Advance Power Electronics and Control
Prof. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology – Roorkee

Lecture - 15
Effect of Source Inductance and PWM Rectifiers

Welcome to our NPTEL courses on Advance Power Electronics and Control. Today, we shall discuss about effect of source inductance. This is a remaining part which was continually discussed in our previous class. That we shall discuss about little modern topic that is PWM rectifier. We have learned about the full controlled rectifier and half controlled rectifier and lot of topics, so we shall see that, but one problem we said, actually the TAC.

So but to reduce that TAC, you require a solution like actually 12 pulse, 24 pulse, even 48 pulse converter. When that require a definite structures, so that is not visible for small power household application where or not appropriate SUTC, like your mobile charger or SMPS of the desktop or laptop, are all basically essentially SUTC. So we shall see that, so it is an important topic have popped up, due to the invent of the actually more and more SUTC applications.

That is PWM rectifier, so we shall continue today, first the remaining part of the source inductance. In this session, we shall discuss in details about the PWM rectifier. So let us go back again actually in this configuration, we can see that we have talked about the RC load.

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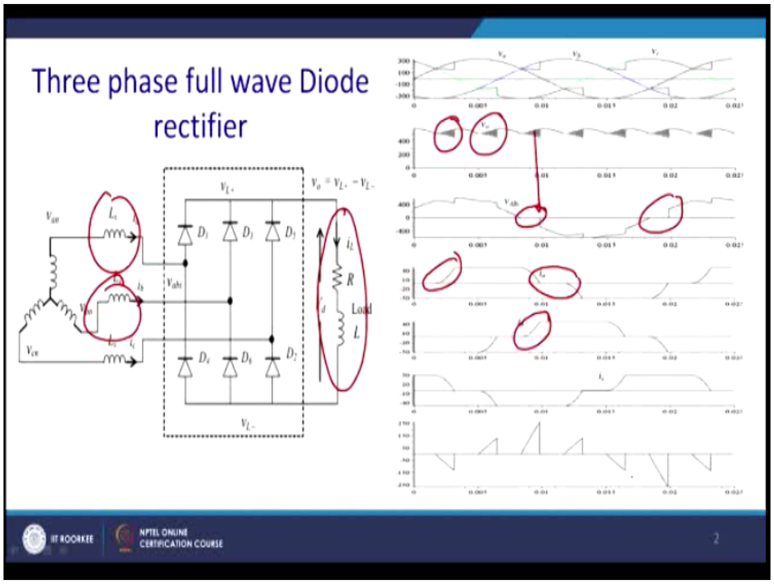

Now we talk about the RL load and we have some amount of a source inductance into the place. It may be due to the leakage reactance of the transformer or any external resistance added or even that actually that line has its own inductance. This is actually the three line voltages, 120 degree ampere balanced and ultimately you will find that actually this is the 6 pulse load voltages, but this hash area essentially you can find that where both diode, three diode is conducting.

Generally, what happens, 1 diode form the most positive phase for forward upcycles and the most negative for the negative cycles, that is the lower part, will conduct, but here we will find in this actually hash region three diodes are conducting. So what will happen, due to this conductions, you will find that actually at some point of time, let us say, this area where actually phase A, AB actually goes to negative, you will find that there is this particular to this area.

So you do not get any voltages. Same way, it will happen also when actually this conduction changes. Since there is an inductance, and actually, we will find that rise of the current like this. So it will take some time. The current through the D1 was actually to rise with some value and since before that D5 was conducting because it was a most positive state, so in this region D1 and D5 both will conduct for some time.

Thus actually there will be a dip in the load voltage. So similarly when actually A goes off, so ultimately it will do the negative half cycle, so then actually outgoing diode will come into the picture. B basically will pick up, so in this region also, so ultimately D3 will come into the picture and in this region also, you will get an overlapping and due to that there will be a little sack in the dispersed voltage and this will be the current of the IC and ultimately you will get basically this is the amount of the current.

