Power Electronics

Prof. K. Gopakumar

Centre for Electronics Design and Technology

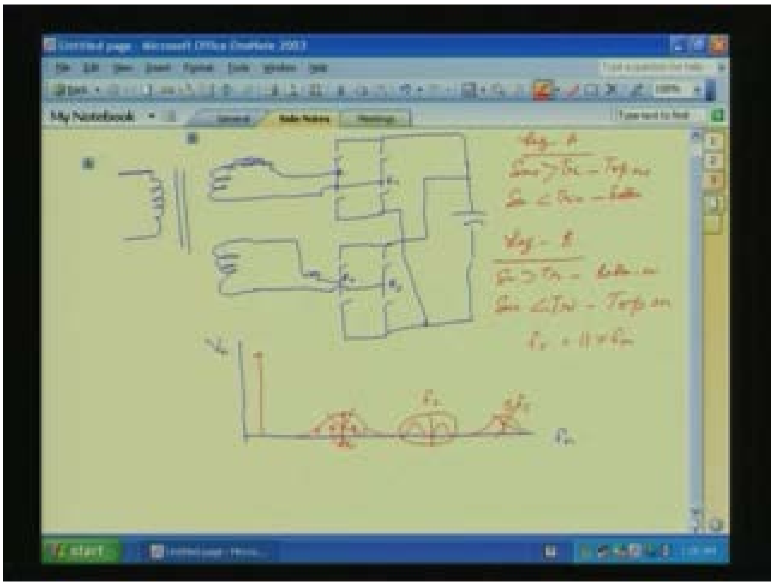
Indian Institute of Science, Bangalore

Lecture - 11

Ac to Dc Converter Close Loop Control Schematic

We discussed about the front end Ac to Dc converter and how we can control the harmonics or suppose some of the low order harmonics without resorting to high frequency PWM switching. So, the configuration used, I will again draw it for a clarity again.

(Refer Slide Time: 1:32)



You have the primary transformer, then two secondaries, then you have the two converters, one is here. We will assume the switches are bidirectional, so diodes I am not putting now. So, we should assume that the diode is there. So here, the transformer either the transformer leakage inductance or extra inductance, you have to put it to take care of the ripple, this should be there.

Similarly the second converter, inductance is here. So, this converters, the PWM; this is converter A_1B_1, this is A_2B_2. For A_1B_1, we will use the same reference wave that is the modulating, same sin wave. But the triangle waves for A_1B_1 are 180 degree phase shift. For A_2B_2 but for the switching sequence for B_1 is reversed.

So, what is for s_1? We will use it for here, the bottom switch of B_1. Then here, for the second converter, the same modulating signal we use but the triangular wave forms for A_2B_2 are 180 degree phase shifted but A_1 and A_2 are 90 degree phase shifted. So, we

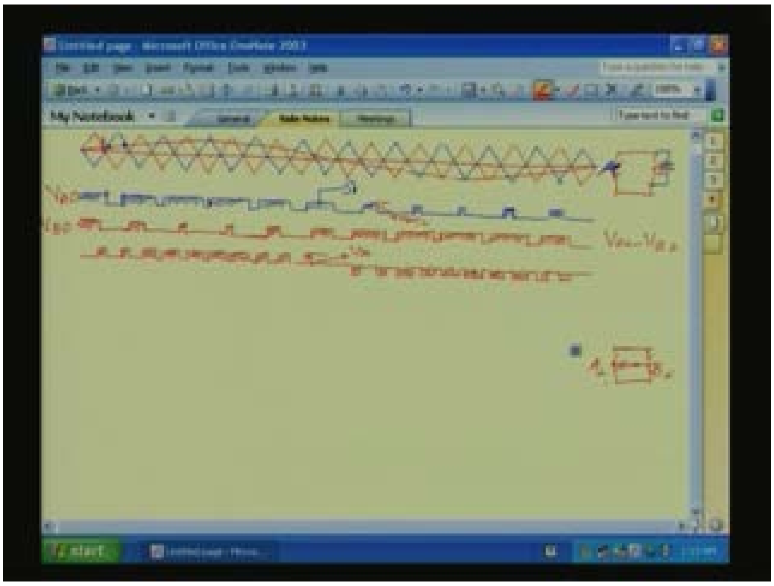
have the output diode is like this; this one will also come here, this one also, this one come here, so parallel operation.
So, by doing this way, what happens? You will have the harmonics like this; you have the V_n here, harmonic order, amplitude, then you have the harmonic order here, number of harmonics. So, you have the fundamental here. Then all the harmonics at F_c and its side bands that is this one; this is F_c and its side bands also at 3 F_c and its side bands, this is 3 F_c and its side bands, all this will get cancelled because of the PWM technique used, sin triangle PWM used for the leg A and leg B.

