Power Electronics

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Lecture - 43

Hello, today probably I will be concluding lecture of my course on power electronics. I will try to cover AC voltage regulators. Input is AC, output is also AC. Frequency of input and output is the same, only the magnitude of output voltage is varied.

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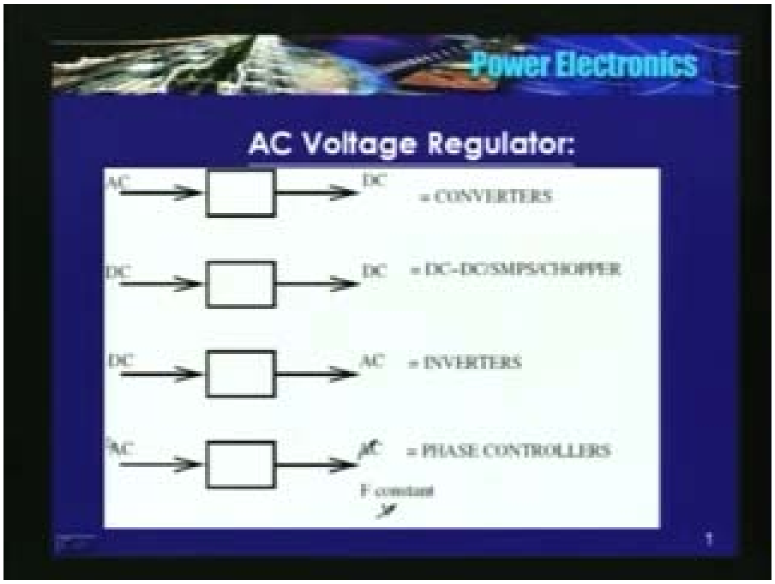

See here, we are here; input is AC, output is also AC. Frequency constant, variable voltage. They are known as AC voltage regulators AC voltage regulators.

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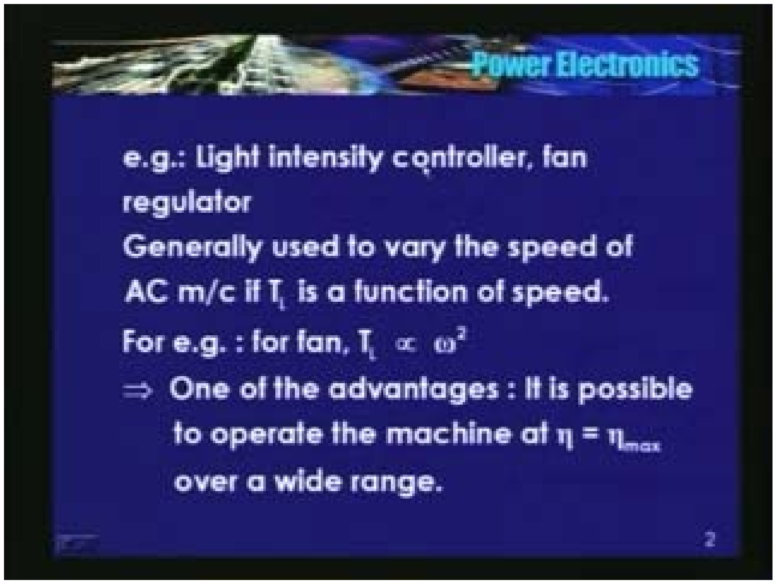

Where are they used? They are very popular in fan regulators, light intensity controllers. I have told you that if the induction machine is driving a fan type of load, the speed can be varied over a wide range by varying the magnitude of the input voltage frequency being the same. The type of load is fan type of load wherein T_L is proportional to omega square. What is another advantage? It is possible to operate the machine at maximum efficiency over a wide range.

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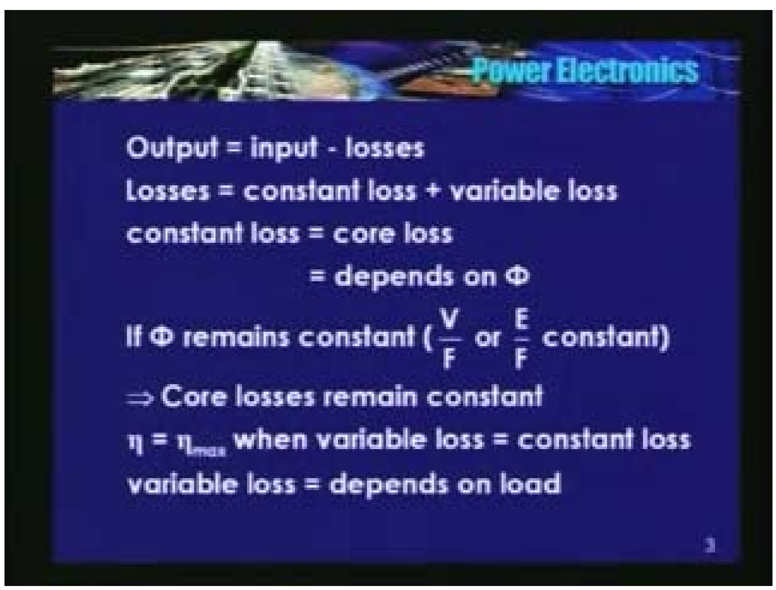

How is that possible? Let us see here. We all know that output is equal to input minus losses. Now, what are the losses? There are 2 types; one is constant loss plus the variable loss. Constant loss is I will name them as core loss. They depend on flux. Frequency remains constant here, so it depends on flux. Flux in the machine remains constant if V by F or E by F is held constant. That we had seen while doing inverters. So, if flux remains constant; core loss in the machine, they remain constant. So, when does the efficiency of the motor is equal to the maximum efficiency? It is when the constant losses equal to the variable loss. The variable loss depends on load. Basically, they are I square R losses. Now, if the load and the machine comes down, I square R losses also comes down.

So, how do I operate the machine at neta is equal to neta max? What do I need to do is as the load comes down you reduce the flux such that motor operates at maximum efficiency. You have to reduce the flux such a way that constant losses is equal to the variable losses. So, in principle using the phase regulators or AC voltage regulator, it is possible to maximize the efficiency at light loads.

If I keep the frequency constant and try to reduce the voltage, we had seen that flux in the machine comes down, it reduces. Therefore, core losses reduces. Variable losses are the function of load. Since the load is reducing; I square R losses, they come down. Efficiency is maximum when core loss is equal to the variable loss. So, in principle it is possible to maximize the efficiency at loads. Why I am saying in principle? The reason I will tell you some time later.