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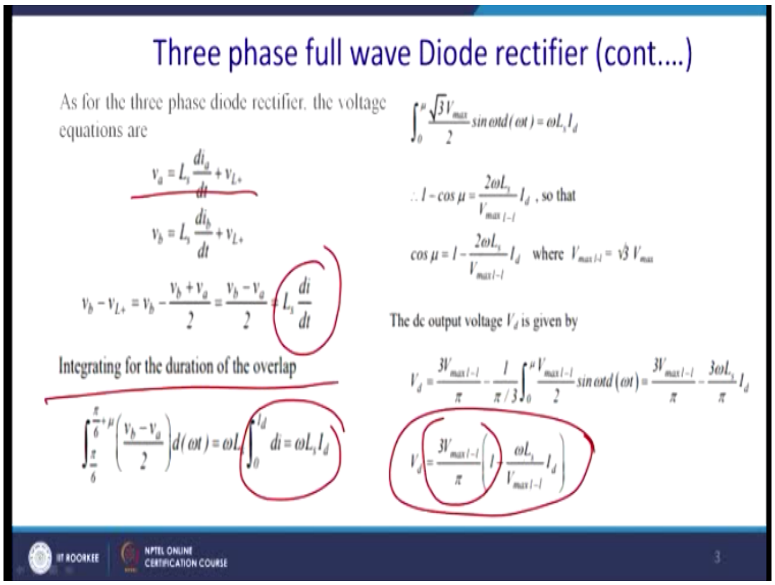

So let us analyse the circuits. So we can write phase values Va= when L Di/Dt of the source inductance plus the load voltage. Similarly, Vb will be the load voltage. So you can write you know actually Va-Vl=basically the source voltage. From there, we can integrate, we can find that actually from the time that is called overlapping angle pi/6 to mu+pi/6, so this incident will occur.

And so you have to find it out what is the amount of the ID the circulating current due to that time. So we will find that by integrations, actually cos mu=1-2 omega Ls. This is basically the line to line voltage into ID, where line to line voltage fall to root 3V max. From there, we can see that this part is basically the received output voltage without the source inductance and due to the source inductance, this part will be added up and that will reduce from the DC bus voltage.

So this is the effect of the source inductance. Diode with rectifier fitting Rl load. Now same way, we can draw the same kind of thing for the thyristors for the full control converter having a source inductance.

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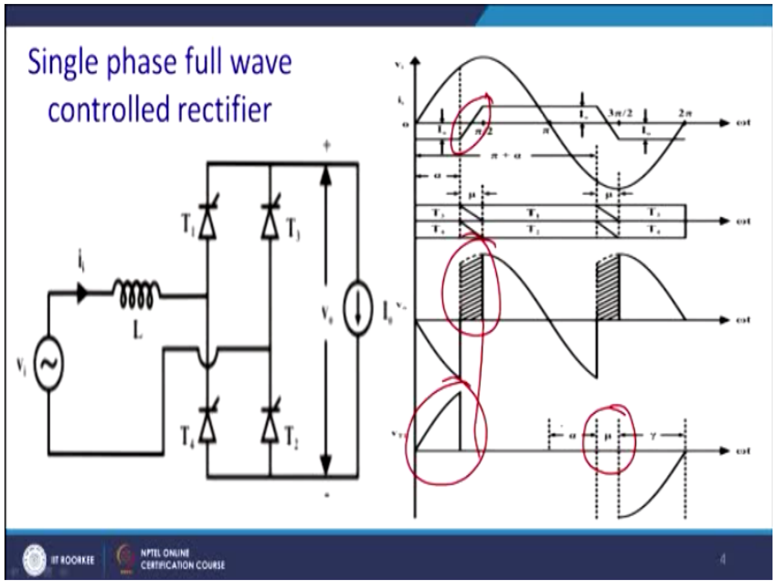

So ultimately, this is your source voltage and this is the input current and since this is the transition takes place. Ultimately, you will find that actually current will actually ramp on in this way due to the source inductance and since this area, you know, here you will find that output voltage, you will find, it is exact. It is basically the conduction of both the thyristors for some interval of time.

So mu is the area where actually you can see that D3 actually going on and D4 is actually going on. So for this, this overlap regions come and this is a voltage blocking capability of a thyristors, Tl, T1, actually at alpha, it will block. So ultimately this voltage will be 0, but unfortunately you know, in this region mu, both those actually thyristors are conducting and similarly in this region also, both the thyristors are conducting.

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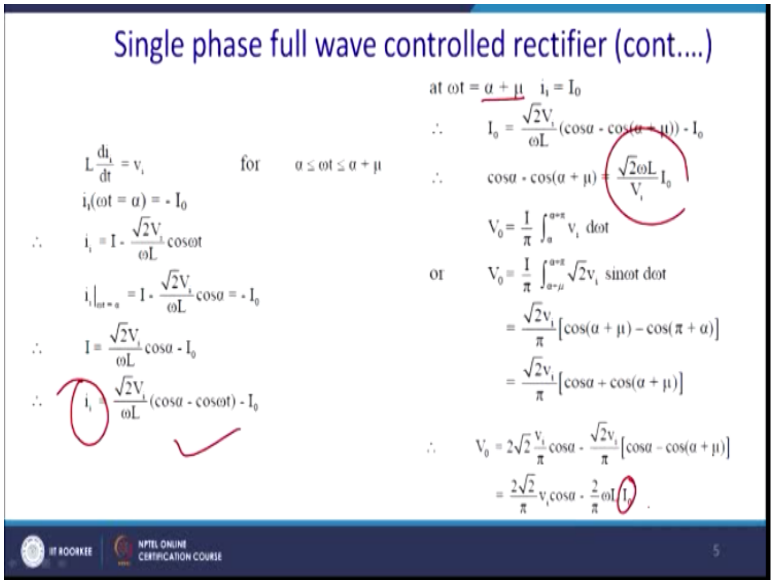