So, last class we learned for A when the sin is greater than the A leg, leg A. Sin greater than triangle; top switch is on, top switch is on. Then sin less than triangle, the bottom switch is on that is for leg A. And for, this is 2 for this converter also. But for leg B, sin greater than the triangle, the bottom switch is on and sin less than triangle, top on. This we are using. By using this one and the triangle, triangle frequency, F_c is equal to 11 times f_m we are using. So, all this harmonics F_c, 3 F_c odd multiple get cancelled.

Now, since this two are parallel, the triangle wave form A_1 and A_2 are 90 degree phase shifted. So, all the harmonics and the side bands of f_2 that is this one because of the 90 degree, it will get cancelled here in the transformer. Here it may be flowing but it has opposite effect in the transformer core and it will not generate any flux and it will not couple to the transformer primary.

So, transformer primary will have the fundamental, then side bands at 4 f_c plus or minus 1 and minus 3, that way it goes. So, this is the thing. Now, let us let us study how the typical wave forms look like.

(Refer Slide Time: 7:11)



We have converter 1, converter 2, this is switch. So, let us draw the modulating wave and the sin wave. So, 11 times, approximately 11 times we can draw it like this. Let us draw that; this how to get a feel for it that is why this the triangle wave form, we will make 11 times. So, let us draw the modulating wave. We will use the same modulating wave, this is the modulating wave.

Now, for the second leg; if this is A, this side is B. So, for B phase, we have the inverted one. Let us draw the inverted one with a different colour. This is 180 degree phase shifted. Now, let us draw the switching pattern, switching pattern; first one let us take for the leg A. Leg A, which triangle we will be using? The blue triangle we will be using for leg A. So, I will mark it accordingly, A is here, A. So, whenever the sin is greater than the triangle, top switch is on; so here, for leg A.

And, when the sin is less than the triangle that means we are comparing the modulating wave and the blue triangle waveform. When the sin is less than the triangle, the bottom switch is on. So, if you do, when the top switch is on, this point, the centre point with respect to our DC midpoint is equal to plus V_{DC} by 2. So, there it will be minus V_{DC} by 2. So, we can see this comparison, we can take it this way that is the second one here. During this portion, it will be triangle is greater than the sin wave.

So, if you use that blue triangle wave form and the, so we are comparing, all the time comparing with the blue triangle wave form and the modulating sin wave. So, whenever sin is greater than the triangle, the top switch is on. So, the leg voltage or the pole voltage A with respect to our fictitious centre point of the output DC plus V_{DC} by 2. Otherwise it is minus VD when the bottom switch is on, it is minus V_{DC} by 2. So, the waveform will look like this, this wave. All this hatched portion shows that the top switch S_1 is on, S_1, top switch is on. The bottom one we will say 2.

Now, for what is the pattern, the voltage wave form, pole voltage or the leg voltage B_0 for the second leg? Then we have to use the sin as well as the red triangular wave form. So, we will go to the red marking. So here, red triangle waveform means here. So, the wave form; so here, if you see here, when the triangle, triangle is greater than the sin wave, here the switching sequence is inverted that is top switch is on.

So, whenever the triangle is greater than the sin wave; the top is on, we will have V_{DC} by 2, the pole voltage wave form, so this way. So whenever, here whenever the sin greater than the triangle; what we are doing? The bottom switch is on. No sorry, whenever the sin greater than triangle, the bottom switch is on. But it is reverse of the other phase. So, what you have to remember here?

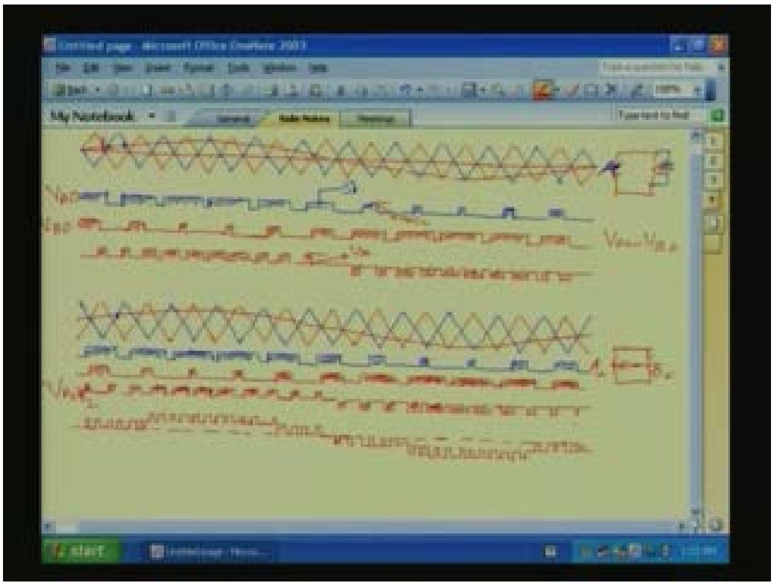
The triangle waveform 11 times, 11 times the sin wave and the triangle waveform for the other one, the leg B is inverted, triangle wave form and the switch sequence for the leg A when the sin is greater than the triangle, the top switch is on; when the sin is less than the triangle, the bottom switch is on. In the leg B whenever sin is greater than the triangle, we are turning on the bottom switch. The logic is inverted.

