Fundamentals of Power Electronics
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Lecture – 02
Overview of Basic Power Electronic Circuits from Layman's Point of View

Welcome back. So far, we have seen the you know the importance of Power Electronics by looking at some examples which are very close to us. We saw an example of a laboratory power supply, and then we saw a computer power supply which actually I took out from a desktop computer, and I showed you that this power supply is actually meant to cater various voltage levels and various power levels in the various sections of the computer. So, there are computers of course a very complex machinery and there are lot of circuits inside which need different levels of voltage and power.

So, we saw that typical power electronics system is required, a complex power electronics system would be required. But I actually gave you an idea that how such reduction in the voltage levels, and how a change from AC to DC form of electricity can be achieved by using a very simple power electronic circuit which we studied as a rectifier. We took the example of a diode-based rectifier first, and it gave us you know after all the filtering and all the other explanation, it explained to us that how we can get a nice and constant DC voltage at the output terminals which we described as X Y of such a rectifier system.

But there is an issue that we observe that there was no way to change this voltage. There is no way to control this voltage across terminals X and Y if diodes are used in the rectifier. So, the only thing if you want to change the voltage across terminals X and Y the only thing perhaps you can do is to change the input AC voltage itself only, that is all you can do. But then I introduced fictitious imaginary device, a three-terminal device I said that it has terminals 1 and 2 in the same way as a diode. But it also has an edit third terminal unless and until we activate the third terminal my device does not conduct this fictitious device does not conduct even though, it may be forward biased. So, basically what I am saying is that it has the ability this imaginary device has the ability to block the forward voltage. It is not like a diode which will start conducting the moment it is forward biased.

Now, let us move ahead from the example of the rectifier, and let us now say that instead of a AC voltage which is available to us, let us say when we are in a remote place where we are generating power supply we have a generating power with batteries. Now, we all know that the batteries will give you a DC supply, so it will give your DC voltage. When you apply a load to it then you will get actually, we extracting the DC current through it. So, it is basically a DC supply.

Now, suppose you have a DC supply which is either through batteries or it could be through DC generators or it could be through some other ways like for example, fuel cells. Fuel cells are you know as you know they actually are the currently the front running candidates for being used as renewable energy sources. And this could be actually a solar photovoltaic source. They are all, they all give out DC voltage. In fact, even a wind energy source they are all used with rectifiers. So, they also give a DC source.

So, let us say we are in a place we have where we have the primary source of power as DC. So, we have the DC which is being produced. But we want to achieve we want to use it in some processes in some applications which need another level of DC voltage. What do we do? So, one very simple way of looking at it is by way of this example. So, let us say if we have something like 48 volts which is being produced by the battery or the DC generator and I just want to get 24 volts then what can I do. So, let me just draw this particular diagram.

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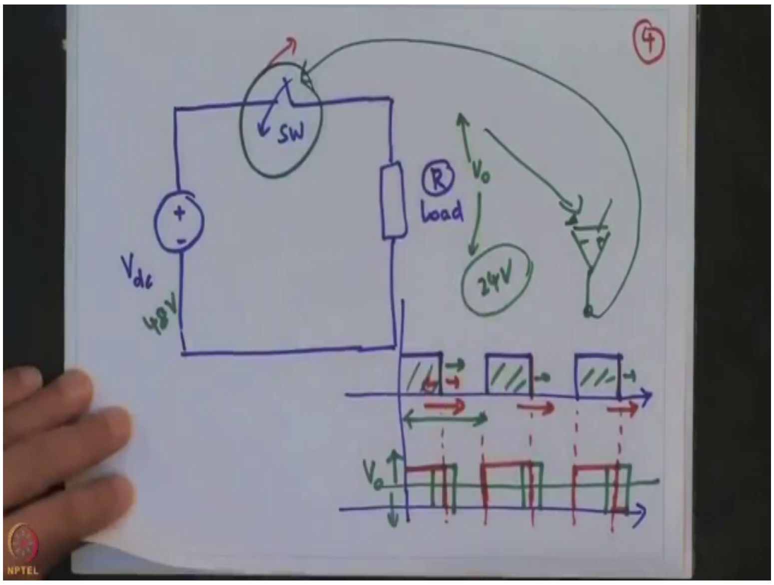

So, this is the V dc which I am denoting the you know, my primary supply which is of the DC form in this case and let us say it is not a regulated power supply, it is a raw power supply, ok. So, it maybe you know it is just whatever the source is giving out, it is just what is it reflected here and there is no regulation closed loop regulation associated with it, ok.