So we can write for a single phase L Di/Dt=V1 and again I1, we have chosen that actually constant load current. So actually it should be called I0. So you can find out actually input current I1=I-under root Vi cos omega t. From there actually, we can find it out the input current, input current will have this fashion. At omega t=alpha+mu, this value you can refer back to this figure, you know, this value is basically I0.

So this is average load current flowing across this actually load and we assume that actually constant load current. So for this alpha=mu, so input current becomes I1, input current becomes I0 and that we can substitute from there we can get the equations cos alpha-cos alpha+mu basically this term. From there we can find out that output voltage, which is supposed to be root 2 Vi Vm/pi cos alpha, then it will change to cos alpha+mu.

And thus, we can rewrite this equations, we can write it in terms of load current which is assumed to be constant, that is 2/pi Vi cos alpha-2/pi omega L*I0. So voltage will drop according to the value of the I0. More the value of I0, you will find more the drop in the voltage.

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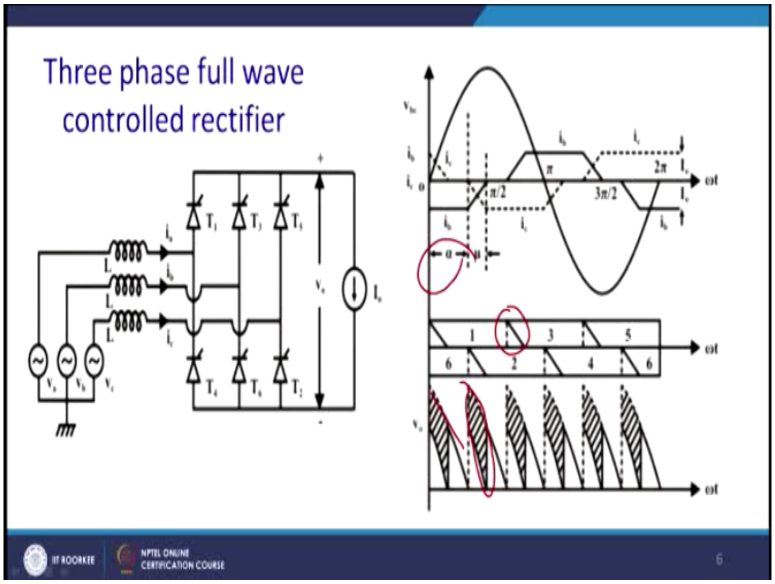

So similarly this is whatever we have discussed in case of the diode was rectified can be extended to same constant to full controlled converter. Here in this case, it is triggered at an angle alpha. So you can see this change over takes place. So T1 was conducting and here in the region, you know, actually there is a change over takes place between 2 and 6. So basically 6 was conducting.

Now since actually 2 becomes more negative phase, and it will be getting into the system and since you will find that actually that current decaying through the T6 and current built up in T2 will take a time mu and similarly same thing will happen in this duration when 1 and 3 will interchange and thus, you know, you will have a drop in the voltage that in fact been short within there, without the source inductance, you should have gained this.

But you will get this much of less voltage due to the source inductance. Ultimately, you get the load voltage as the unshaded part that is the white part. Total voltage would have been basically the shaded part. So huge, you can see that there will be a huge drop in case of the thyristor, because turn on you can control. This is the case, almost alpha is less than 60 degree.

