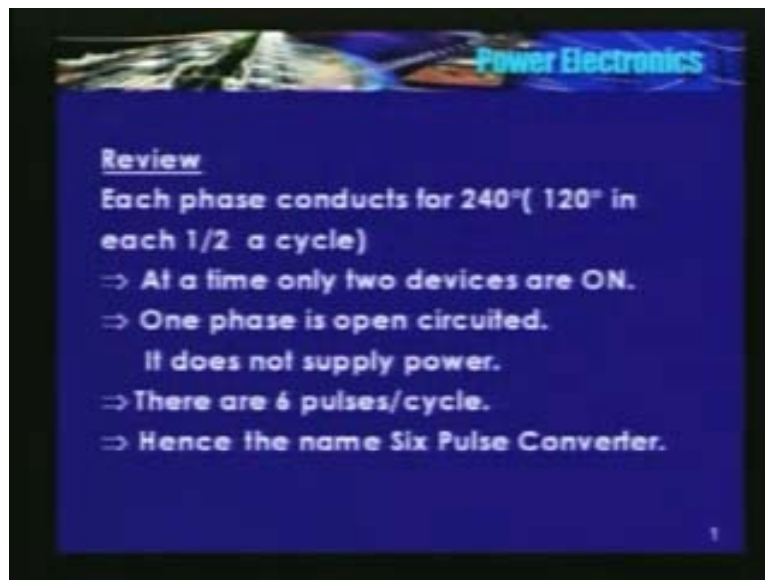**Power Electronics**

**Prof. B.G. Fernandes**

**Department of Electrical Engineering**

**Indian Institute of Technology, Bombay**

**Lecture No - 17**

In my last lecture I discussed the operation of 3 pulse converter that is 3 phase half wave rectification. We found that each device conducts for 120 degrees and each phase is also supplying power for 120 degrees.

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So, each phase supplies power only in half a cycle for 120 degrees duration. We used 2 such bridges and we got a 3 phase full wave rectifier and we found that there is 1 common cathode configuration and there is another common anode configuration. Each device conducts for 120 degrees but then each phase supplies power for 240 degrees in a cycle, provided, the load current is continuous.

So, in other words, at any given time, 1 phase is open. It does not supply any power to the bridge. There are only 2 devices are conducting at a time. 1 device in the upper half, another device in the lower half and they do not belong to a same phase, remember.

So, at any given time, in a 3 phase full wave rectifier, 1 phase is open and 2 phases are supplying power to the load and there are totally 6 pulses per cycle, each pulse of 60 degree duration. See

remember, each device conducts for 120 degrees but then there are 6 pulses, each of 60 degree duration. Hence, the name 6 pulse converter.

So, we have so far you have studied, 1 pulse, 2 pulse, 3 pulse and 6 pulse converter. What are the advantages of increasing number of pulses? I will just show you a ... slide.

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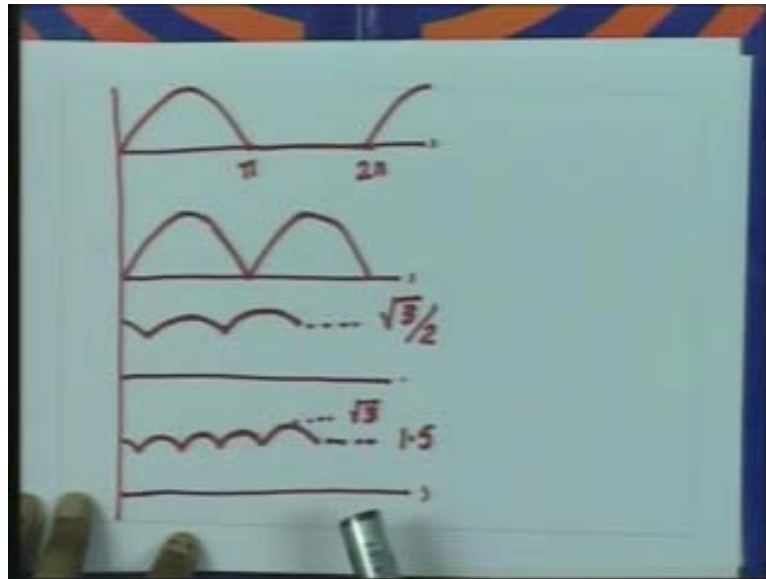


This is the waveform for half wave ratification. I am assuming, it is a pure resistive load or may be a half wave rectification using a freewheeling diode, full wave rectifier, 3 pulse converter and a 6 pulse converter. I said this is AC to DC conversion. I would like to have almost a constant value of DC voltage. So definitely, I would filter this waveform to get a constant DC.

Now, if you compare here, in which case the filtering requirement is maximum and which case it is minimum? To have a constant DC in half wave rectification, definitely, the filter requirement is the highest because for 0 to pi, the load voltage is same as the input voltage and pi to 2 pi it is 0. Now, I need to have a constant DC. So, definitely, my filter requirement here is more, whereas in 2 pulse converter, there is no 0 voltage duration, there is no period, wherein, output voltage is 0 here. So, definitely, filtering requirement reduces. But then output voltage changes from 0 to $V_m$.

