-DC converter, we have DC voltage applied and are actually this switch, this DS1, D1 and D2 are actually switching with that let us say switching frequency $f_{s\omega}$ and thus the period corresponds to that FSW is nothing but TS. So, we can say $T_s = \frac{1}{f_{s\omega}}$. and this in this switching period some of the portion of this switching period we will turn on the S1 and some portion we will turn off the S1 switch and we will see the operation of this converter. Now let us see the first let's see in dts period my switch S1 is on so at this period we can say S1 is on whenever the S1 is on what happens is that the the V_{in} voltage is applied across the primary winding. So, let us take this as V_P voltage which is applied over here so this $V_P$voltage will be nothing but my voltage nothing but equal to V_{in} voltage since my this S1 switch is on, so this V_{in} the voltage if you do the KVL in this loop this V_{in} is directly applying across the primary winding of of this transformer so that's when we are actually applying across the V_P V_{in} voltage at this point. So, we can say during DTs period, during details period my V_P or you can say V_s/V_P is nothing but N_s/N_P and which is nothing but equal to 'n' and that we can say that $V_s = n * V_P$ and $V_P = n * V_{in}$. So, we are applying across this $V_s/n * V_{in}$, $n * V_{in}$voltage is appearing across here.

Now since I am applying nvin voltage the positive polarity voltage here negative polarity voltage here because of this positive polarity voltage this D1 gets forward biased this D1 gets forward biased since this D1 gets forward biased this nvin is applied across one end of the inductor and on the other side we are having the Vo voltage applied across the other end of the inductor so if we do the KVL in this loop we will find my VL is nothing but N Vin minus Vo and since my this diode is forward bias I am applying the plus minus or voltage of this polarity across this D2 and that is why my D2 is reversed bias so this is become reverse bias and this is actually forward bias and because of that we are applying across VL and Vin minus Vo voltage some positive voltage we are applying across this inductor and this forward converter is nothing but is also called as a buck derived topology why we can say it is a buck derived topology because if you look very carefully at the output this this part of the circuit is similar to that of the output stage of buck converter where we have the inductor and capacitor connected at the pole of the half bridge.

So if we take the buck converter we have S1 S2 or you can take diode also L, C and R so this is our simple buck converter which looks like so if you look the output state it is similar to that of the buck converter. So that's why it is nothing but the bug derived topology since it is a bug derived topology we already know our v naught voltage what we are getting is actually smaller than that of the nv voltage which is applied over here. So, let us go ahead and see how the things look like.

So now if you look here we have our $V_L = n - V_o$voltage applied across the inductor at DTs period and since we have positive voltage applied across this winding. So we can say that our flux will go up this because of the voltage we know that $\frac{d\varphi}{dt}$ which is nothing but here which is $\frac{V_{in}}{N_p}$, this this N_p is the number of turns of the primary because

$$V = N\frac{d\varphi}{dt}$$

so $\frac{d\varphi}{dt}$ the slope is actually a constant slope because we are applying a constant voltage of V_{in} across the primary winding. So we can has this flux going from zero some zero value to some value let's say define this one value as let's say phi m and if you look very carefully since we are applying the positive voltage from across this inductor so our current through the inductor if we define current through the inductor let's say this is I_L this I_L is nothing but having the rising slope and this rising slope is nothing but the slope of this will be $\frac{nV_{in}-V_o}{L}$, where L is the inductance we put in the circuit. and since my DS1 is off. So, we can say that my DS1 the current through DS1is zero because the current is only going through the S1 switch and we can say that the voltage or you can say if you try to see the voltage of across V_{DS1} the V_{DS1} voltage the V_{DS1} voltage is nothing but since there is no current in this path and there is a V_{in} voltage which is applied across V_p. So, it has the voltage which is nothing but equal to V_{in} voltage. We are applying a constant V_{in} voltage across this particular diode. So that is what we have drawn this V_{in} voltage. Since the S1 switch is on, so the voltage across S1 switch is 0. And since we have this I_L current which is flowing through this, we have to take from the secondary side to the primary side. And that's when we will see we have the current $N\Delta I_L$ is there. And along with this, we have in this some portion is the inductor current which is reflected in the primary side and along with there is also the magnetizing component of this transformer because if we draw the equivalent circuit of this diagram of this transformer, so it will look like this. We have our If we assume the winding resistances are nearly zero, so we can say this is some Lm of this transformer core and this is nothing but the leakage inductance of this primary side.