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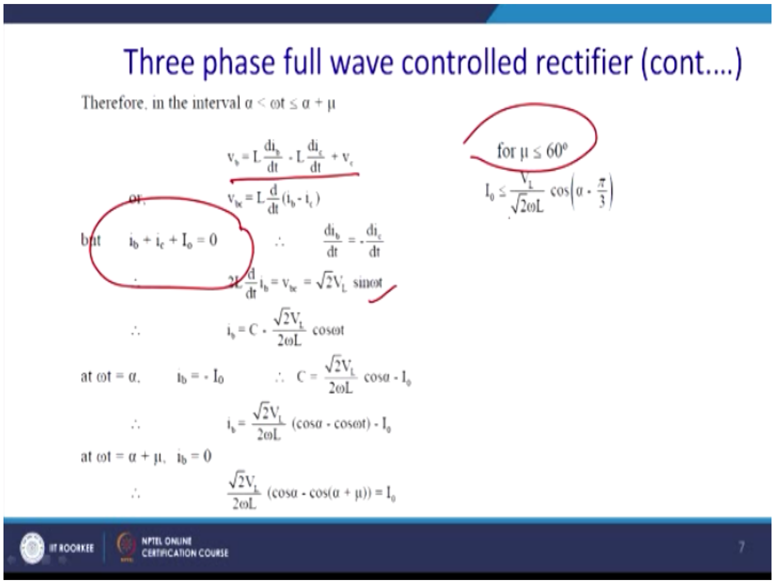

So we can write the equation here also that is omega D should be greater than alpha and vertically at an angle alpha to alpha to mu. So you write it down by equation with phase B. So similarly phase BC will be actually the current between IB-IC*L Di/Dt. Since it is 3 phase 3 wire system, so these equations will hold good. So for this you can actually substitute Di/Dt=-this and you have assumed also a constant load current that differential leads to 0.

And so from this equation, we get 2L Di/Dt= voltage BC= under root BL. Similarly, you can substitute these values and ultimately you get for alpha+mu for IB=0, where under root VL to omega L cos alpha-cos alpha+mu=I0 and thus, for mu</=60 degree, so I0 should be </= Vl/under root 2 omega L cos alpha-pi/3. This equation will hold and for the continuous conduction mode.

We have to have this condition satisfied, so that this will get a continuous conduction mode operation. So what should be the expectation of the voltage in this case. So we shall write it down the voltage.

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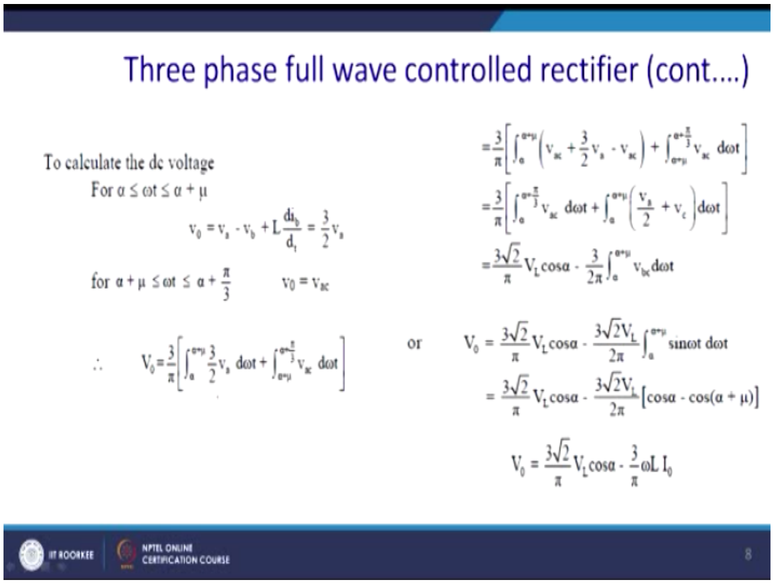

Output voltage should be equal to 1/pi, since there is three such cycles. It is multiplied by 3 and it is a region basically alpha to alpha+mu VA, D omega D, alpha+mu 2 alpha+pi/3, you will get a voltage of the line voltage AC. So you will just expand it and ultimately you get 3 2/pi Vl cos alpha-3/2pi alpha+mu PDC. From there, you can calculate you know this value is 3*2/pi Vl cos alpha-3/pi omega L I0.

So if you can compare the results of the diode with rectifier, it is almost same. So this is the value actually for the diode with rectifier. So it is 3/pi line to line voltage 1-omega LsIt/Vl and here you are getting essentially 3 root 2/pi Vl cos alpha-3/pi omega L*I0. So cos alpha term will come because you have a choice of triggering in case of the full control converter.