What happens in 3 pulse converter? We found that yesterday, there are 3 pulses and the minimum value of $V_0$ it is proportional to sin 60. It is root 3 by 2 or root 3 by 2 per unit and this is again the peak value is $V_m$. For alpha is equal to 0 half 3 phase half wave rectifier, the voltage output voltage varies from root 3 by 2 to 1.

What happens in 6 pulse? We discussed yesterday for alpha is equal to 0 or that is equivalent to an uncontrolled bridge. We found that this voltage changes from 1.5 per unit to root 3 that is approximately 1.7. So, in 6 pulse converter with half alpha is equal to 0, the variation in the

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output voltage is 1.5 to 1.7. So, that is approximately a constant for an engineer, <mark>it,</mark> I can say that output voltage remains approximately constant. I may not require any filtering.

See, therefore, as the number of pulse increases, your filtering requirement comes down. The maximum in 1 pulse converter, minimum in 6 pulse converter. 6 pulse converter, we will see somewhere while doing DC to AC conversion. We will find that filtering requirement there is minimum. In some cases, you can do away with this filtering, even to have a constant DC.

Now, what is the expression for the average value of the output voltage? There are 6 pulses per cycle, each pulse of 60 degrees duration. Alpha is measured with respect to the point of natural commutation.

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So therefore, if I need to integrate from pi by 6 plus alpha to pi by 6 plus alpha to pi by 3 and we found that when $D_1$ or $T_1$ and $D_6$ or $T_6$ are conducting, output voltage is $V_{ab}$. So, the magnitude of $V_{ab}$ is root 3 $V_m$ sin omega t plus 30. So, <mark>we will found</mark>, if you simplify this, you will find that it is 3 root 3 by pi into $V_m$ into cos alpha where $V_m$ is peak of the phase voltage.

See, we have taken $V_{an}$ is $V_m$ sin omega t. This is a phase, so it is, V is the RMS value. So, if I substitute for $V_m$, you will get 2.54 into V into cos alpha where V is the RMS value, alpha is the trigger angle. So, this is also equal to 2 into this expression and we found that this is the expression for output voltage of a 3 pulse converter. So, average output voltage for a 6 pulse converter is twice the 3 pulse converter.

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Power Electronics

$\Rightarrow V_s = 2[\text{o/p 'V' of 3-phase half wave controlled rectifier}]$

value of source current $= [\frac{1}{\pi} \times I_s \times \frac{2\pi}{3}]^{\frac{1}{2}} = \sqrt{\frac{2}{3}} I_s$

$\therefore$ Equivalent circuit

2.54Vcos$\alpha$   $I_L$   Load

So, here is the equivalent circuit. It is 2.54 into V into cos alpha. RMS value of the phase voltage is variable because there is a function of alpha. 2 devices are conducting at a time and here is the load voltage, this is the load voltage, the current.

I told you that each device conducts for 120 degrees. So, if I find the RMS value of the source current, it is found to be root 3 by 2 into $I_0$. So, source, if alpha is equal to 0, phase A supplies power from pi by 6 to 5 pi by 6. In the positive half and in the negative half, it is 210 degrees to 330 degrees. So, each phase in each cycle, power supplied by the source is of 120 degree duration.

So, if I assume the load current to be constant and ripple free that means load current is constant of value $I_0$. If I find RMS value of the current, source current, it is found to be this value, root 3 root 2 by 3 into $I_0$, whereas, in a single phase bridge, if I assume that load current is of constant and ripple free, RMS value of the source current is same as $I_0$, whereas here, it is different because each phase supplies power for 240 degrees.

So, if I assume a load current of a constant and ripple free, source current is of a square wave of duration 120 degrees in each cycle. In a single phase case, it was a square wave of pi radians. So, if I take the harmonic series or if I write the Fourier series for a single phase bridge, we found that all the triple N harmonics are present.

In other words, all odd terms are present; sin omega t, sin 3 omega t, sin 5, 7, 9, 11 so on. All odd harmonics are present in a single phase case, whereas, in a 3 phase, 3 wire system, you cannot have triple N harmonics. I am sure, this result your teacher who was teaching machines might have told you. So therefore, in a 3 phase, 3 wire system, you cannot have triple N harmonics.

So, if I write the Fourier series, you will find that there are only 6 N plus or minus 1 harmonics. In other words, there is fundamental sin omega t. Next is sin 5 omega t, sin 7 omega t, sin 11

omega t, sin 13 omega t. This is also equal to sin 6 N plus or minus 1. N takes a value of 1, 2, 3 so on. So, in a 3 phase, 3 wire system, there are only 6 N plus or minus 1 harmonics and the fundamental.

So, harmonic content is also reduced in a 3 phase. There are no triple N harmonic. The frequency of that harmonics present in a 3 phase, 3 wire system also increases. What implication it has? We will see some time later.