Now, what is the final wave form across the load V_{AB}? That is we are more interested in that one that is equal to V_{A0}, V_{A0} minus V_{B0}. Let us do the V_{A0} minus V_0. This is, the top one is V_{A0}. So, this is V_{A0} and this one is V_{B0}. Now, V_{A0} minus V_{B0}, we can do it like that, we can just subtract it. So, these type of pulses, appear across the across the waveform.

Then, height of this one will be, previously it was V_{DC} by 2, the height will be V_{DC}. Here it is V_{DC} by 2, this height, if you take it, this height is equal to V_{DC} by 2 that is 2 here also. But in this case, it is V_{DC}. So subtraction; that minus, minus get added. So, to make all the wave form within the phase, I have slightly scaled down the height. But the actual height is V_{DC} here that is V_{AB} waveform. So, if you do field analysis of this wave form, it will have the fundamental, 2 times the individual leg A or individual B. At the same time, it will not contain the harmonics at f_c and it side bands and 3 f_c also. Here, with one converter, the next higher amplitude harmonics happens at the side bands of 2 f_c. Now, with one more converter, we will try to cancel the 2 f_c side also so that the final high order harmonics happens, happens at the side bands of 4 f_c. So 4 f_c, f_c is 11 times; 4 f_c means 11 into 44 times. So, 44 time the fundamental.

So, we by a very interesting technique without resorting into high frequency switching, we have shifted the harmonics to very high, to the very high frequency side this is V_{DC}. Now, for the next converter that is the converter, the bottom converter, again I will try to the draw the figure. It is like this; here we will say, this leg is A_2, this leg is B_2. Our AC side is here. So here, with respect to this triangle wave form, for the same A leg and same leg A leg here, it is 90 degree phase shifted. So, let us draw the 90 degree phase shifted wave form.

(Refer Slide Time: 18:56)



So, this is the one; 90 degree phase shifted. This is for leg A_2 sorry this is according to this one, if it is 90 degree, this for leg B_2, red one. Sin wave is the same, same modulating wave we are using. So, all the fundamental get added. Now, for the for the blue triangle of this one, 90 degree triangle we will draw there, 90 degree phase shifted that is this one. This is for leg A_2, leg A_2.

Now, for A_{01} let us draw V_{A20} let us draw. V_{A20}, when the sin is greater than the triangle, the top switch is on that is from here and here, V_{DC} by 2. So, if you repeat for other triangles also, you will get this pattern. But here the height is V_{DC} by 2 and plus V_{DC} by 2 minus V_{DC} by 2, it will go. So, this is the pole voltage wave form of the second converter with 90 degree phase shifted triangle with respect to the same leg of the converter 1 that is this converter.

So, I will just mark it to get the pulse width, the change of pulse width, the feeling for the change of pulse width. Then for leg B, we will change to the converter. It will be like this; sorry, this is the one. So, we are comparing the red triangle with the modulating wave, sin wave. Here, whenever the sin is greater than the triangle, the bottom switch is on; when the sin is less than the triangle, top switch is on, the switching logic interchanged, same as before.

Only the case is the triangles for the, similar index for the second converter is 90 degree phase shifted with respect to the same converter, the top converter or the converter 1. So, this is the case. So again, the pole voltage wave form V_{A2} B_2 that is V_{A2} B_2 sorry I will, the V_{A2} B_2 will be V_{A2} B_2 that means V_{A20} minus V_{B20} will be like this. So, this height will be again V_{DC}. We will go to plus V_{DC} here and here it is minus V_{DC}. So, these are the V_{A0} V_{B0} wave form coming across the two converters.

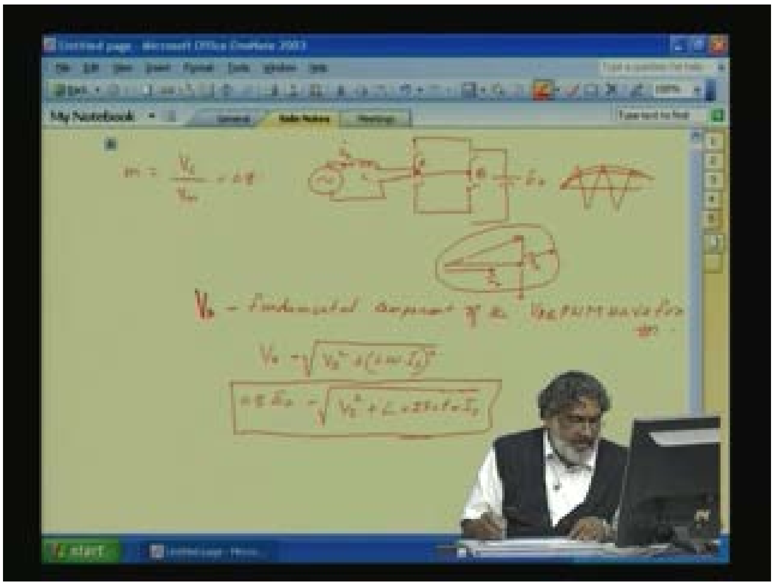
Now, if you sum these two voltage, that voltage will have a shape like this because that the current wave form to get a feeling of the harmonics, in instead of summing the current wave form if these two voltage wave form you can sum; this may be the replica of the voltage waveform appearing across the transformer - two secondary's and reflector on the primary. If you see here, transformer, primary we will be giving the voltages and in this wave form, all the harmonics, individual harmonics will dropped across the leakage inductance.