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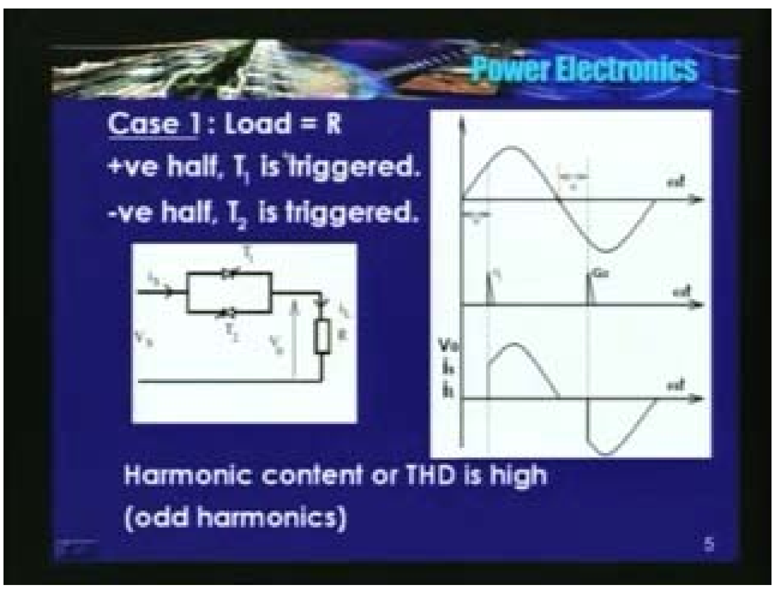

So, case one; load is purely resistive, input is single phase AC. I have used 2 SCRs, T_1 and T_2. They are connected anti parallel. Now, you can replace this combination by a track; the device which is used in fan regulators. I had shown the fan regulator also the device during my introductory lectures.

So, load is purely resistive. So, this is the input voltage, this sinusoidal. In the positive, half T_1 is triggered at alpha. Gate pulse to thyristor 1 and in the negative half cycle, T_2 is triggered at an angle alpha. When T_1 is triggered, input voltage V_S is equal to output voltage. Load is purely resistive, current and voltage are in phase. So, the waveform of source current which is equal to the load current is same as V_0 itself. So, input voltage become 0 at omega T is equal to pi. At that instant, even V_0 becomes 0, I_s also become 0, the load current also will become 0. I am assuming the device is ideal.

So, from omega t is equal to pi to pi plus alpha, there is no current flowing in the circuit. Load is purely resistive that is the reason and at again at pi plus alpha, T_2 is triggered and negative voltage is applied to the load. So, what is the limitation of this sort of a control? Harmonic content is high, is an odd function. Source current as well as the load current, they have all odd harmonics and they give rise to heating in the load and in the source side, they affect the voltage at the point of common coupling, I have told you that. Effect of harmonics I have discussed during my converters lecture. If there are harmonics in the line due to the finite impedance of the line voltage at the common point of coupling, it gets affected.

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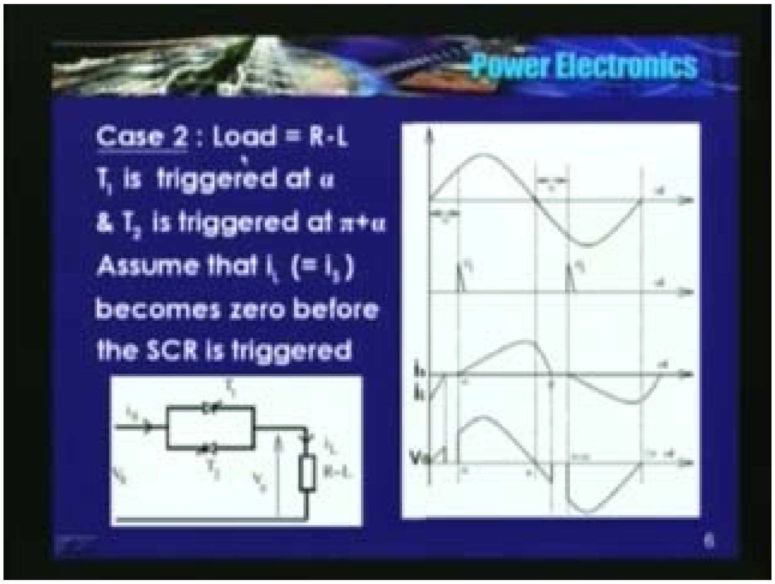

Now, we will take a second case. Load is RL. Things are not as straight forward as when the load is purely resistive. T_1 is triggered at alpha and again T_2 is triggered at pi plus alpha and I am making another assumption; assume that i_L that is equal to the source current become 0 before the SCR is triggered.

I will repeat; the assumption is i_L become 0 before the SCR is triggered. So, load is passive at alpha T_1 is triggered. So, when T_1 starts conducting, input voltage is same as the load voltage. So, voltage is applied to RL load. Now, it is the circuit equation is R into i plus L di by dt is equal to V_m sin omega t.

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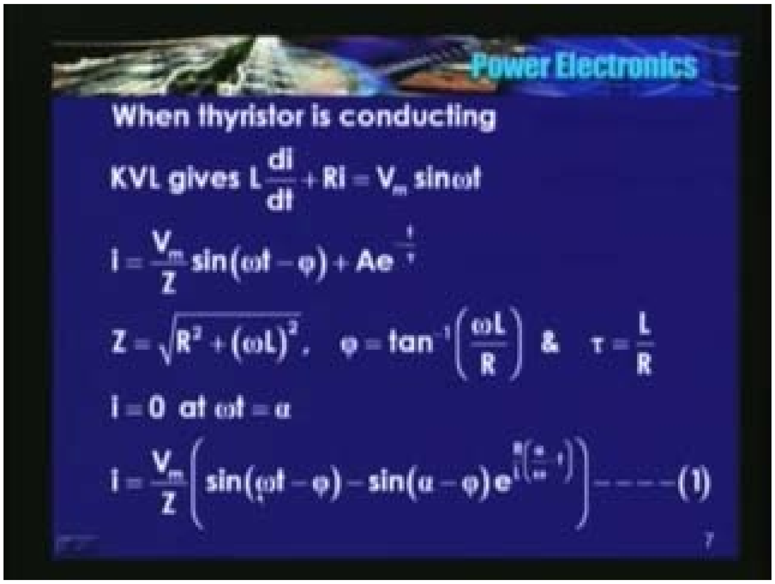

See, I will show the equations. These are this is the equation. The solution looks like this or solution can be given by this equation V_m by Z sin omega t minus phi plus A into e to the power minus t by tau. We have derived this equation in the very first lecture in converters where Z is equal to square root of R squared plus omega L square. phi is tan inverse omega L by R and tau is L by R.