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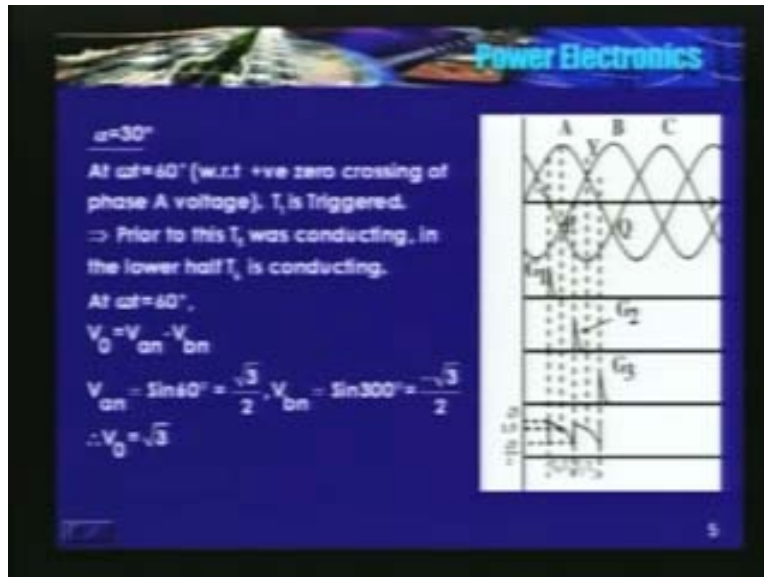


Yesterday, we discussed for alpha is equal to 0. Today we will study the waveform for alpha is equal to 30 degrees. Alpha is measured with respect to the point of natural commutation. So, $T_1$ is the reference for thyristor $T_1$, this is the reference point. $T_3$ - this is the reference point, $T_5$ - this is the reference point while device that is connected that is 2, this is the reference point, 4 - this is the reference point and this is for $T_6$. See, D phase is getting negative.

So, at alpha is equal to 30, this is alpha is 0, alpha is 30, $T_1$ is triggered, $G_1$ is getting a triples. So, prior to point P, $T_6$ is conducting. At P or P is the reference point for 2. So, prior to 2, 6 would conduct in the lower half, so, 6 was conducting. Now, what is the output voltage?

When $T_1$ starts conducting, the positive DC bus or potential of X is $V_{an}$ and potential of Y is $V_{bn}$. Refer the bridge which we have drawn it yesterday. So, $V_{an}$ is proportional to sin 60, mind you, alpha is measured with respect to this point. But then, we need to find out the instantaneous value of the phase, the corresponding phase with respect to its 0 crossing.

So, at alpha is equal to 30, instantaneous value of $V_{an}$ is proportional to sin 60 that is root 3 by 2 and $V_{bn}$, it is sin 300, 6 was conducting. So, it is minus root 3 by 2. So, therefore the peak is therefore, the value of the output voltage, $V_O$ is $V_{an}$ minus $V_{bn}$ is found to be in a root 3. So, with alpha is equal to 0, the peak value of the output voltage is root 3. So, even at alpha is equal to 30, the peak value of $V_0$ is still root 3.

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Now, let us see after 30 degrees, what happens? So, V or somewhere at this point that is P, we will find that A phase is at the peak that is sin 90, 6 is still conducting, so instantaneous value of phase B is sin 330 that is minus half. So, output voltage is 1.5. This corresponds to 1.5.

Now, 30 degrees beyond P, $T_2$ is getting triggered. Let us see the output voltage just prior to triggering 2. At that instant, $V_{an}$ is proportional to sin 120 or say 120 minus that is still root 3 by 2. $V_{bn}$ is approaching 0, may be, 360 minus. Therefore, it is 0. So, the load voltage is $V_{an}$ minus $V_{bn}$, it is proportional to root 3 by 2 itself. So, just prior to triggering $T_2$, output voltage is root 3 by 2.

The moment you trigger $T_2$, now, the load voltage is $V_{an}$ minus $V_{cn}$ because $T_2$ starts conducting. $T_2$ is connected to phase C, so load voltage is $V_{an}$ minus $V_{cn}$. Instantaneous value of $V_{cn}$ is proportional to sin 60 or sin 240 that is again minus root 3 by 2. $V_{an}$ is 120, again it is root 3 by 2.

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Output voltage is $V_{an}$ minus $V_{cn}$. So, output voltage jumps to root 3, root 3 by 2 minus of minus root 3 by 2, it is root 3 itself. So, peak value of the output voltage even with alpha is equal to 30 degrees is root 3. But then the minimum value is reducing. It is now root 3 by 2 and now … there is a sudden jump, root 3 by 2 to root 3 because at this instant you are triggering another device, incoming device.

So, from in this instant, $T_6$ and $T_1$ are conducting and $T_1$ and $T_2$ and so on. I encourage you to draw the remaining 6 pulses also. So, what is the effect of increasing alpha on the power factor or the instance at which the source supplies power? Phase A voltage is becoming positive here, this is the positive 0 crossing. If alpha is equal to 0, it would have started supplying the current from this instant. I cannot reduce this period beyond this. So, alpha is 0 is here, so it can, the phase A can start conducting only at alpha is only at omega t is equal to 30 degrees.

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Now, I am triggering <mark>at omega t is</mark> alpha is equal to 30 degrees that is omega d is equal to 60. So, phase A is open till omega t is equal to pi by 3 radians. So, the positive crossing of the source current can be at this instant. If alpha is equal to 0, the positive crossing could have been somewhere here. Now, with alpha is equal to 60 degrees, the positive crossing becomes here. In other words, I am delaying the current. In other words, source current started becoming more and more lagging.