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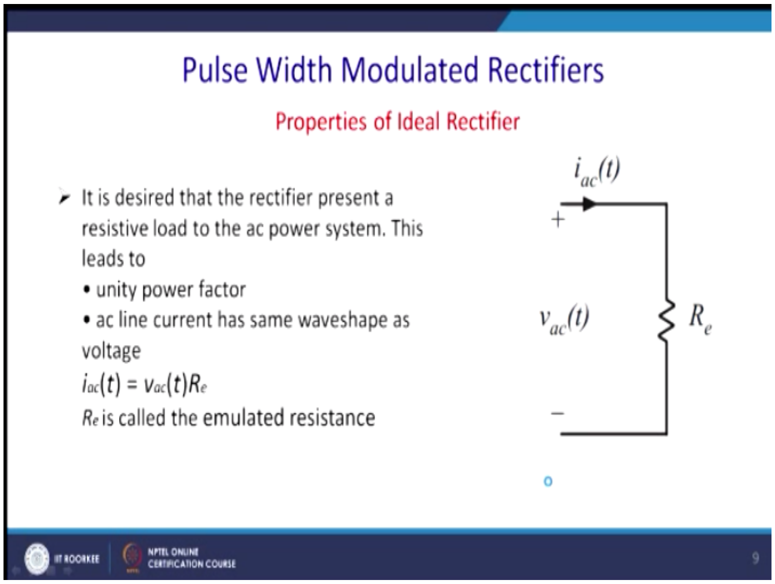

So now let us conclude the defect of the source inductance all the type of actually the converter as well as the rectifier. Generally, what happen, due to the effect of this actually, due to the effect of this source inductance, THT generally improves, but you get lower DC voltage and lower power factor. So this is actually practically problem of the source inductance and some time you may have a commutation failure. Source inductance is quite high, because you may have both the thyristors were conducting in the same length and that may lead to a line shorting condition.

Now let us come to the little bit new topic that is pulse with modulation rectifier. So now actually we have seen you know, with the conventional SUTC converter has few demerits. Demerits are the power qualities and you know for the high power applications, we may go for basically instead of 6 pulse and 3 phase, we can go for the multiple pulse operations and we can see that considerably the power factor will improve. TSD will improve, but that requires a complex transformer and things are bulky and costly.

So why cannot we wish to have an improved power factor without those hassles. That was the basic motivation to do that and another aspect is that that is visible also for the very high power application, where nowadays actually due to the penetrations of electronic gadgets, mostly SMPS, laptops, and mobiles. So we have huge requirement of the small power DC charging, DC power. So in that case also, we require an entity, which actually improves the power quality issues and it is not visible to port zig-zag transformer for household applications.

And for this reason, a new actually has popped in power electronics and that is pulse with modulated rectifier. So what are the desire? It is desired that the rectifier presents a resistive blot to the AC system and we require basically unity power factor and AC line current are same web shaped as actually Iac=Vac*Re and Re is called the emulated resistance. So we shall see that as if that a resistive blot is connected, so there is no power quality issues. Unfortunately, what happens, we have a non-linear transformation that is with harmonics.

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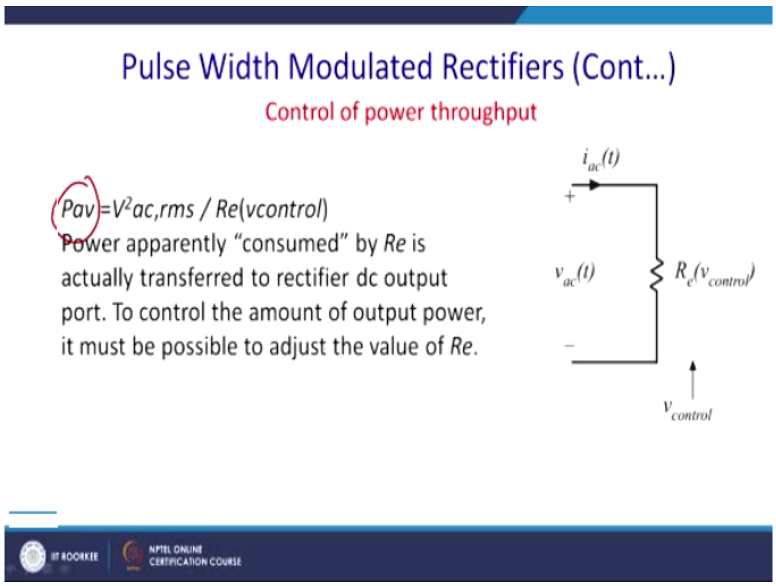

And average power basically V square/Re the upper end leak ensured where Re is actually transmitted to the rectifier. This is output port. To control the amount of the output power and it must be possible to adjust the value of Re. So we can control the value of Re to way to control the output dispatching into the system, like you searching a mobile. So there is a different kind of searching method.

First you go for basically the first searching, because when you are and it will consume actually more power. So for this is not required to be changed. Then you may actually charge with the constant current mode. Thereafter, you know actually when you have actually increased the actually SOC or the battery searching around 80%, then you may actually go for the boost searching, thereafter once it is fully charged, but it will be discharged slowly.