This is the leakage inductance of the secondary side. So, $L_{lkg,p}$and $L_{lkg,p}$refer to L. primary side and this lm is also referred to primary side so this there is some current which is also going because since you are applying the constant v in across this this terminal. So we are having the some current which is you can say that i am magnetizing component of current and that magnetizing component of current will also be rising linearly and that's why this particular slope or you can say from here from here to here you can say there isΔI_L because this ΔI_Lgoes from this minimum value to maximum value that the current going from I_{Lmin} to I_{Lmax}. So, this is nothing but you can say $N\Delta I_L$ and some portion is because of this $N\Delta I_L/2$ and there is some portion because of I_m.

And that's why this point is nothing but $\frac{\Delta I_L}{2} + I_m$. where I_m is the current which is going through the magnetizing branch of the transformer to magnetize or to build the flux in the transformer core. Now what happens after DTs period we will now turn off my switch S1 that's when we are now applying during 1- DTs period we are actually turning off my S1 switch S1 is off during this point so we can say that since my S1 switch is off what happens is that in this transformer there is a current which is going in this direction before the switch was off it was a current which is going in from here it is going in the this direction and suddenly you have turn off this S1 switch Since you have suddenly turn off this S1 switch, this current which was some non-zero value will now goes to zero because you have suddenly turn off the S1 switch. Since there is current value or you can say the current going through the primary winding is actually going from some non-zero value to zero value, you have negative di dt which is appearing across this Vp winding.

because now you have some non-zero value let's say some i value and you are now going to value 0 so it is $\frac{0-I}{\Delta t}$, so that's why we have $\frac{di}{dt}$ which is a negative quantity and since i have negative $\frac{di}{dt}$ we will be applying $-L\frac{di}{dt}$ across this across this transformer and as a result of which because of this $-L\frac{di}{dt}$ we have on this side we have some negative voltage which will be appearing across the secondary winding and since the negative voltage is appearing it's because the dot polarity is now negative . So this V_{in} other winding also the dot polarity will be negative and that's when my diode D1 will get reversed bias. and since my diode D1 gets reversed bias the current which is going through the output inductor will be actually need to find a pathway and that's when it will find a pathway through this D2 diode and since there is no path for this current to go so this I mean the current through inductor could not be changed suddenly. So, this current will find its path through this diode , so this current which is coming over here will now find this path and you have this circuit in which the current gets circulated and if you look very carefully this side is reversed bias so there is it is like this side of the circuit for this transformer is open circuited the output inductor current will be going through this diode D2 and the primary current which was already there at some non-zero value will be actually flowing through this DS1 and R_f resistance. Now in this particular circuit we have something like , we have something like you know this kind of circuit. This diode gets forward biased. And we have this circuit which is. This diode is forward biased. DS1 is forward biased.

And this we have R_f. So this is nothing but going through here. And only the magnetizing component will be here. Because the load component is actually flowing through this part. Because if you look very carefully when S1 was on.

So the current through S1 is carrying the load part which is carrying the I_L current and along with that it is also carrying the magnetizing component of current as well. So now only the magnetizing component of current remains. which will be actually flowing through this R_f. And then in this circuit, it is a simple $\frac{L}{R}$ circuit. And the flux, which was reached to some maximum value of flux, will now decay down through this RF resistance.

And if let us say, if this winding is having inductance Lm, which is a magnetizing inductance, so this flux will die down with nothing but the time constant to be equal to Lm by R_f.

$$\tau = \frac{L_m}{R_f}$$

And finally, by the end of $(1 - DTs)$ period, the flux will be completely zero and it will come back to its original state. And then in the next cycle, it will again start from same zero value going the straight line. And now during this point, since this side, since my D1 is reversed bias, the I_L current because of this, in order to keep this I_L current flowing, it will be flowing through this D2. What we will see is that across the V_L, we will have the voltage to be equal to minus V_O voltage is appearing across this I_L and that is what we are writing down, which is $- V_O$ voltage which is being applied.