If alpha is equal to 0, the 0 crossing of the source current would have been here, now, it is here. So, this angle is increasing. The angle between the positive 0 crossing in the voltage and positive 0 crossing of the source current is increasing. In other words, power factor is deteriorating. Remember, as you increase alpha, power factor deteriorates.

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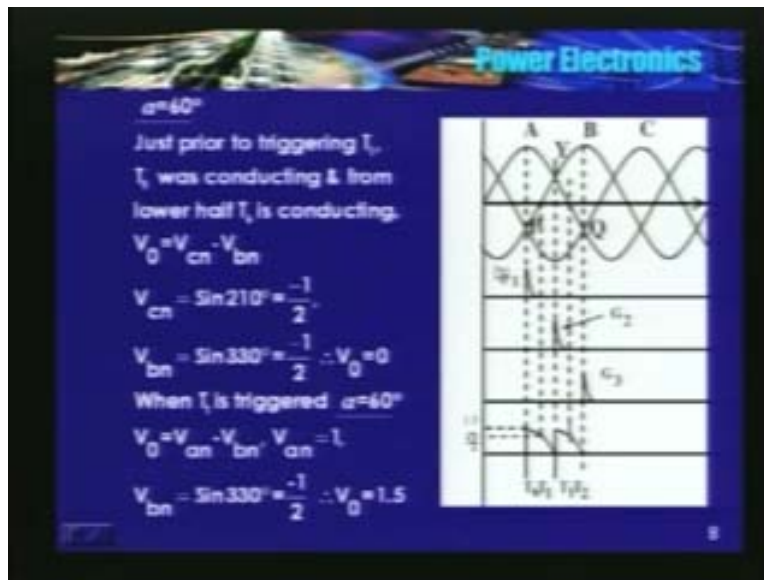


Now, let us see what happens with alpha is equal to 60 degrees? At this instant, $T_1$ is triggered. Prior to $T_1$ or prior to triggering $T_1$, $T_5$ was conducting. In the lower half, in this instant, $T_6$ is conducting. So, what is the output voltage just prior to triggering $T_1$? It is $V_{cn}$ because 5 is conducting, minus $V_{bn}$, 6 is conducting in the lower half, upper half 5 is conducting. So, $V_{cn}$ minus $V_{bn}$.

What is $V_{cn}$? $V_{cn}$ is 210, proportional to 210 degrees that is minus half. $V_{bn}$, it is 330 degrees. It is again minus half. So, output voltage is $V_{cn}$ minus $V_{bn}$, it is 0. So, now it is touching 0, whereas, in the both the cases with alpha is equal to 0 and alpha is equal to 30 degrees, it did not touch the X axis. Now, with 0, <mark>with X,</mark> alpha is equal to 60 degrees, it is does touching the X axis.

Now, at point P or at this instant, you have triggered $T_1$. Now, output voltage becomes $V_{an}$ minus $V_{bn}$. What is $V_{an}$ at this instant? Proportional to sin 90, it is 1, whereas, $V_{bn}$ is still at 330 plus. So, it is again minus half. So, $V_O$ is 1.5 times the peak value or 1.5 per unit. See the

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difference, now. For alpha is equal to 0 to 30, we had still the peak value of root 3. So, alpha increase above 30 degrees, the peak value comes down. Now, with alpha is equal to 60 degrees, we found that peak value is 1.5, minimum is touching 0 now.

Now, what happens to the output voltage waveform beyond 30 degrees from there? At this instant, $V_{an}$ is sin 120 that is root 3 by 2. We have not triggered $T_2$, 6 is still conducting. So, $V_{bn}$ at this instant is 0. So, output voltage is root 3 by 2 itself. $V_{an}$ minus $V_{bn}$, $V_{bn}$ is 0. So, it is root 3 by 2 and what is the output voltage just prior to triggering $T_2$? It is same as the output voltage just prior to triggering $T_1$, whatever that happen to $T_1$, it will happen to $T_2$ also, may be, in the lower half. So, you will find that output voltage is just touching 0.
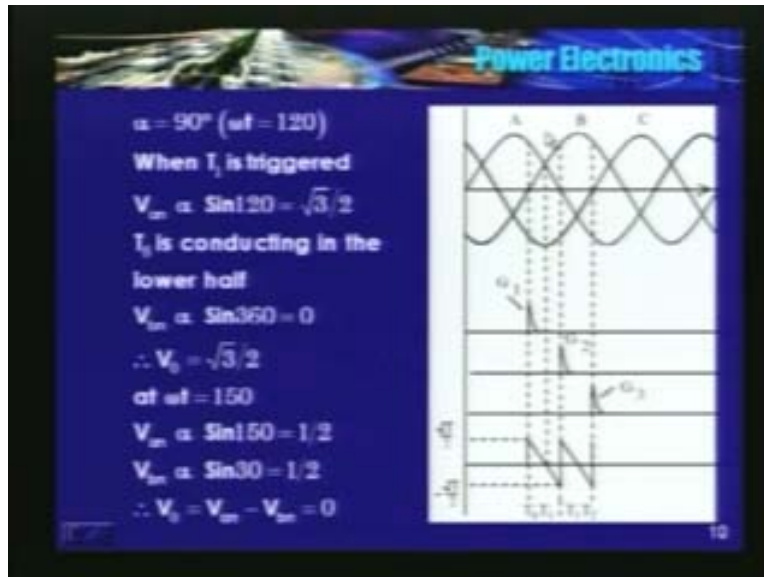
The moment you trigger $T_2$, output voltage jumps to 1.5. So, output voltage here varies from 1.5 to 0. Now, it is touching 0 with alpha is equal to 60 degrees.