So, how do I determine the value of A? The boundary condition is i is equal to 0 at omega t is equal to alpha. I had told you that current becomes 0 much before the thyristor is triggered. Substituting or using this condition, I can solve the equation. I will get the expression for current. It is given by this equation; V_m by Z into sin omega t minus phi minus sin alpha minus phi into e to the power R by L into alpha by omega minus t. So, this is the equation for current. So, there is a sinusoidal component and a decaying component.

So, the current wave form looks something like this. It starts from 0, it attains a peak somewhere in between pi by 2 to pi. It attains a peak when instantaneous value of the input voltage is equal to R into i. When i is equal to i_{max} L di by dt is 0. So, at that time V_i should be equal to i_{max} into R. Somewhere here, it attains a max. It reduces and it becomes 0 somewhere after pi and till the current is flowing in the circuit, input voltage is equal to the output voltage. So, at beta, current becomes 0 and till another thyristor is triggered that is T_2 is triggered at pi plus alpha, there is no current flowing in the circuit there is no current flowing in the circuit.

See, from beta to alpha or pi plus alpha, there is no current and therefore there is no voltage and at pi plus alpha, you trigger T_2 and whatever that happened in the positive half will happen in the negative half. Actually, this should continue beyond beta here. See, current becomes 0; that I have shown you I have shown this waveform here. Actually, this part should come here. So, whatever that happened from pi to beta will happen from 2 pi to beta.

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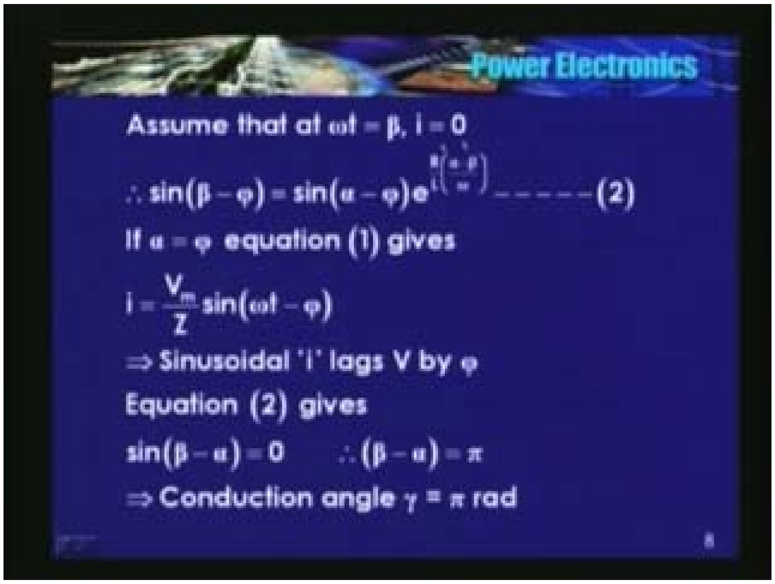

Now, see this is the equation. Assume that at omega t is equal to beta, i will again become 0. So, you substitute this condition in the previous equation. So, what do I get? You will get sin beta minus phi is equal to sin alpha minus phi in this term. Now, if alpha is equal to phi, in other words, if the trigger angle is same as the power factor angle, what does the equation 1 say? It says that this term will become 0.

So, you have the current which is given by V_m by Z into sin omega t minus phi. Current is sinusoidal current is sinusoidal, lacks the input voltage by an angle phi which is given which is equal to the impedance angle. So, if trigger angle alpha is equal to the if the power factor angle; current is sinusoidal, lacks the input voltage by an angle phi which is equal to the power factor angle. How does the voltage and current look like?

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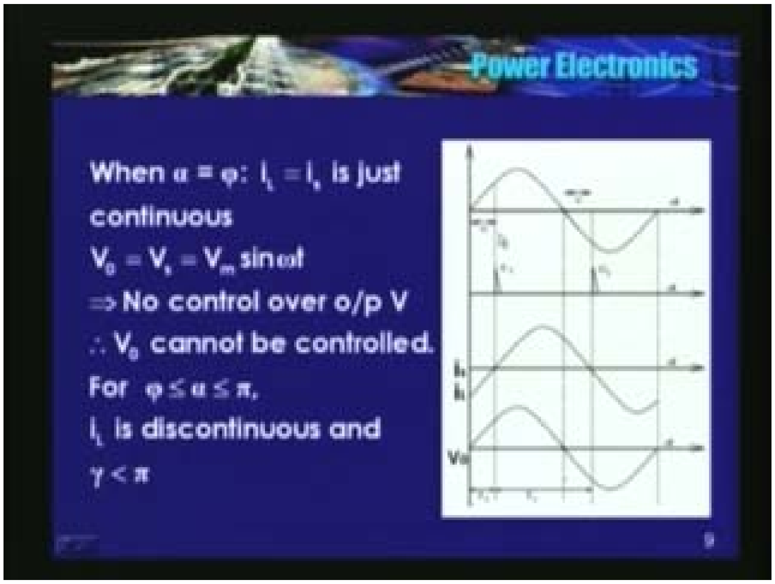

See here, trigger angle alpha is equal to phi, current is sinusoidal. Now, current is sinusoidal. That means either it has to flow through either T_1 or T_2. So, you will have the input voltage is same as the output voltage. The output load applied voltage to the load is sinusoidal and it is equal to the input voltage V_i itself.

Therefore, V_o is equal to V_S is equal to V_m sin omega t. There is no control over the output voltage, whatever is there at the input appears at the output. Current is sinusoidal, lacks the voltage by an angle phi because SCR is triggered at an angle alpha which is equal to phi. The previous case, we saw current most discontinuous current was discontinuous. This can happen only when alpha is greater than the power factor angle.

I will repeat; current is discontinuous when alpha is greater than the power factor angle. So, this is the condition. When alpha is equal to phi, i_L is equal to i_S, it is just continuous and V_0 is equal to V_i. At this instant, T_1 is triggered. It continues to conduct till pi plus alpha. At that instant current becomes 0. So, T_1 turns off. Immediately T_2 is triggered. So, it goes on. So, output voltage cannot be control or in other words, input volt output voltage is equal to the input voltage. Whereas, if alpha greater than phi, i_L is discontinuous. See, current become 0 here and thyristor may be triggered somewhere here, current starts increasing. So, this for during this period you will not have any current. So, during this direction T_1 is conducting and the conduction period for each device is pi radians pi radians.

So, we have seen in a in a AC voltage regulator you can control the output voltage if the trigger angle alpha is greater than the power factor angle. Current is discontinuous, current is just continuous and it is sinusoidal if the trigger angle alpha is equal to the power factor angle. Output voltage is equal to input voltage. There is no control over the output voltage. Conduction period for each thyristor is pi radians. Now, what happens if alpha is less than phi?