So, why I am summing? This is not actually happening in the converter; these two wave form never summed. But this wave form when you sum, this the resultant wave form, frequency spectrum of the resultant wave form approximately gives the harmonics spectrum of the suppressed current wave forms. We can get a feel for that one if you do the effective of that one. So, this is a stepped wave form, PWM with stepped wave form.

This wave form will not contain all the f_c and its harmonics f_c, 3 f_c, 5 f_c and harmonics will be highly suppressed and then the side bands at 2 f_c. So, this will have only harmonics, the zero line is here; this will have the harmonics only at the side bands of 4 f_c. So, you will get a stepped wave form and the primary current will be more sinusoidal here. So, we will have a stimulation study of this one later. But now the PWM technique, we know it.

Now, how to generate the required V_m so that the required V_{AB}, V_{AB} is generated such that the transformer primary always used to draw unity current with unity power factor or the current drawn from the transformer, primary side will be nearly sinuous order and in phase with the main. So, we will study that part now. Before going to the study, controller part; see, one more thing we have to learn here. How to design this L and C? Let us study the how to design the inductor for one converter. Let us draw the converter once again.

(Refer Slide Time: 27:38)



This is the mains, this is the inductance, this is the switch, here; so, this is our A and this is B. Now, according to the phasor diagram with unity power factor; this is V_S and this is I_S in phase with that is this current I_S in phase with V_S and the drop cross inductance L will be, for power flow from source to the load, it will be like this. Otherwise, it will be like this so. V_{AB} will be like this, this is the V_{AB}.

Now, so V_S plus I_S, if you take the fundamental component of this AB, AB fundamental component that we will represent as V_r, V_r, V_r is the fundamental component of the V_{AB}, V_{AB} PWM signal, PWM wave form, wave form that is V_r; fundamental component of the V_{AB} PWM wave form.

Now, if you assume the harmonics are highly suppressed, due to fundamental, there is a drop across this inductance. So, from this diagram, what is the relation between the fundamental voltage and the inductive drop that is this one and the V_{AB} wave form? It will be equal to V_r is equal to root of V_S square plus L omega; omega the mains frequency, this is the L into I_S square. This L omega I_S is the peak value of the sinuous order current here; L omega, have drawn.

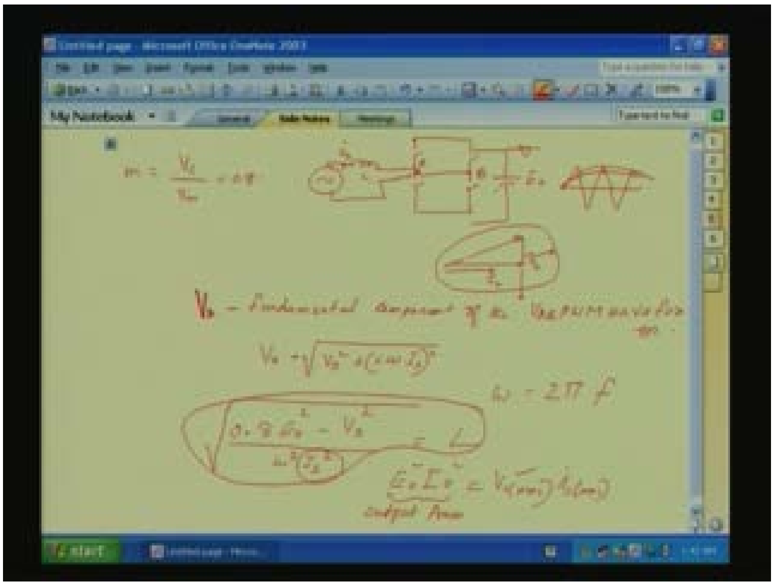
Now, this V_r is generated by modulating the sin triangle PWM and from the previous sin triangle PWM and our V_0 is here. This is our V_0 sorry E_0. So, V_{AB} will be for from the previous sin triangle analysis, what you have done two days before; the V_{AB}, for one leg, the maximum amplitude of V will be proportional to the maximum will be equal to V_{DC} by 2 or E_0 by 2.