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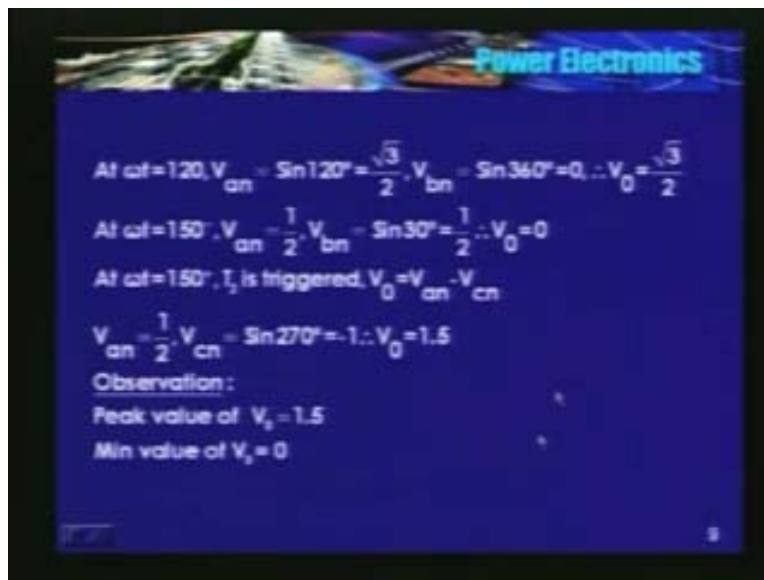


So, here is the procedure. I would expect you to continue the complete the remaining 4 pulses also.

Now, let us see what happens with alpha is equal to 90 degrees? Corresponding value of omega t is 120. $V_{an}$ is root 3 by 2, bottom of 6 is conducting, $V_{bn}$ is sin 60, it is 0. So, $V_0$ is root 3 by 2. The moment I trigger $T_1$, it jumps to root 3 by 2. What happens after 30 degrees? At this instant, $V_{an}$ is sin 150 that is half and $V_{bn}$ is sin 30, it has become positive. So, instantaneous value of $V_{an}$ is same as instantaneous value of $V_{bn}$. So, output voltage is 0.

Now, what is the output voltage just prior to triggering $T_2$? $V_{an}$ is, may be, 180 minus is approximately equal to 0. $V_{bn}$ is sin 60 minus. It is approximately, root 3 by 2 itself. So, $V_{an}$ is 0, $V_{bn}$ is plus root 3 by 2. So therefore, output voltage is $V_{an}$ minus $V_{bn}$. It is minus root 3 by 2. So therefore, for alpha is equal to 0, output voltage varies from root 3 by 2 to minus root 3 by 2, provided, the current is continuous, remember. Provided, the current is continuous, output voltage when alpha is equal to 0 is varies from root 3 by 2 to minus root 3 by 2.

So, if I summarize the 3 waveforms, you can have a peak value of root 3 till alpha is equal to 30 degrees. So, anywhere from 0 to 30, peak value of the output voltage is the same. For alpha less than 60, $V_0$ is always positive. At 60 degrees, $V_0$, the instantaneous value or minimum value of $V_0$ becomes 0 and if I increase alpha beyond 60 degrees, minimum value of $V_0$ now, starts becoming negative. It becomes negative.

So, if I ask a question, if the load is purely resistive, so, what will be the instant or what should be the trigger value of alpha beyond which current becomes discontinuous? Definitely, it is 60 degrees because at 60 degrees, the minimum value of $V_0$ is 0 that is a voltage appearing across the resistor, current also will become 0. So, current is just continuous in the case of a resistive load for alpha is equal to 60 degrees. Above 60 degrees, current becomes discontinuous and mind you, you cannot use the expression 2.54 into $V_m$ into cos alpha if the current is discontinuous. That is valid only if the current is continuous.

Alpha is equal to 90 degrees, we found that average value becomes 0. What sort of a of load we are talking about? What sort of a load we are talking about or in which case average value of the output voltage is 0 but the current is continuous? It can happen only if the load is purely inductive because average voltage across the inductor is 0. So, what happens is, in this waveform, this is positive L di by dt and this is negative L di by dt. Current starts from 0, reaches a peak here because at this instant L di by dt is 0. So, current has to be peak and again comes down and becomes 0. It is just continuous, just at the boundary between continuous and discontinuous.

For other loads you cannot have a continuous conduction for alpha is equal to 90. For anywhere, for even if the load is of RLE type, I into R is always positive, E is positive. So, average value, you cannot have. Average value across the inductor is 0. So, RI plus E should be 0, it is just not possible. So, load current can be continuous for alpha is equal 90 is only for an inductive load, purely L load.