So you keep it in the trickle searching mode. So in those 4 modes, actually you require different kind of power to supply to the load for the modern power electronics gadgets, and thus the value of Re required to be changed accordingly. So the ideal rectifier we shall define what is ideal rectifier, it never happens, but we can aspirate to get those things.

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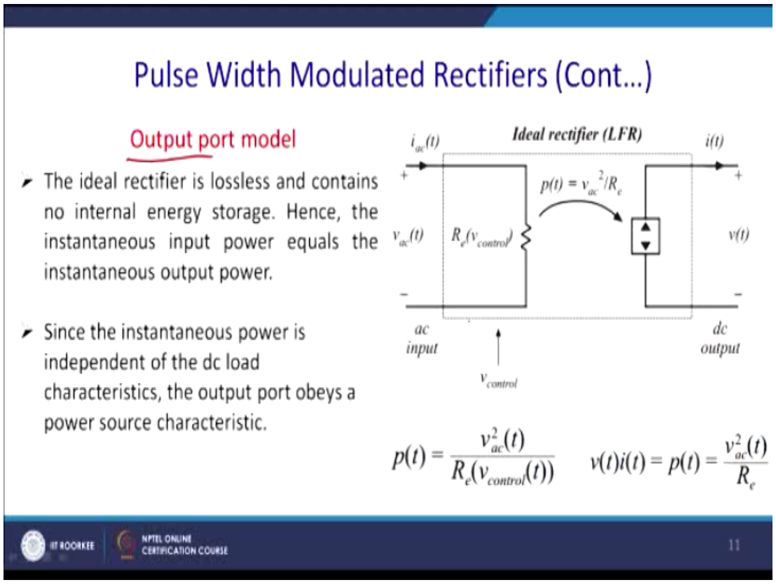

So this is the output model, something like you have studied an equivalent model of the transformer. So this is output model. The ideal rectifier is lost less and contains no internal energy storage. Hence the instantaneous power equals the instantaneous output power. So whatever power has been consumed, it is just like a transformer. Unfortunately, we require power electronics, it is because of that we cannot have a transformer operation in DC.

So DC transformer operation requires the help of the power electronics. Hence, the instantaneous power is independent of the DC load and DC load characteristics, the output obeys the power source characteristics. So this is basically the input voltage AC. It may be regulated or unregulated and this is the current through it and you have a controlled resistance that will change according to the power you are trying to submit into it.

So ultimately power will be AC square Re and so you will get a DC output voltage as desired by the consumer, but the AC side will see as if our existence is connected to a system, like you are switching on one fan, some power is consumed, but that is also wrong, because fans also comes with inductance and that is resistive heating. You switch to another resistive heating, so accordingly basically the Re changes, something like that.

So you have to aspirate to get that kind of features while conversion of AC to DC. So power consumed is essentially you know V square/Re and where we have a control over the Re and ultimately it is VI*TI=Pt AC square Re.

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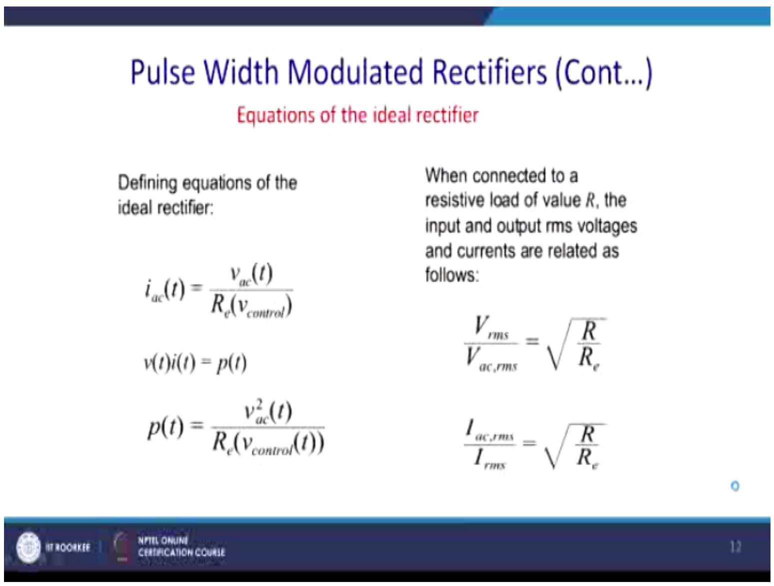

Now define the equations of the ideal rectifier. Ideal rectifier will assume that as if where resistive load is connected, power factor is unity, THD is 0. So what happen here, so AC/Re control so that will be the actual current flowing through the AC part of the circuit. No actual trapezoidal, no square, it will be a pure sinusoidal. That is what we expect to have.