So, when subtract A and B, the maximum value, the fundamental maximum value of V_{AB} will be equal to E, E_0 that is the maximum voltage V_r we can get. But in all practical applications, we will not go to the extreme modulation. If you take a sin triangle like this, we will not go to this range.

See, if you go here, the pulse would become very narrow; the system may not respond here. So, we will always restrict the modulation index that is the height of the sin wave modulation index m I will say is equal to our V_C value by V_m maximum value will be always theoretically this will be equal to 1 but we will restrict to maximum, it will be equal to 0.8 for practical limitation.

So from here, V_r will be 0.8 of the maximum E_0, the output E_0. This will be equal to root of V_A square plus L, for a 50 hertz operation omega is equal to 2 pi into f, f is equal to 50 into I_S maximum. How do you find out this I_S maximum here? How do you find out what is the maximum I_S so that from these two equations; from this equation, let us find out what is L. We will square this one such that V_r is equal to as I told, in the modulation index, we will go upto not to 1, it is only 0.8.

(Refer Slide Time: 33:30)

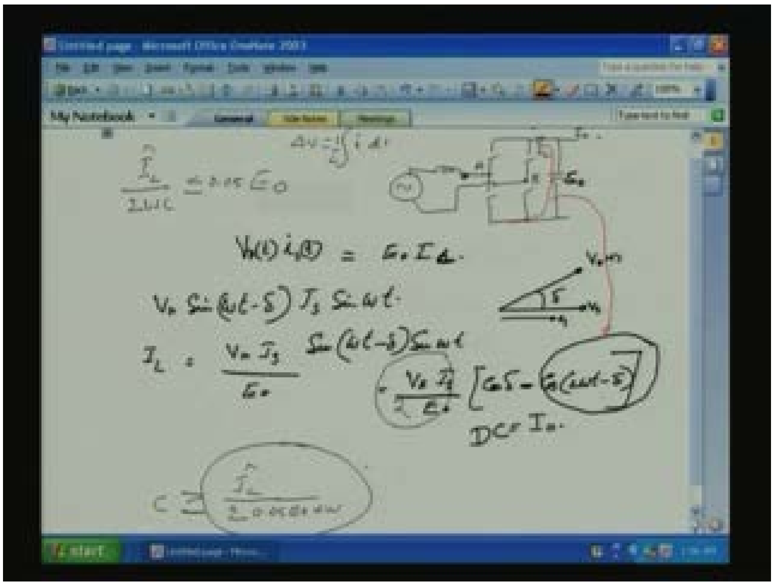


So, 0.8 E_0 square minus V_S square divided by omega square I_S square is equal to or square root of this one will be equal to our L value. Now, if you see here, this L value depends on V_S we know. How to find out this I_S? Omega we know, omega is equal to 2 pi into f, our mains frequency. So, how to find out this I_S? I_S varies with our load that means load which is connected here, what load it is coming here; this is DC voltage, so load. So, may be I_S we can find out from the power balance.

See, output power is equal to E_0 into I_0, output power and for with unity power factor, we will be assuming, we will assume the efficiency of the system is it is across the system 100%. So, input power should be equal to output power. This is the output power, output power, this will be equal to, input power is how much? That is V_S rms into I_S rms. So, E_0 we know, I_0 maximum load current we can find out, V_S rms is known; from this one, we can find out what is for a maximum load, what is the I_S rms? From the I_S rms, we can find out ISP. We can square it, you will get it. So, L this way, we can find out.

Now, how to find out the value of this capacitor? That is very important. So, let us find out the next one, how to find out the value of the capacitor? Let us draw the converter once again that is only one side converter only we will draw it.

(Refer Slide Time: 36:09)



This is our input source here, then we have this is the A point, A leg, this is our B leg and your capacitor. Capacitor has to take care of the ripple current coming from here. If this is the I_0, the current ripple current coming through this current, the current which is coming from here, let us say this is I_L, I_L contains sorry I_L contains, this I_L contains DC current plus the ripple power. The ripple will pass through the inductance that is the oscillating part not the DC part. The fluctuating part, it will go through the capacitor and the capacitor we should choose it such a way, it should give a stiff DC link.

That means due to the ripple current, fluctuating current, the voltage ripple across this one should be as small as possible. Small means how much? 5% of the DC, we should, can have only that much ripples. So, let us find out what is the ripple current coming here? Here again, if you see here, this is V_{AB}; fundamental component input power of this converter should be also be equal to output power of this one.

So, the input power to the converter is equal to V_r (t) into our i_S (t) that is coming from here, this is the i_S (t). This current, input assuming 100% efficiency V_S (t) and i_S (t) should be also be equal to this is we assuming, this is equal to E_0 into I_0. Now, sorry V_0 that is sorry not I_0, that current E_0 into the output power input power should be equal to the output power. So, output power is equal to E_0 plus I_L into I_0. So, we will take I_L here.