Since this is the scenario, so this$I_L$will be now dropping down. I mean the $\frac{di}{dt}$ is negative. So it is nothing but with a slope $\frac{-V_O}{L}$ slope and Since there was a current $\dot{l}m$ current, which is actually since the flux is die down exponentially, the current also will die down. $\dot{l}m$ current will also get die down because of this transformer core flux gets reset through this R_f resistance.

And that's why you will see that this I_{DS1} current is actually from this peak. Let's say the i_m is the peak value. Capital I_m is the peak value of the magnetizing component of current. So, it is nothing but the magnetizing component of where I am and it is dying down and that also has the time constant $\tau = \frac{L_m}{R_f}$

And since we have current which is died down from some peak value to 0, we will have voltages applied across this going from negative value of $I_m R_f$ because if we do the KVL in this loop, we will get $I_m R_f$ and it is going down to 0.

Again, here also the time constant is nothing but $\frac{L_m}{R_f}$. And if we see the V_{DS1}, since my V_{DS1} is now on, it will have only the forward voltage drop of this DS1. That's why it has some negative forward voltage drop or you can say because we have defined the polarity positive and negative in this way. So, there is some negative voltage which will be coming across. And now, if we look very carefully, since my S1 is off, so in this loop, if I do the KVL, what I can say that my VS1 is to be nothing but equal to whatever at the initial period is nothing but it is imrf which is the current which is going through here plus be in voltage which is applying over here that's why you will see this part of this there is a huge voltage which will be appearing across the vs1 and this form from here to here it is nothing but you can say imrf and that will die down and finally by the end of it when it died down it will have only the Since there is no current through this, this circuit will no longer exit and this V_{in} will directly apply across the S1 switch. And that's when we have at the end, we have the V_{in} voltage applied across this converter. And then in the next switching cycle, again the same thing repeats itself. And here I_{S1}, since I_{S1} is off, it is actually completely zero, before in DTs period the S1 will be carrying the reflected current of I_L along with magnetizing component of the current which is used to magnetize the transformer core. So that is why we have something like this, so what we see is that if in this particular circuit when we see the output inductor for DTs period

$$v_L = nV - V_0$$

and for $(1 - DTs)$ period

$$v_L =- V_0$$

so, we can apply the volt second balance balance of inductor l

why we are doing because obviously in inductor also inductor is also wounded on the core and when the positive voltage is applied across this inductor the flux in the core will rise up and then when the negative voltage is applied it will die down and finally it will be ready to actually use it for the next switching period and that's why we must ensure that the volt second balance or because volt second is nothing but the flux so flux must die down to zero whatever flux is going up has to come down to zero so that in the next cycle it will start from the same point otherwise it will because here if let's say the flux goes like this comes back here then in the next cycle it will again start from the same point zero If it is not like this then what happens there is some DC offset in the flux which will keep on grow and after some time the inductor will get saturated. So we must ensure that volt second balance of this L must exist.

So now when we do the volt second balance, we can apply

$$\left(nV_{in} - V_0\right)DT_S \pm V_0(1 - D)T_S = 0$$

$$\left(nV_{in} - V_0\right)D - V_0(1 - D) = 0$$

And then if we do that calculation, finally we will get V_0 is $V_0 = nV_{in}D$

and D value will always go from 0 to 1. So that is why this is nothing but n equal to 1 then we will get the voltage output voltage. Similar to that of the buck converter that's why it is a buck derived topology. Here two things we can control once I mean in the design stage which is 'n' and once we decide the number of 'n' it is only we have control over the duty ratio which can be done. It is and this particular in this one we are applying a constant frequency.

And if you look very carefully in the I_L, we have I_L goes from I_{min} to I_{max} then comes to I_{min}. And so that particular ripple, it has the some DC component along with that it has the ripple. That ripple will be flowing through the capacitor C while the average value is actually going through the load R_L. and that we can say that load R_L. And similarly, this load value will also get reflected on the primary side. And in this one, this has the I_L.

So, this is peak value is $= \frac{nI_L}{2 + I_0 + Im}$

Maximum value is going up to I_0. Because I_0 plus this term which is $nI_L/2$ and this term which is Im. So, if we can write very clearly this one, So, this is nothing but my $nI_L/2$, this is my Im. So, we can write this overall term to be $\left(\frac{nI_L}{2 + nI_0 + Im}\right)$ which is get reflected onto the primary side.