Thereafter the power it is simply the multiplications of V and I that is you got a real power without any imaginary or ripple component. Ripple component comes from the harmonics. So that is we defined the power V square AC that is basically the identities, Re is the voltage controlled and when connected to a resistive load of value R, the input and output voltage of the current is related as follows:

Vrms/ac rms=under root by R/Re and similarly it is actually ac rms/Irms is R/Re. So it is something you know, it just looks like something like a transformer. So how you can achieve it, we can achieve it and please understand that these are mostly applicable for the at present household application due to high penetration of the laptop, desktop and mobiles and so power rating of this actually device is quite low.

But you have a 4 laptop in your house, and 4 mobiles, so you know that also create a huge distortion into the system.

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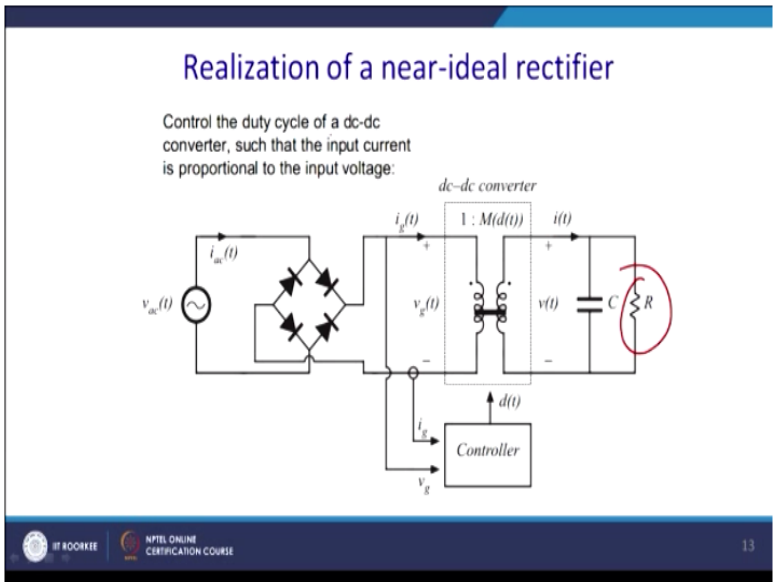

The control duty cycle of a DC to DC converter such that input current is proportional to the input voltage. So here essentially, you cannot do much. You have to have a rectification here and it is simple. Actually the diode with rectifications and thereafter you get a DC voltage, you take an example of actually mobile charger or laptop charger. In a laptop charger, we will have a voltage of 18 volt, 18-24 volt depending on the power rating of the different kind of system.

So generally, so if you rectify it, since load is quite low, so you get around this voltages around 310 volt. So that is almost straight, it is not actually 2Vm/pi, that is average value. So here actually you have a control and power will flow from it and the D to T ratio instead of 1: n that will be actually multiplied by the modulation index of this actually the switching of the converter and you will be actually stepping down maybe 1: n.

Thereafter you will continue to do that, you know and you may get actually 18 volt DC here. This is the purpose of actually a simple DC to DC converter. Let us see what is actually its methodology involved to design these circuits or the principle of operation.

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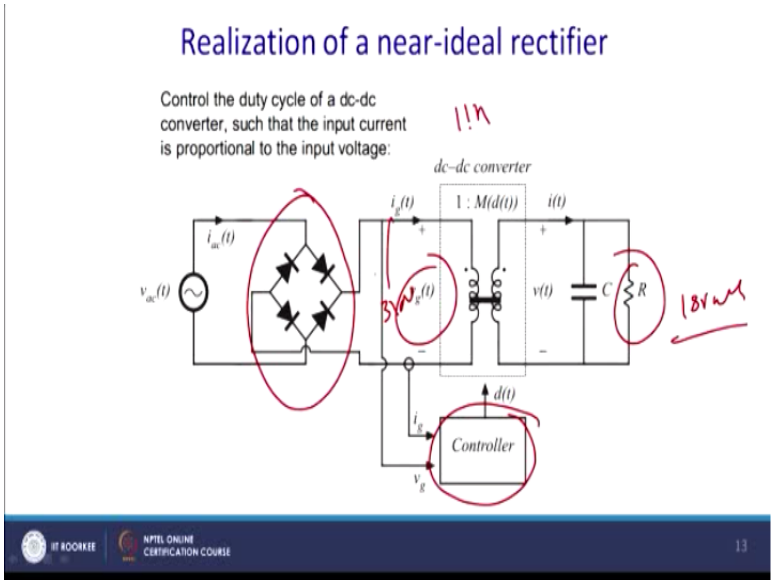

So we have Vm that is wadding and please note that different voltages here. Since it does not have any capacitor, so this point voltage will change according to the input voltage. So you have a just double frequency ripples that, which will be 100 ripples DC, not that a constant DC. So but if you do that and you actually distort the power factor, for this we do not do that. So you have PSC that will be actually, that require to be basically a sinusoidal 1.