Now, let me just put a simple switch here, and let me just denote at the output a load. Let us say for again for simplicity for convenience of understanding and explanation, let us say that this is a pure R load resistive load. Now, the switch that we see is turn on and turn off continuously. So, basically the switch has these kinds of pulses which are applied to its control terminal. By the way this switch is again a controllable switch a three-terminal device, one the kind of one that we assumed. This is the same three-terminal device.

And what we see here are the control pulses applied to the terminal 3 of this device. Now, when that happens assuming that there are no losses, there are no other issues, they are device is very ideal and so on and everything else is ideal in the circuit. What we can see at the output is that when the switch is on then the V dc will appear at the output across the load and when the switch is open, that this part is broken. So, this load cannot see the voltage tall, so you actually get a 0, ok. So, what you get at the output, its basically these kinds of pulses, these kinds of output voltage pulses which are as you can see in the shape in the appearance, they are same as the control pulses applied to the switch or the switching device the controllable device.

Now, you can see that by changing the time for which these pulses are applied to the controllable device the switch, so I have just put these arrows just to say that this right-side boundary it can be shifted, it can be shifted actually to this side or to this side. So, as that happens, as you shift on to this side, you extend the boundary you stretch the boundary of the control pulses what you will see is that here these pulses will also stretch out. While if you move to the left side you will find that they will shrinking.

So, what is the result of this? Now, if I was to look at the overall result of doing this what I observe is that, if I was to denote the average of this as the DC voltage content of the output I can see that by stretching the control pulses right or left I am able to move my average value of V o up or down, V o is the voltage across the load; V load or V o we can just denote it the way we like. So, that is what is going to happen. So, this is a very simple example.

Now, if I want to get for a 48 volts DC voltage, I want to get 24 volts output I can see that the control pulses should actually be half of this duration. If they are exactly half of this, we will get about 24 volts here. But the problem is that with this circuit how do we get a voltage which is more than 48 volts across a load. Is it possible to get a voltage which is output voltage V o which will be more than the applied 48 volts? The answer is with this circuit no, but power electronics also gives you a way to do that. So, what we use is basically in this circuit we modify this configuration, and as we will see in the course that we apply certain energy storing elements like inductors.

And we use the mechanism of storing the energy into the inductor and then releasing it, storing the energy into the inductor and then releasing it, more like a spring action compress release, compress release, and we will see that this section leads to the boosting of the input voltage. So, you actually are able to locate a voltage which is much higher than what you have the input. But just to understand the very basic example of power electronics for this kind of a situation where you have a DC input or the DC power as the primary source, how do you actually get a variable output voltage is this example that I have given.

And, mind you that regulation problem which I explained with the help of a rectifier is equally valid here because I can say since this output voltage as before, I can compare it with a reference and based on the error I get from what I want V o to V and what I am actually getting from that difference I can always modify I can always manipulate and control the pulse to the terminal 3 of the switch shown here. So, this is an example where you can see that from a given from a DC source how you get variable levels of DC, how you get a different level of DC voltage and how you can control this voltage, ok.

Now, talking about the DC source; now, there are several applications where it is desirable to have a DC source, and then manipulate it, and then get the kind of power that you need to supply your load. Now, one example of this is in AC drives, AC motor drives. Now, we all are aware of the electric machines. We have the two types the DC machines and the AC machines. In the DC machines also, we have DC generators and we have DC motors. And this motor works when you apply a DC supply. And to change the speed of a DC motor, so suppose your application is such that you wish to change the speed of you know of your motor, you change the voltage supply, you change the DC voltage supply apply to the or measure of the motor, DC motor.

Now, when you go to the AC motor and you want to actually control this as the motor, so you apply AC and AC as you know is an alternating current waveform AC waveform, you apply to the AC motors. Now, one way of controlling let us say the speed of these AC motors is just by changing the voltage, but the problem with these AC motors is that if you just change the voltage levels but you do not change the frequency of the voltage supply that you are applying to the motor. Then you actually are running the risk of saturating the core which makes of them of the machine.

Therefore, you must have heard, at least some of you must have heard about what is called a V by f control where the voltage applied to the AC motor windings two stator and its ratio with the frequency. So, the voltage rms voltage applied to the three-phase stator of an AC motor to the frequency of this voltage supply that is always kept a constant. Now, this basically means that we need a mechanism that given a DC supply, primary DC source we want to create AC supply whose rms voltage we can vary and whose frequency also we can vary in such a way that the rms voltage to the frequency ratio remains constant.

Now, I will just show you with the example very again we will take the layout the Layman's approach we will not talk about very specific you know terms very technical, involve technical terms in this just for understanding will come to these things slowly in due course. So, one of the I will just give you the example how this is done.