And this is how we can ensure that the operation of this forward converter works in this way however this particular converter structure has some disadvantages let us see what are those disadvantages and of this particular converter so let us take the disadvantage of this one some of the disadvantage of this kind of architecture which we discussed this forward converter configuration is nothing but first In order to ensure this transformer does not get saturated, we must ensure that the flux which was rises up to φ_m or maximum value must die down to zero. Let us take my flux starts from here. Let us take my flux start from zero.

Assume it goes to this point phi m and then it comes back and it is not falls to completely zero. that is at this point it falls down then and the next stage it will again rise. In the next point, it has not completely gone down to zero. It is some non-zero value. Then in the next slide, it will go back slightly up φ_m in the next cycle.

And then it will fall down again at some higher value, higher than the previous value. And then again, after some time, if you look after some time, what we will see is that this flux goes here. What we will see that after some point, we will see the flux will start from some very large non-zero value goes to the φ_m and then falls to this point that means at that point this phi m could be greater than the maximum phi max of the core and that's when my core gets saturated after certain point this is quite unfavorable condition so i must ensure that the flux must die down to 0 and that I can ensure if I can ensure that my this $(1 - DTs)$ period is sufficiently larger enough such that the flux gas die down to 0 and if we ensure that sufficient $(1 - DTs)$ duration is there that's when we have to limit our switching frequency so we can write sufficient

1 minus gt has period and that is the reason why it will limit the switching frequency because we actually want good amount of time we should give to the transformer core flux to die down to zero and so we must provide a sufficient time for the core flux to get to zero that means we must ensure that we must provide a good amount of one minus gts period and that will actually put limitation on my switching frequency because if i have the some minimum value of the one minus gts period has to be provided then we have to provide some minimum value of Ts, because in order to ensure we have sufficient DTs duration as well. So, we our switching frequency is limited as the transformer core must reset, must reset to 0, 0 value. Then the second point what we have here is since we are using the diode we have the reverse recovery losses of the diode

and this will also limit our switching frequency operation a third point if we look very carefully we have lossy reset of

the transformer reset of the flux in the transformer core. We have a lossy reset of the flux in the transformer because it is getting a reset using resistance R_f, and that has I^2R loss. So, we have the lossy reset of the flux in the transformer. Then, the fourth point is the core utilization is limited. Why are we saying core utilization is limited? Because if we look very carefully in this particular system, the flux value is going from zero to some maximum value and then coming back to zero. So, we are only using one quadrant of the B-H curve. We are not going to the other quadrants of the B-H curve. That's when we are actually utilizing our core to half the value. So, that's why we can say the core utilization is limited. Because if we can say that $V = N\Delta BAf$ and frequency$f$, since if the ΔB goes from Bmin to Bmax, then my area of the core will get reduced accordingly. And if my ΔB goes from zero to Bmax in this case, then a larger core area is required. Just to ensure the core does not get saturated, a larger core area is required here since the flux goes from zero to Φ_m, or you can say the B is going from zero to Bmax value. So, our core utilization is just half. We can say that core utilization is limited. We are only using the first quadrant of the B-H curve. Then, the fifth point is, if we look very carefully, this switch S1

has to block higher voltages when it is turned off. So, the switch S1 voltage rating is higher than Vin voltage, higher than Vin. What it indicates is that we have to size our switches accordingly for the higher voltage ratings. So, let us say if we are using V_{in} equal to 100 V, we have to size our switches for more than 100 V nearly 200 V or accordingly, whatever the value of R_L and I_m we have while designing. This particular topology has some advantages because it limits the switching frequency. So, we can also say that the size of the transformer core is pretty big. And since we are using the diodes, we have the reverse recovery losses associated with the diode, and that will again increase the losses in the system.

And that also limits our switching frequency because if you go for higher switching frequency, we have more amount of reverse recovery losses, and those reverse recovery losses are generally very large in terms of semiconductor losses. Similarly, we have the lossy reset of the flux in the transformer, and that core utilization is limited, and the switch ratings are also higher. So, we can say that this particular converter has some disadvantages. To address this, there are also other derivatives of the forward converter. We will discuss that in the next lecture. Thank you very much for patiently listening to this lecture.