If alpha is less than phi, V_0 and i_L do not vary with alpha. In the positive half, you might have triggered T_1at alpha and alpha is less than the power factor angle. Current is negative and cuts the 0 axis at phi. So, even if you have triggered T_1, it will not carry the current or current will not flow through it because current is negative. See here, current is negative only when it cuts the X axis. This current starts flowing through T_1 and this instant is fixed by the power factor angle phi. So, till phi, current is negative. So, even if you try to trigger T_1, it will not carry the current it will not carry the current. This current is being carried by T_2.

So, if there is just a sharp pulse as I shown here and if your trigger angle alpha is less than the power factor angle, there may not be any current because there is only 1 sharp pulse. Current is negative, it is flowing through T_2. It has to become 0 and that instant is fixed by the power factor angle. We know that in SCR gate gate signal should be present till the current through it is higher than the latching current. There is only one pulse and that has come much before current becoming 0 and then it has to become positive.

So, there may not be any current or T_1 may not go into conduction. So, you need to have a series of large number of pulses. Till omega t is equal to phi, in other words till omega t is equal to phi, you should have or there should be triggered pulses. Only then you will have a sinusoidal current and a sinusoidal voltage applied to the load. So, even if you trigger at alpha which is less than the power factor angle, change over from one device to another device will take place only at omega T is equal to phi.

To achieve that you need to have a series of pulses. There should be a gate pulse present at omega t is equal to phi, a theoretical element. Of course, it is always preferred to have pulses beyond omega t is equal to phi. So, there is a control over the output voltage for alpha greater than phi. For alpha equal to phi and alpha less than phi, there is no control over the output voltage. Both voltage and current, they are sinusoidal. Current lacks the voltage by an angle phi.

So, that is about the single phase AC voltage regulators: the principle that is used to control the speed of a ceiling fan or light intensity controller. Now, how about controlling the speed of a 3 phase induction machine or a 3 phase load? What are the possible circuit configurations? I will show you.

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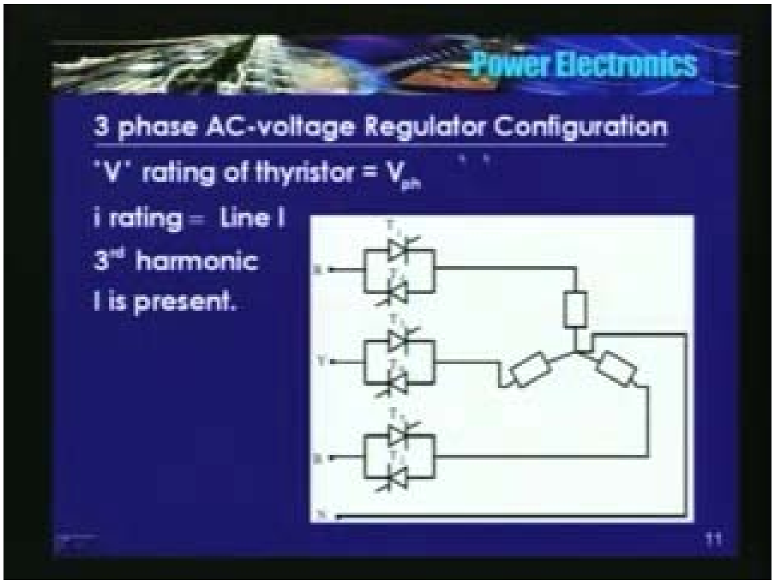

There are various configurations, numerous. I will just show you very few. There are 3 bands here, see, numbering is the same as what we did in 3 phase AC to DC converters. 3 phase bridge T_1 T_4, T_3 T_6, T_5 T_2 or say T_1 3, 5, 4, 6, 2 and load is star connected and the neutral wire, the star point is connected to the neutral. I have told you that in single phase load current which is equal to the source current is an odd function. There are all odd harmonics.

How about in 3 phase? We know that in 3 phase 4 wire system, a current that is flowing in the neutral wire is minus of i_A plus i_B plus i_C. So, all the triplen harmonics or third harmonic currents will flow through this wire because the fundamental component that is i_A sin omega t, sin omega t minus 120, sin omega t minus 240; the some of these component, the fundamental component will be 0. Whereas, third harmonic component, they add up and they will flow through this line because sin 3 omega t, here sin 3 into omega t minus 120 that is 360 that is equal to sin 3 omega t itself and same here. So, all triplen harmonics will flow through this. So, you will have triplen harmonics in the line current. So, voltage rating of each thyristor is a phase voltage and current rating is the line current that is flowing. Because it is a 3 phase 4 wire system, you will have a third harmonic current here.

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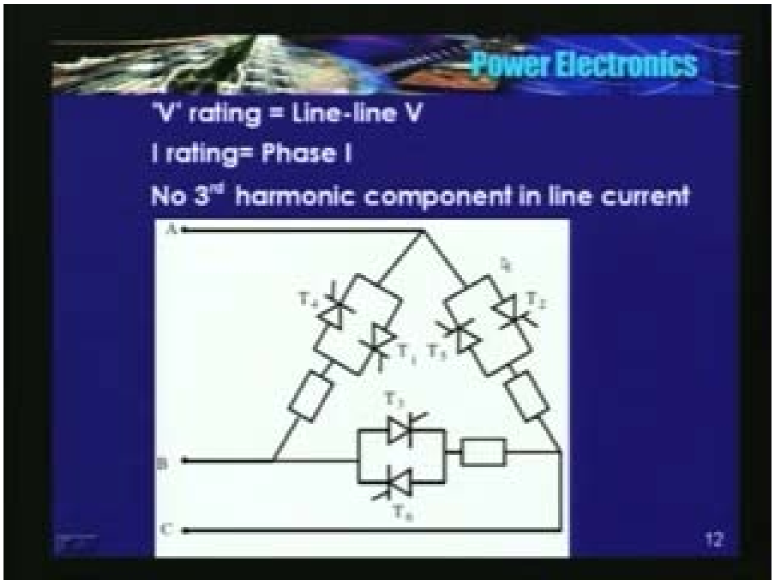

Now, when the load is connected in delta? This could be one of the configurations. Again, back to back 3 bands; these are 3 loads, they are connected in each phase. What happens here? The current through the SCR is the phase current but then the voltage is the line to line voltage. But then you will not have third harmonic current in the line. In the previous case, because there is a neutral you will have third harmonic currents in the line. But in a 3 phase 3 wire system no triplen harmonics.