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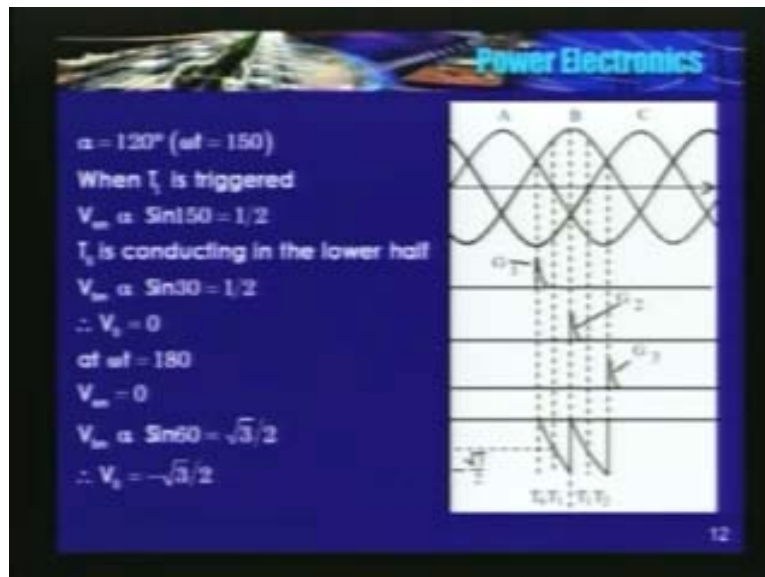


Last case, I will just increase alpha is equal to 120. Now, corresponding omega t is equal to 150. So, $V_{an}$ is proportional to sin 150 that is half. Beyond, in the lower half, $T_6$ is conducting because we have not triggered 2. 2 is triggered somewhere at this instant. So, 6 is conducting, the potential of Y is $V_{bn}$ and potential of X is $V_{an}$. Instantaneous value of $V_{an}$ is same as instantaneous value of $V_{bn}$. So, output voltage is 0. $V_{bn}$ is sin 30 and $V_{an}$ is sin 150, output voltage is 0.

Let us see what happens beyond, 30 degrees beyond from this point? $V_{an}$ is sin 180, 0. $V_{bn}$ is proportional to sin 60 that is root 3 by 2. Output voltage is $V_{an}$ minus $V_{bn}$, it is minus root 3 by 2. What is the output voltage just prior to triggering $T_2$? Just prior to triggering $T_2$, output voltage is still $V_{an}$ minus $V_{bn}$. $V_{an}$ has become negative, it is sin 210, 210 minus or so and $V_{bn}$ is sin 90 minus. So, $V_{bn}$ is minus 1 approximately, $V_{an}$ is minus half. So, output voltage is minus 1.5, this peak is minus 1.5. So, at this point $T_2$ is triggered.

Now, the moment $T_2$ is triggered, now output voltage is <mark>$V_{an}$ minus $V_{cn}$, sorry $V_{cn}$, right, $V_{cn}$.</mark> Instantaneously, this voltage becomes 0. Instantaneously voltage becomes 0 because AN is 210, CN is 330. So, both are minus half. So, minus of minus half minus half is plus half, it is 0. So, for alpha is equal to 120 degrees, if I summarize, it becomes 0 and always negative, whatever that happened for alpha is equal 60 degrees. Alpha is equal to 60 degrees, we found that instantaneous value or minimum value of $V_0$ is 0 and it is positive. So, at alpha is equal to 120 degrees, it is 0 and negative. Just the opposite, these are the 2 pulses.

See, we have triggered $T_1$ at this instant. <mark>The positive value</mark>, the positive 0 crossing of the current is somewhere here. Positive crossing of the phase A voltage is somewhere here. So, this and this goes on increasing. Power factor deteriorates with increase in alpha. I am not going to do for alpha is equal to 150 and alpha is equal to 180. Same procedure, you follow it and you will find that whatever that happened for 30 degrees, it will happen for alpha is equal to 150 but negative. Whatever that happened for alpha is equal to 0, it will happen for alpha is equal to 180.

So far we drew the waveforms for alpha is equal to 0, 30, 60, 90 and 120. Suppose, now that you have to go to the lab, you have been given a 3 phase bridge, there is a load. Now, what value of alpha will you choose? Now, forget about 3 phase. Let us talk about single phase, relatively easier. Say, assume that we have a DC motor as a load, RLE type load, DC motor. Motor is stationery, in the sense, motor rotor is not rotating. What will you choose the alpha to be?

In our machines lecture, our teacher has told that you need to apply, reduce voltage to the DC machine. Full field reduced armature voltage, so that the current drawn with the motor reduces, also, it accelerates faster because when the motor is at stand still, back EMF is 0. The current is limited by the armature resistance itself.

 Invariably, students say that we should choose alpha is 90 degrees, if a single phase fully controlled bridge is feeding a DC motor. Why? because, if alpha is equal to 90 degrees, average value is 0. So, <mark>alpha is equal to</mark> I am applying a very small volt, in fact, 0 voltage and go on reducing alpha. Now, my question is can we start at alpha is equal to 90 degrees? Answer is simply no, why?

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See the waveform here. The input AC, RLE the load, E is 0. Say, inductance is very small here. I am assuming that there is no filtering inductor in the DC side. Things, of course, things do change if there is a filter inductor here. Now, the current is limited by R itself, which is very small, armature resistance is very small for a motor. Again, armature inductance is also very small.