So, what are, what is V_r (t) into i_S (t)? V_r (t) is equal to if you take this is V_S, this is I_S, this is our fundamental V_r (t) and this has a delta here. So, V_r (t) will be V_r sin omega t minus delta into I_S sin omega t. So, net current I_L is equal to V_r I_S into sin omega t minus delta into sin omega t divide by E_0. This is the current I_L coming out of this one. Input power is equal to output power. Now, if you see here, this can be extended like; V_r I_S divided by E_0 into cos delta minus cos 2 omega t minus delta.

So, I_L contains a DC part that is DC, this is the DC part that is equal to the I_0 and there is a fluctuating part that is 2 times the input frequency. This will go through this capacitor that is this will go through this one, this part, this one, the one which is this one. So, we have to design the capacitor for this 2 times the frequency, there is a second harmonics current flowing through this one. So again, once again, this is the input power, sinusoidal fundamental, sinusoidal current, input power voltage into current, this is the output power from the converter.

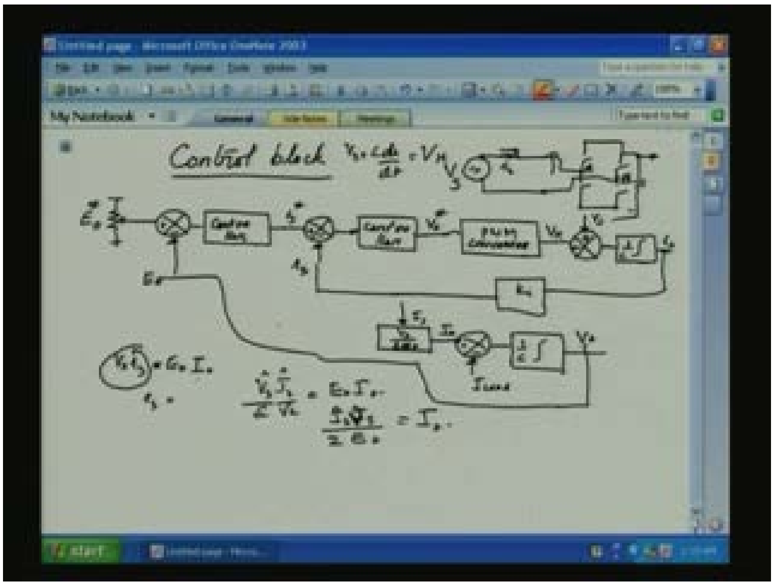
Now, V_r (t) from this, from this definition, it is V_r into sin omega t minus del into I_S sin omega t. So, the I_L which is coming from here, if you see here, you will get this equation but when you convert to this one, there is a two halves to be there because sin A sin B, we are converting to cos. So, these two halves to be there sorry there is a mistake here. So, I will correct that one now. So this, there has to be a 2 here; so 2 is here. So, this current, this into cos two omega t, this value into cos omega t will, cos 2 omega t will flow through this one. That will generate a ripple current across this one and let us see what is that current. If it is cos to omega t; we will integrate approximately.

This is the ripple peak, let us take the ripple peak, let us take as I_L hat, ripple peak. If we integrate divided by 2 omega c if you do the capacitor, capacitor is equal to integral, the voltage delta V is V is equal to integral 1 by c i dt. So even that, this function if you integrate, you will get this one. So, this will be you want is equal to 5% of the delta V, 5% of our less than or equal to 5% of 0.5%, 0.05 of E_0, this has to be there.

So, E_0 we know, I_L peak we know, we can find out C. So, if you see this equation, I will write it here, the C will be, from the inequality here, C should be greater than or equal to I_L hat that is the ripple peak that is from here, I_L hat divided by 2 into 0.05 E_0 into omega. So, from this equation, we can find out the value of C approximately. So, C should be greater than this value.

Now, L and C we have found out. Now, what we want? We want to control the output voltage. So, what is the control block we require? What is the V_r we have to generate? That is fundamental of V_{AB}, we have to generate for all load conditions such that the input current in the phase with our mains voltage. How we will, how we will do it, control block of the front end converter?

(Refer Slide Time: 44:14)



What we want here? We want an output E_0, output E_0. So, this is our reference. So, reference I will mark it as E_0 star. So, this is the reference. Whatever we want, we can fix it as reference. So, it will be, it will be compared. That means our output voltage, we have sensed and feedback to this one. So, the moment we are comparing the reference plus the feedback, this is the feedback; there should be a controller. So, what type of controller, we will decide later. We will just put controller. So controller, what it should give? It should give the I_S. Why?