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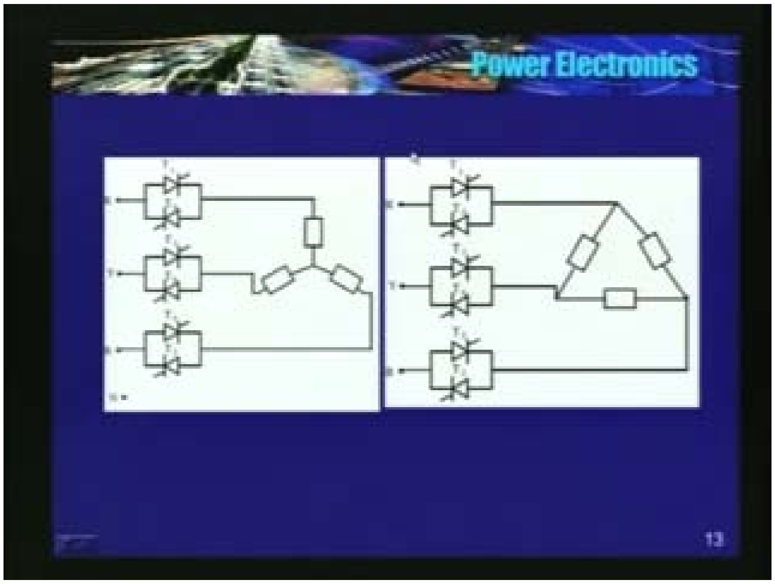

So, this is another configuration. Another 3 bands connecting, feeding a star connected load, isolated neutral isolated neutral. Now, there are no triplen harmonics here, no triplen harmonics because if I apply KCL at this point; i_A plus i_B plus i_C should be equal to it should be 0. Now, we found that third harmonic components; sin 3 omega t, this also will be sin 3 omega t itself because 3 multiplied by 120 is 360 that is again 0. This is also sin 3 omega t. So, they will they are in phase. They add up here. So, KCL fails. So therefore, you will not have triplen harmonics in this case. So, if you there will be triplen harmonics if there is a fourth wire.

Now, same as before we have connected this band outside, not in series with the load. There are various possible configurations. We will analyze one of them: a 3 phase AC regulator feeding a star connected load.

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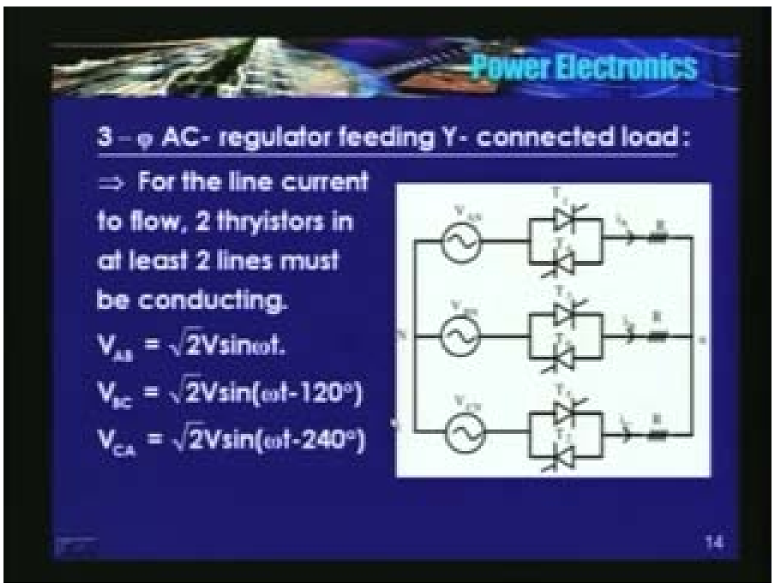

Let me tell you one thing; analysis of 3 phase AC voltage regulator is bit difficult compared to a 3 phase AC to DC converter. So, that is a reason I will use a resistive load. I will not analyze the circuit for a RL load. So, this is the possible configuration; AN BN CN are the phase voltages, a 3 phase resistive load, star connected and you have 3 pairs of back to back connected SCRs.

In this circuit, for the current to flow in the load, 2 thyristors at least 2 thyristors in two different phases should be on. So, if T_1 is on, current can flow through T_6 or T_2. So, this is the condition: for the line current to flow, 2 thyristors in at least two lines must be conducting. Now, for the analysis I will take the line voltages as the reference. So, I will take V_{AB} as root 2 V sin omega t. BC lagging AB by 120 degrees and CA by 240 degrees.

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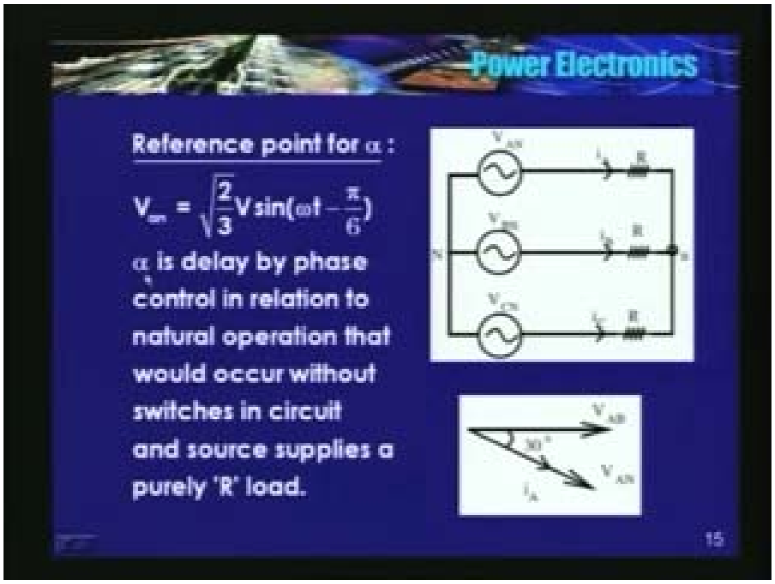

Now, what is the reference point for alpha or where do I start measuring alpha from? What did you do in 3 phase AC to DC rectification? We took the point of natural commutation as the reference point. Now here, the reference point is taken as I will show you, see, here it is mentioned alpha is a delay by a phase control in relation to the natural operation that would occur without switches in circuit and source supply a purely a resistive load.

It is like this. What this sentence means is I have a 3 phase voltages, load is purely resistive, alpha is the instant where I_A cuts the X axis or a 0 axis and becomes positive. That is the reference point. I will repeat; so reference point alpha is when in this circuit i_A become 0 and becomes positive goes positive. So, when does it occur? I have defined V_{AB} line to line voltage as root to V sin omega t.

So, we know that phase voltage lacks the line voltage by 30 degrees. So, it is like this. So, V_{AN} is given by this equation - minus pi by 6. So, in the vector diagram if I draw V_{AB} is here, V_{AN} is lacks by 30 degrees and this current is in phase with the phase voltage. So, i_A. So, reference point for alpha is 30 degrees from the 0 crossing of the line to line voltage V_{AB}. I will repeat; reference point for alpha is 30 degrees from the 0 crossing of the line to line voltage.