Prior to triggering these devices, there is no current. So, if you trigger the bridge at alpha is equal to 90, the instantaneous value of $V_n$ is $V_m$. That is the peak value. So, your peak voltage, you are applying to the motor terminals. If it is 230, you will get around 320 or so. 320 volts, current is limited by R plus small L. It will so happen that a large current will flow and may damage these devices.

So therefore, a safe value may be, towards 150 to 160. It is all depends on the parameters of the machine or the DC side. If I have an inductor, of course, you can decrease this value. Otherwise, may be, start somewhere near this point and reduce alpha towards 90 degree. Now, do not say that sir, you are triggering at 150, average value is negative. Average value becomes negative beyond 90 degrees only if the current is continuous. You have not even established the current in the circuit. So, the question of current being continuous does not arise.

So, depending upon the value of R, L, E, current builds up and it may become 0 because if you keep the same alpha it may become 0 much before that. So, if you want to accelerate the motor, you go on reduce the alpha towards 0. What happens for a 3 phase case? Things are not very straight forward here, why?

At any given time, 2 devices are conducting. Change over from 1 device to another device, 1 device in the top and 1 device in the bottom; they do not take place at the same time. So, change over from $T_5$ to $T_1$ takes place at some omega t. After 60 degrees, change over from 6 to 2 takes place. The second is at any given time, 2 devices should be on. There is no current, you have not

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even established any current in the bridge. You have put on the AC supply, to establish the current in the bridge, 2 devices have to be triggered. So, your pulse patterns should be such that 2 devices or any pair $T_1T_2$, $T_2T_3$, $T_4T_4$ or whatever, should get trigger pulse simultaneously.

So, all the waveform that I have drawn so far, I have just drew or just shown you only 1 pulse? That scheme may work at steady state, provided, the current is continuous. I repeat; I have shown you only 1 pulse in the gate circuit. That may work at steady state, provided, the current is continuous. So, while starting or if the current has become 0 in between, to re establish the current in the bridge, 2 of them again will be triggered the same time.

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So, the pulse pattern should be something like this, $T_6T_1$, $T_1T_2$, $T_2T_3$. So, I need to have 2 pulses separated by 60 degrees. See here, 6 and 1 are triggered at the same time. Now, 6 also may be triggered at the same instant but the moment you triggered 2, say, after 120 degrees or so, from here, 6 will turn off and 2 will come.

So, at any given instant, 2 devices should be triggered simultaneously. By the way, ==this pulse should be== this is an ideal case. Do not think that just because we are triggering again here, 6 will continue to conduct for another 120 degrees, no. See, you are triggering 2 after 60 degrees. See, this duration is 60 degrees. The moment you trigger 2 somewhere here, 6 turns off and 2 starts conducting. So, ideally you need to have 2 pulses which are separated by 60 degrees.

In a single phase case, we found that if the load is of RLE type, current may become discontinuous. You have triggered the bridge $T_1$ and $T_2$ in the positive half, they started carrying the current. Now, E is higher than the instantaneous value of $V_i$. In that case, we found that di by dt is negative and it may so happen that current may become 0. Please recall, I have discussed all this.

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Therefore, we said that instead of having only 1 pulse, have series of pulses. Same concept is still valid in 3 phase case because if the load is highly inductive, we know that gate signal should be present till the current through the device is higher than the latching current. So, gate signal should be present. We know that if the load is highly inductive, current cannot change instantaneously, a current slowly builds up. So, if there is only a sharp pulse, by the time $I_G$ becomes 0, current would not have increased to, is the latching current. So, SCR may not even turn on.

So generally, a series of pulses of duration 70 to 75 degrees is used. I might have said that theoretically, 2 pulses of 60 degree duration, sorry, 2 pulses which are separated by 60 degrees are required. General practice is; have a series of pulses, of the total period is of the order of 70 degrees or so is used. What is the maximum value of alpha to start the bridge in a 3 phase case?

We found that for alpha is equal to 120 degrees, minimum value of $V_0$, in other words, $V_0$ touches 0 and becomes negative. It does not become positive at all. I have not even established the current in the circuit. Let it be, whatever may be the type of load, we have not established the current in the circuit. To establish the current, I need to have a positive voltage across it. If alpha is equal to 120 degrees, it is either 0 or negative. So, you cannot establish any current in the circuit.

So therefore, in a 3 phase bridge, the maximum value of alpha to start the bridge is or should be less than 120 degrees. It is only then a positive voltage appears across the load. For alpha less than 120 degrees for a small duration, a positive voltage appears across it. If the positive voltage appears across the load, current starts flowing, current builds up, then it can go on reducing alpha depending upon the load requirement.