Because any time the E varies, changes with respect to reference value that means the there is a change in the capacitor voltage. That shows there is a change in the output load current. So, any change in the load current assuming 100% efficiency and the input power should be equal to the output power. So, for the required current, there should be an input current required. So, this indicates, any change in E_0 with respect to E_0 indicates that there is a current demand, change in current demand from the mains side. So, this will indicate to the I_S, load current I_S which is flowing through the inductance or which is taken from the mains, this I_S. This I_S, again we have to sense it from our mains, you have to sense it from here.

I will just draw it here; this is our input that is this is the current I_S. This we have to sense it using a Hall Effect sensor LEM current sensor we have to use it, we have to properly scale and give it to here. So, here also we need a current controller to control. What type of controller; we are not, we do not know. So, this controller, what it should give? To get the correct I_S and I_S star, I_S to match, what is required is the fundamental component of the AB, AB with PWM. It should be the required V_{AB} or reference value you should get it.

So, the V_{AB}, the reference value for V_{AB} is the output from here. So, this will go to the V_r reference. So, controller we take it with for only a one converter but the two converters, appropriate gain of two we have to give at the various places. But the same controller is used we can use it for the both converters. So, this is for V_r star. So, this V_r star, it will go to the PWM converter, PWM - pulse width modulation of the converter. So, converter will give what? It will give the correct V_r. This is the reference value and the converter will PWM will give the correct reference value.

Now, this V_r, so if you see here, this is V_S; so V_S plus, V_S plus L into d I_S by dt is equal to V_r here. So V_r, all already we got here, we know the V_S value. So, if you want this is V_S, so V_S, this is plus; V_S minus V_r, V_S plus L into di by dt is equal to V_r. So, V_S minus V_r is equal to L into di by dt. So, this you integrate with the gain of 1 by L. Here you will get the I_L. This I_S, these are actual currents; we have to bring it to the controller side. So, we may require a gain, gain function to reduce it or if you want to filter it, you may have filter also over there or you will put simple gain function k, current gain so that I_S reference and if it is for used, if the controller is built using analog controllers, may be I_S can vary from plus minus to plus ten only.

So, actual current when we sense it and bring it back to this one, there is a gain function is required. This is how you do it. Now, we have, this is an inner current loop is there. So here, if you see here, again I will explain, you have the E_0 reference and feedback we have taken from the converter. If there is any mismatch in E_0 and E_0, it reflects on the type of load current required. Load current, there is a variation in the load current.

So, there is a variation in the load current that should reflect on the input current drawn I_S. So, this controller output should point to the I_S. This I_S and actual current I_S, we will compare and this compare out, would give a controller. So, this controller should, this I_S star and I_S should match, controller should give the correct V_r reference that is the reference for or the modulating wave for sin triangle PWM. So, if the correct waveform is given, the PWM converter, PWM converter will give the correct V_r here.

Now, this is the converter output, this V_r or V_S minus V_r, integrate 1 by L integrate will give you I_S value. This I_S is stepped down, you can feedback it here. Now, I_L we got. How to find out the or how do you get the E_0 value? How do you make the block diagram for the E_0? So, if you see, from the power balance with unity power factor, V_S I_S rms, V_S I_S, these are the rms values is equal to E_0 into I_0, E_0 into I_0. V_S I_S are the rms values; so if you take the peak value, if V_S and I_S are the peak value, then V_S peak I_S peak divide by root 2, divide by root 2 is equal to E_0 I_0. I_S we already know it, so V_S I_S divided by 2 E_0 is equal to our I_0. This is the dc value current.

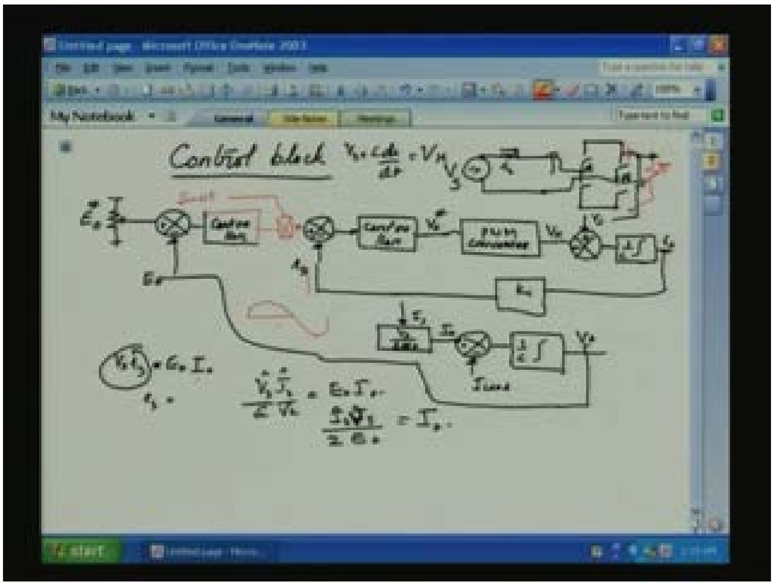
So, if there is no disturbance and the load is pakka matching, this I_0 will, I_0 coming from here. So, we have designed the, we are now we are worried about the DC value. We have chosen the capacitor such that the fluctuating part will go through this one and capacitor value you have chosen such that the voltage ripples is very minimal. So, the DC value, it will go here, this I_0. So, this both already we have to use it this way.