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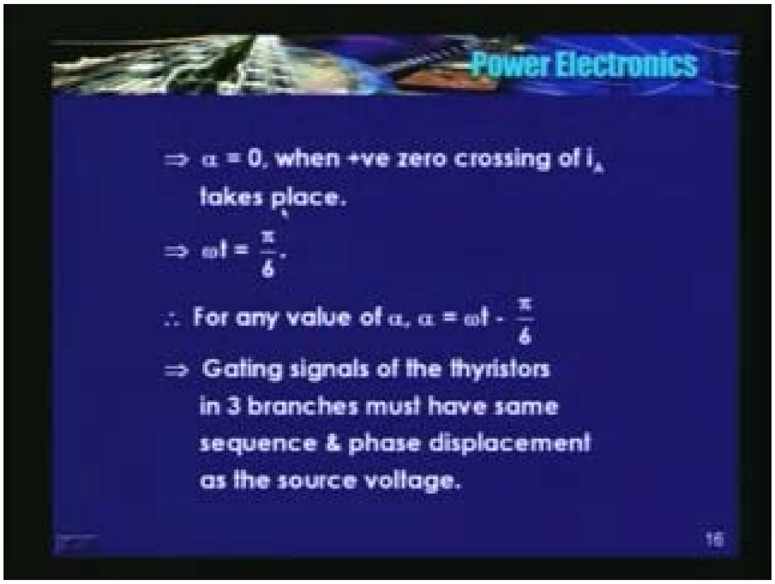

Now, I will show you, see here, alpha is 0 when positive 0 crossing of i_A takes place. That is omega t is equal to pi by 6. So therefore, for any value of alpha; that is this, omega t minus pi by 6. Now, what is another condition? We all know that a 3 phase supply is being applied to a 3 phase load, voltages have to be balanced. So, the gating signals for the thyristors in 3 branches must have the same sequence and the phase displacement as the source voltages. See here, gating signals of the thyristors in 3 braches must have the same sequence and phase displacement as the source voltage.

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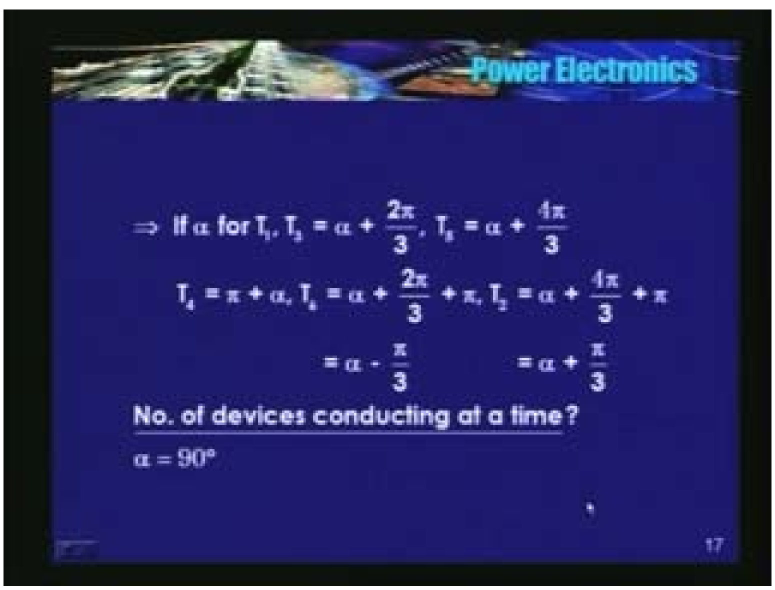

What does it mean? It is this. If alpha for T_1, so T_3 is connected to B phase. So, alpha plus 2 pi by 3 and T_5 and alpha plus 4 pi by 3 and T_4 is anti parallel with the T_1, it is pi plus alpha. For T_6, this angle plus pi and T_2 this angle plus pi. These are the angles. So, T_1 is triggered at alpha, T_2 is triggered at alpha plus pi by 3 - 60 degrees, T_3 is triggered at alpha plus 2 pi by 3 - 120 degrees, T_4 alpha plus 5, T_5 alpha plus 4 pi by 3 because pi plus alpha plus 60 degrees it is this and so on.

Now, coming to the number of devices conducting at a time; things were straight forward in AC to DC conversion with 0 source inductance. That means there is no overlap, commutation overlap here. At any given time 2 devices were conducting. Things are not very straight forward in AC voltage regulators. I will just show you 2 different cases: alpha is 90 and in another case is alpha is 30.

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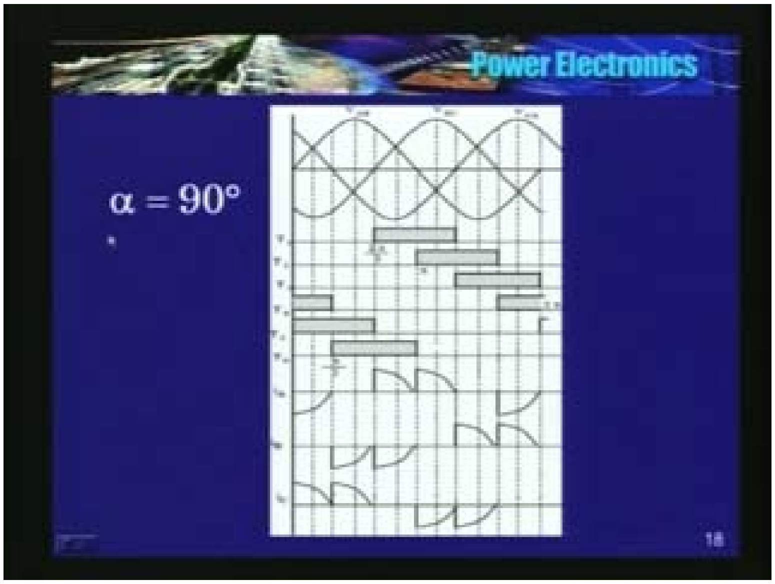

For alpha is equal to 90 degree; see, I have drawn the line to line voltages V_{AB}, V_{BC} and V_{CA}. Alpha is 90 degrees, reference point for alpha is this point. Wherein, this point is 30 degrees from V_{AB}, pi by 6. So, this is the reference point. From here 90 degrees: wherein, you will trigger T_1. So, if this is this is 30; 60, 90. At this point, T_1 is triggered. I will not tell you the width of the pulse at the gate right now. May be sometime later I will tell.