But you know how the voltage looks like in case of the actually diode with rectifier, input of the diode with rectifier. So instead of this kind of thing, we want that this to be pure sinusoidal. For this, what we require to do? Since we have no capacitor, you put a capacitor, then current will be actually picky and actually corrupted with the lower harmonics. So Pg is this, since you have not put any capacitor and Ig should be the same thing, because you know, you have assumed that basically it is just divided by R, just it is the amount of the scaling.

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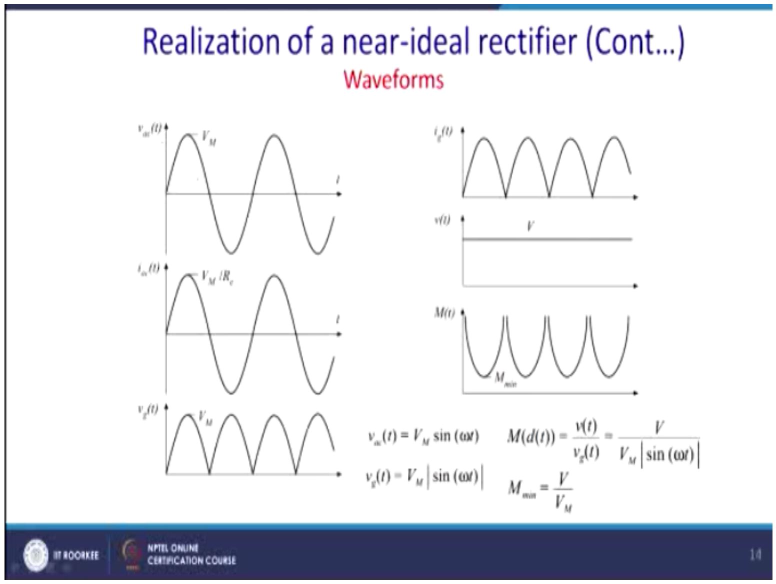

But in output, you want a constant DC voltage, that is 18 volt or whatever maybe. So we require to change the modulation index. It is something like your trans ratio itself is modulating because you have a variable trans transformer maybe. So accordingly basically since voltage is varying like this, and your trans ration require to be varying like this. Then only, you can actually get this kind of constant DC voltage. So what is the advantage of it.

Advantage of it that you do not have a problem of all the nasty power quality issues that comes into the picture due to the AC to DC conversion. So can we have it, that is the challenge. So let us define some parameters of expressions and we will continue our discussions also in next class. So average, so it will be the value of I(t) is given by actually Vgt*Ig/V that is basically we can write it like V square gV*Re and for the period I(t), you can write V square m/VRe sin square omega t.

Thus, since it is rectified, we have a double frequency oscillations and thus we will find that current will have a double frequency ripple, that is V square/m*VRe, this part is essentially DC, but you have 2 omega t with cos, that will be giving you the double frequency ripple and average over the AC line period will be basically It TL, so it is V square m/2VRe, so this will be the power, that is V square/V square m, that is the pin value of it by 2Re.

So this is the expression of the output site current and this is the expression of the average AC input site current. So this is the overall topology and the realizations of the near ideal DPWM rectifier. Now we shall continue our discussions in our next class with the PWM different kind of PWM, different kind of PWM rectifier and its application, how we can achieve this actually desired feature by this technique. So of course, we will have a lot benefits to use it.

And beauty of it, it is a high frequency transformer since actually it is very high frequency. Generally, you know actually expression of the voltage of the frequency, if you assume to be this partly sinusoidal, it is BANF. So you know, if you increase the value of F quite high that frequency, then this part will essentially that this is actually the geometry of the core. B is the flax density and the ADI is the core.

So B depends on the material that kind of material that we will choose and A is the area of cross section of the core and that is what happen if we keep the V value finite or anything, that depends on the matter of choice and the cost and you can reduce the value of A by increasing the value of the frequency. So and thus, we can see a very compact actually transformer, which can be modulated by the power electronics switching.

Thanks for your attention. I will continue with our discussion in next class with a PWM rectifier. Thank you.