You already know I_S. So, from the I_S, there is a gain block. This gain block is equal to sorry, this is the V_S not I_S, this is V_S into V_S peak, I_S peak V_S peak. So, I_S is coming here. I_S we know it, we can generate the I_S value here, get the I_S peak value. I_S into V_S divide by 2 E_0 is our I_0. I_0 at any instance, any load change happens if I_0 and the I_{load} are same, then the difference is 0. So, there is no discharging in the capacitor voltage wave form.

But suddenly, load changes increase or decrease; I_L I_{load} will change immediately. So, unless that is indicated to the converter I_0, immediately there is a fluctuation can happen in the capacitor voltage. So, this difference immediately goes to the capacitor. That will generate a ripple; 1 by C, this is the integral that will give the V_0 side. This V_0 we will feedback to this one. This is the complete block diagram for controlling the converter.

So, again I will say how this one is. You have the E_0 reference and E_0 feedback; that we are taking tapping from here with proper sensors and we are giving it there. With proper sensors we are taking from here and we are giving it here. Now, when the load current and the DC value of the current coming from here, this converter, when they are equal, the capacitor voltage will not fluctuate, capacitor voltage will be steady and the controller will be in the steady state.

(Refer Slide Time: 56:11)



But due to sudden change in load that is what in your control. This I_0 can change but our controller is giving some steady id. Unless this is modified, V_r is modified, this will not change. So, sudden change in load, the difference will immediately go through this one and there will be a change in the capacitor voltage V_0. That change in current, difference in moments, sudden change in load I_0 minus I_L load integral 1 by C integral, this difference; that will feedback to this one here.

Now, the moment change happens, immediately I_S has to change. So, I_S you are sensing from here, I_S is given. Any change in the I_S through the controller, we will generate the correct V_r. We will give the power converter so that the power converter, reference wave form that is the modulating wave, we will give to converter such that this converter will give the correct V_r.

So, from this equation, V_r, V_S minus Vr integral 1 by L gives the current I_S here. That I_S, instantaneous value of I_S divided by K, we will feed it here. So here, if you see, this current is a sinusoidal current and we are this current, we are controlling with this one and all our controller here is due to through PWM. So, we will assume the PWM frequency is so high. So, during the control action, we can assume this I_C, the sinusoidal part of this current I_C with a small ripple, it is not changing much. So, we are using a sinusoidal current reference and sinusoidal current feedback here.

Then that is the one of the simplest way of doing the thing. Otherwise, the other way to convert this converter is alternating current to the DC equivalent and then do the controllers; then you require other signalling process. So here, what we assume? The PWM action is so fast. During that small moment I_S reference and I_S feedback are not, sinusoidal feedback are not changing. There is not much variation in the I_S. So, what you have to give this I_S value?

Peak value of the I_S reference comes; so we have to give a sinusoidal reference here. So, with that sinusoidal reference I_S should be in phase with our mains voltage V_S. So, that will take care of the unity power factor. So, this I_S will break here and this controller because we know, this I_S is a sinusoidal current, so this current also has to be sinusoidal. So, this sinusoidal current we are assuming that control is through PWM with high frequency. During that PWM operation, this I_S and I_S star not, there is not much change in the I_S and I_S star. So, but we want unity power factor. So, this I_S, what you drawn should be in phase with V_S.

So, we should generate a sinusoidal reference wave form in phase with this one with unit amplitude and we should multiply with this I_S and give it here. So, we have to modify this part. Let us see how we can do that one? So, the controller has to be accordingly modified. So, the controller output is here, then we will generate a sinusoidal signal which is in phase with our Vsd that is sin omega t 10, we have to generate, a sin omega t ten with unit amplitude.

This we should multiply, these two we have to multiply. Multiplication block, I will make it like this, this is the multiplication block. We give it here and this one, you should give it here, output should be given here. So, this sin omega t which is in phase with this one that will ensure that this current drawn I_S will be in phase with V_S all the time and you have to generate V_r.

So here, what is more important is how to find out this controller, this controller and this controller? What is the function of this controller such that input should track the output or the output should track the input as close as possible so that any change in I_S with I_S, immediately we have to generate the V_r. So, that controller has to take care of that one. So, let us study out some of the standard controller like P controller is there, PI controller, PID controller.

So, if you use this controller with how the whole system, whole the current block; first we will start with inner current block, how inner current block will work. That we will study in the next class. So, we will go to the controller and what are the controllers, standard controller, what are its problems? Then we will try to fit in one of this standard controller blocks and we will choose the correct one.