After 60 degrees T_2 is triggered and again after 60 degrees T_3 is triggered and again at 60 degrees T_4 is triggered and again at 60 degree is T_5 is triggered and this T_5 this is 2 pi, just see here. This is this wave form has completed one cycle. In case of V_{AB} has completed one cycle. At that instant T_5 is getting triggered. So, this point is same as this and after 60 degrees from here, T_6 will get triggered. Now, since the width of the gate pulse would be anything. So, I have drawn even T_4 here. See, it has started from here. It is 2 pi; I can continue in this direction, instead of continuing in this direction I have drawn it here.

Now, if you see at the 0 crossing omega t, T_4 and T_5 are gated or there triggered pulse exists for T_4 and T_5 and V_{CA} is positive V_{CA} is positive; 4 and 5 there are trigger pulses, can they conduct? Let us see the equivalent circuit.

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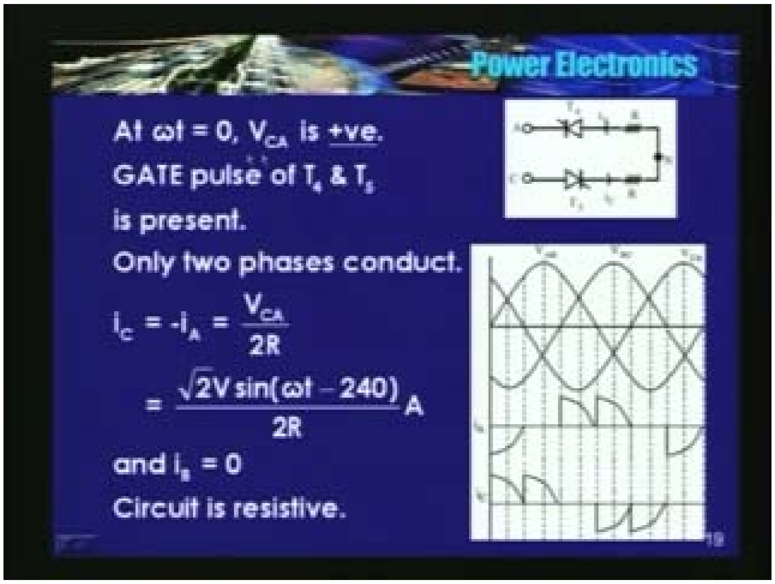

At omega t equal to 0, V_{CA} is positive. Gate pulses for T_4 and T_5 is present. Now, V_{CA} is positive; 5 connected in this manner, 4 is connected in this manner. Resistive load current can flow, current can flow in this direction because V_{CA} is positive. Nothing happens in B phase because sixth that is connected. See here, nothing happens in B phase here. Sixth that is connected gets trigger pulse after some time. So, only 2 phases are conducting, only 2 phases and what is the equation for current?

i_C is equal to minus i_A i_C is equal to minus i_A. It is given by V_{CA} V_{CA} divided by 2R. Two circuits are in series, I am neglecting the drop. So, V_{CA} is this waveform. Magnitude of current is divided by 2R. So, almost the same waveform; magnitude could be different, that is all. Same waveform as V_{CA}, current i_C and i_R I_A. I_A is negative but i_C is positive. Now, what happens at omega t is equal to pi by 3?

At omega t equal to pi by 3, V_{CA} is 0 and becomes negative. That means potential of A is higher than potential of C. Resistor circuit, current cannot flow in this direction. So, at this point, T_4 turns off and if you see the previous waveform, see at this point, I had stopped the gate pulses for T_4 because no point having gate pulses beyond this point. But if you see at that point itself, T_6 is getting triggered T_6. At this point, T_6 is getting triggered.

Now, T_5 is connected to C phase, 6 is connected to B phase. See the circuit configuration, it is something like this; C, B - 6 and 5. Now, current can flow in this direction, provided, V_{CB} is positive. V_{CB} should be positive, only then you can have current in this way. Now, let us see what happens. See here, V_{BC} is negative. So, omega t equal to pi by 3, V_{BC} is negative.

Therefore, V_{CB} is positive. So, V_{CB} is positive, therefore and current can flow and what is that current? i_C is equal to minus i_B equal to V_{CB} divided by 2R.

Now, V_{BC} is V_m sin omega t minus 120 degrees. For CB, I am adding 180 degrees because we have defined AB, BC and CA. So, divided by 2 R and I_A is equal to 0 and what is this value of current? This value of current, you need to substitute omega t is equal to 60 degrees. So, you will get the value of this current by substituting it here. That is the value of i_C.

So, where does T_5 stop conducting? Now, at omega t is equal to 2 pi by 3, V_{BC} becomes 0 or V_{CB} become 0 and V_{BC} becomes positive. In other words, V_{CB} becomes negative. T_5 has to turn off at this point because see in this direction, current to flow in this way, C should be at a higher potential than B. So, that means V_{CB} should be positive. So, when it is 0, T_5 turns off. Where does it become 0? At this point, it becomes 0. So, at that point, i_C or T_5 turns off.

So till here, I have shown the gate pulses for T_5, see this figure. See here, at this point I have shown the trigger pulses for 5 and that point, T_1 gets triggered T_1, 1 and 6 will conduct, 1 and 6, voltage is V_{AB}. See, I will show you; 1 and 6 1 and 6; same thing that we did for 4 and 5, 5 and 6 and 1 and 6. So, at any given time, only 2 thyristors are conducting where alpha is equal to 90 degrees.

Now, we will see for alpha is equal to 30 degrees, what does it? So, here are for alpha is equal to 90 degrees, I have shown you the line voltages, gate pulses and currents. Only 2 phases carry current at a time, one phase is open one phase is open. See, there is no current here. Now, for alpha is equal to 30 degrees. Now, I have shown here; in addition, I have shown you the phase voltages also.

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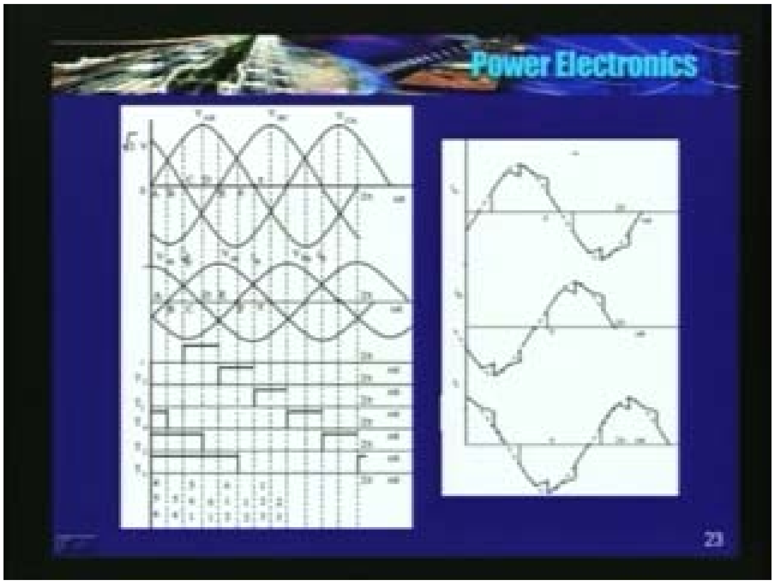

Phase voltages as well as the line to line voltages. Alpha is equal to 30 is somewhere at this point. This alpha is equal to 30 degrees. There is T_1, T_2, T_3, T_4, T_5 T_6. Now, if you see in this figure, at omega t is equal to 0; T_4 is getting a trigger pulse, T_5 is getting a trigger pulse, T_6 is getting a trigger pulse. Now, can they conduct? See, if you see the equivalent circuit; T_4 is connected like this, T_5 is connecting in this fashion, T_6 is connected in this fashion.