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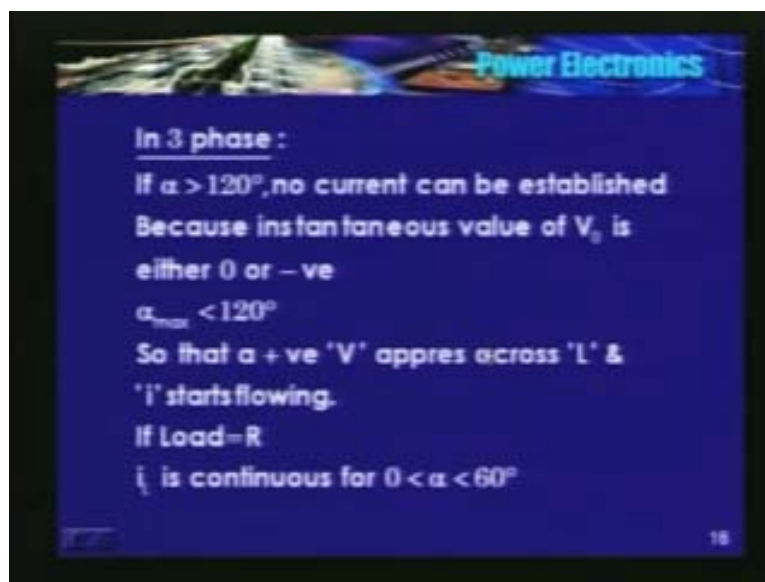


So, alpha$_{max}$ should be less than 120 degrees, should be 120 degrees so that a positive voltage appears across the load, voltage across the load and i starts flowing. Again, I am assuming here

that load is passive. Things will change if I have a battery there, things will change. So, if the load is a passive, alpha$_{max}$ should be less than 120 degrees.

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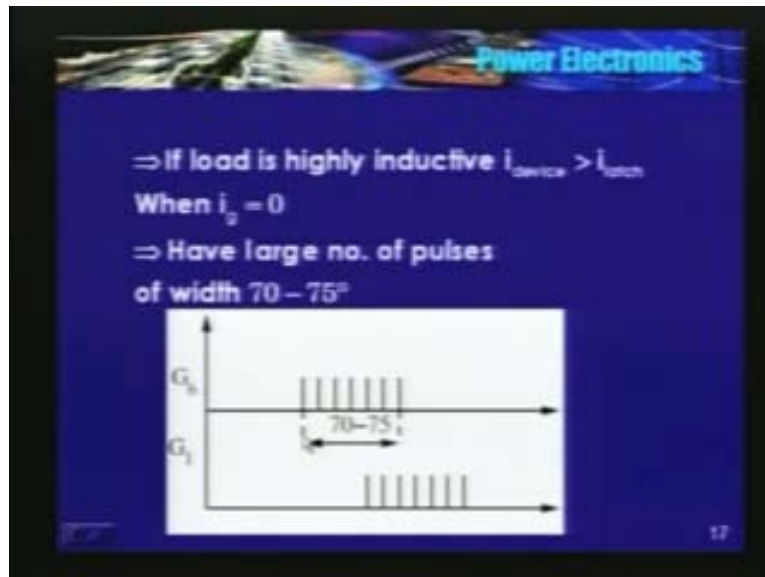


So, here is the sequence. A series of high frequency pulses of 70 to 75 degrees and see, there is an overlap here. This is the overlap, this duration, this is the overlap. 1 and 6 are triggering at this point or this is the instant were $G_1$ should be triggered. So, at that instant, $G_6$ still have few pulses because even if the current has become 0 somewhere this, at this instant, $G_1$ has also started conducting, $G_6$ sorry at this instant, $G_1$ is getting a trigger pulse and there is a trigger pulse for 6 also.

So, current can establish in the circuit, so far, so good. On this analysis, we discussed for source inductance is 0. We are neglecting the source inductance. So, that is why current changes instantaneously from 0 to the value of load current, the moment you trigger the thyristor and if I consider a finite source inductance, instantaneous change is not possible and in the single phase case we found that during commutation period, output voltage is 0. So, during the overlap period, mu, output voltage is 0. So therefore, there is a net reduction in the voltage applied to the load. This is due to the source inductance.

What happens in a 3 phase case? Will the output voltage is 0 during commutation period? We will see.

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Assume that I am, case 1, I am just assuming an uncontrolled half wave rectification or rectifier. $D_1$ was conducting, $D_2$ starts conducting at the point of natural commutation, when the positive when the $V_n$ becoming more positive then $V_{an}$, for sometime $D_1$ and $D_2$ starts conducting, there is a short here, $D_3$ is still open. So, what is the KVL for this loop? It is $V_{an}$ minus $V_{bn}$ is $2L_{Si}$ ds by dt is the current that is flowing here. Current increases, this current decreases, iT. So, output voltage is $V_0$ is equal to $V_{an}$ minus $V_{an}$ minus L $di_s$ by dt.

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So, if I substitute here, $V_0$ is found to be $V_{an}$ plus $V_{bn}$ by 2. So remember, in a 3 phase case when the 2 devices are conducting, output voltage is the sum of the 2 voltages, phase voltages

divided by 2. So, just see here, at this instant is the point of natural commutation. Prior to this point is the load voltage. Whatever it be, whether, it is An or Bn or Cn, does not matter. At this instant, both the devices have started conducting.

Now, this voltage is this voltage is instantaneous value of this plus instantaneous value of this divided by 2. So, I need to add up these 2 voltages and divided by 2, will give you the output voltage. I am assuming mu to be 30 degrees. So, at this instant, overlap is complete, so outgoing device turns off completely. Now, the output voltage is corresponding to the instantaneous value of the incoming phase. So, there is a jump.

Though I have used diodes, I should have had a smooth waveform. There is no jump in a uncontrolled rectification. Now, here you find that due to source inductance, there is reduction in the voltage and there is going to be a jump in the output voltage. This is for controlled bridge.