Now, you can have a current flowing from T_5 to T_4, provided, V_{CA} is positive V_{CA} is positive. Yes, in this region V_{CA} is positive, C_A is positive. You can have current flowing from T_5 to T_6, provided, V_{CB} is positive. Yes, V_{BC} is negative. So therefore, V_{CB} is positive. So therefore, T_4 T_5 T_6 can conduct because all the conditions are satisfied. They are getting trigger pulses, they are forward biased. Since all 3 phases are conducting, I need to use the rule that is which is used in 3 phase circuits that i_A plus i_B plus i_C should be equal to 0.

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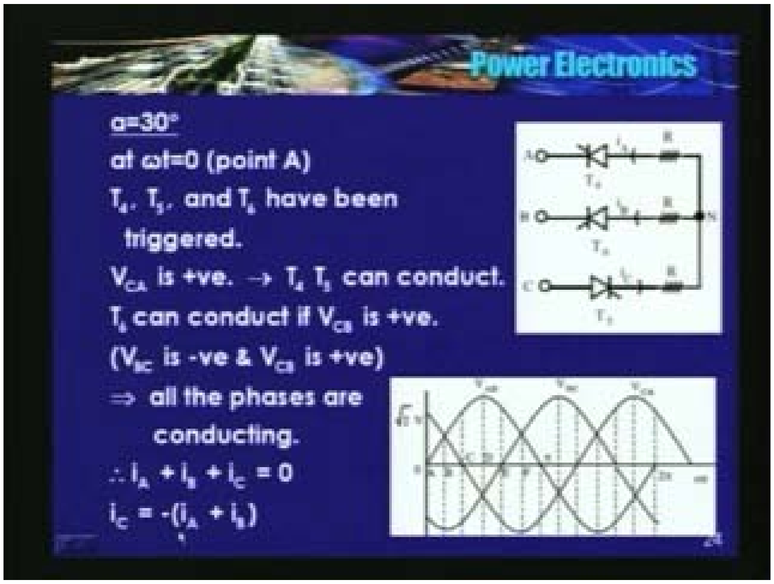

So, i_C is equal to minus of I_A plus i_B and where does i_A becomes 0? See here, I_A becomes 0 at this point where V_{AN} becomes 0 where V_{AN} becomes 0. At this point, i_A becomes 0. So, when i_A become 0, T_4 turns off. So, at omega t is equal to pi by 6, V_{AN} becomes 0. Therefore, I_A becomes 0, T_4 turns off. Now, T_1 is getting triggered at this point. See, alpha is measured with respect to this point at 30 degrees. See, T_1 is getting triggered at this point.

So, for the first sometime of 30 degrees, only 5 and 6 are conducting. What is the condition for 5 and 6 to conduct? 5 is connected to C phase, 6 is conducted connected to B phase. V_{CB} should be positive V_{CB} should be positive. See here, this is V_{BC}. So, V_{BC} is negative. Therefore, V_{CB} is positive. So, they can conduct; 5 and 6 can conduct at this point. Now, the circuit equation is i_C is equal to minus i_B and current is V_{CB} divided by 2R. So, the current waveform is see in this region, 0 to pi by 6 i_A plus i_B plus i_C is equal to 0. See, i_A is negative, i_B is also negative and i_C is positive.

Now, from pi by 6 to pi by 3, I_A is 0 and at that time, i_C is equal to minus of i_B. This is correct. At omega t is equal to pi by 3, T_1 is triggered. Now, what happens? Now, the circuit diagram is something like this; T_1 is triggered, now current can flow from T_1 to T_6 if V_{AB} is positive. Yes, it is; V_{AB} is positive V_{AB} is positive.

See, at this this is a line to line voltage. Reference point is alpha is equal to 0. This is the point alpha 30 is this. So this beyond, V_{AB} is positive. Now, current flow in this way, V_{CB} also should be positive. Yes, see here, this is V_{BC}, we are somewhere in this zone. Now, V_{BC} is negative, therefore V_{CB} is positive. V_{BC} is negative, therefore V_{CB} is positive. So therefore, it is possible.
So, current will starts flowing in this direction. So, in this mode 3 thyristors are conducting. What are they? T_1, T_5 and T_6. This continues for another 30 degrees. At that time, after 30 degrees, T_5 turns off. Why? When 3 thyristors are conducting, I need to use this same rule; i_A plus i_B plus i_C should be equal to 0. So, if any one of the phase voltage has become 0, at that time the thyristor which is connected to that phase should turn off.

See, I will show you the phase voltages. After 30 degree, somewhere at this point, see V_{CN} is becoming 0 V_{CN} is becoming 0. So, T_5 turns off T_5 turns off. So, I have stopped or this is the boundary for T_5 gate pulses. So remember, if 3 thyristor are conducting, I need to use i_A plus i_B plus i_C is equal to 0, load is resistive. So, till the phase voltage becomes 0, the equivalent circuit which consists of 3 thyristors is valid. The moment the one of the phase voltage is becomes 0, the thyristor which is connected to that phase turns off and till the new thyristor is triggered, only two of them will be carrying current and this principle you need to use to analyze 3 phase AC voltage regulators.

It is not very straight forward as compared to a 3 phase AC to DC bridge rectifiers. That is the reason I told you this is not very straight forward but then it is not very difficult either. With that I conclude my lecture on power electronics. For the last 43 lectures or so, I have tried to give you just the overview of the power electronics. Subject is really vast. I encourage you people to take up a good text book. Fortunately, a large number of very good text books are available which was not the case during my under graduate days. Not many books on power electronics were available which is not the case now. Large number of very good books are available. Pickup a book, a good book on power electronics and start reading it. Only then, the efforts which have taken will bear fruit.

Thank you and good luck to all of you.