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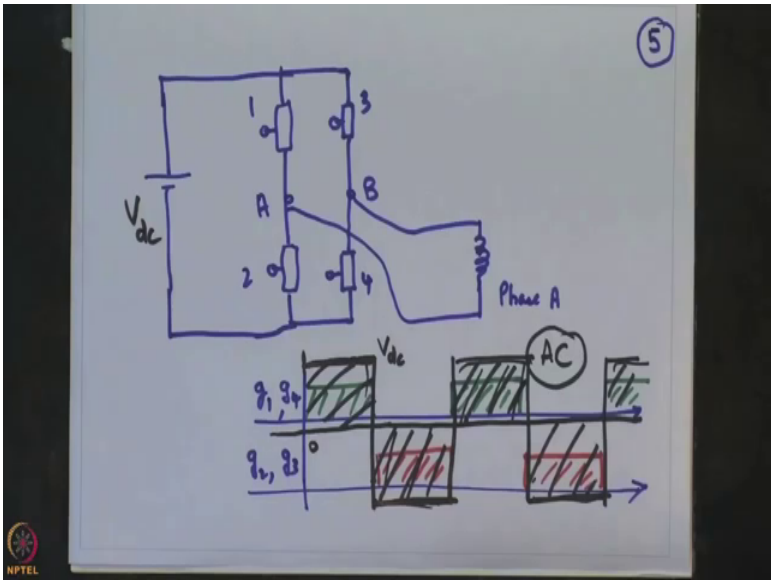

So, let me just start with a DC source, and let us say that I have that t terminal device with all the ideal assumption, ok. And I show its control terminals with this as you can see there is a line with a small speck segments with a bubble like this. And I just apply it to this bridge which I have form of these of these special devices the controllable devices. These are different from diodes mind you as I told you. It has got a third terminal which can control which can control precisely when these devices will start conducting and when they will stop conducting the current.

The load is connected here. So, let us see here this is the output and I just mark this as A and B, and let us say that this is going here and let us say that this is going to one of the phases of my AC motor, let us say. So, let me just call this as the first as phase let us say A of my three-phase AC motor. Now, for there are three-phases in the AC motor; there are single phase motors as well but let us talk about three-phase AC motors right now. So, basically what we need is we need to create another two phases here. But for now, let us assume that we are just talking about one of the phases of the three-phase AC motor and what will happen.

Now, let us say we just have; so let me just mark these devices as 1 2 3 4 and let us call the control pulses to these various devices which are applied to the various terminals as g 1 and g 4, and g 2 and g 3, ok. So, there are control pulses to these two pairs that I want to draw and show you. So, let us say these are the control pulses which are given to the control terminals of devices 1 and 4, and let us say these are the pulses which are given to the devices 2 and 3. Now, when this happens, when you apply these kinds of control pulses to the various devices what would you observe? At or across terminals A and B which is supplying power to the one of the phases of the stator windings of the AC motor. What kind of waveform we will get? So, we will see that if we apply this waveform, let me just draw another.

So, I will basically get a waveform of this type, which is shown with a black color and it is; so assuming that we are taking all precautions to keep symmetry between the various waveforms. So, this is what is going to be the output. And we can just check this here, so if this voltage is V dc that we have applied, then when the devices 1 and 4 will be applied to control pulse and they will be conducting we will find that V dc will appeared across terminals A and B directly, and that is why this level V dc will appear here. And when devices 2 and 3 will be applied the control pulses and then they will conduct 1 and 2, and 1 and 4 are not conducting at that time as you can see. Then at that time a minus V dc will appear across terminals A and B. This can be very easily verified. By assuming the ideal assumptions, we have made for the special device.

We have assumed that there are no drops, there are no losses in these devices. So, you will get this negative sign. So, like this this will repeat and you will get this square wave it is not sunny suicidal but it is an AC nevertheless, positive, negative, positive, negative. Now, if I can play with the frequency if I can bring these pulses control pulses shown with green and a red, if I can bring them closer or if I can take them away I can play with the frequency. So, by controlling their width of these pulses I can play with the rms output voltage and by bringing them together or away I can play with the frequency. So, in effect this kind of a system it actually gives me starting from a DC voltage it is able to give me a AC output voltage whose rms voltage I can control and whose frequency I can control. Such a power electronic system or circuit is called a DC to AC converter or simply an inverter and has several applications.

Now, let me just give you the last you know last example which will kind of complete this family of; it will exhaust all the permutations and combinations of the power conversion. So, this one is actually if we have a primary source of electricity as an AC source. So, AC source is the primary form of electricity and we are trying to get another level of AC voltage at the output, then we call it as an AC voltage controller. And I will just explain to you how this works.

So, just like we have seen the examples of earlier the AC to DC rectifier, then DC to DC you know converter and then DC to AC converter. Now, let me just draw an AC to AC converter.

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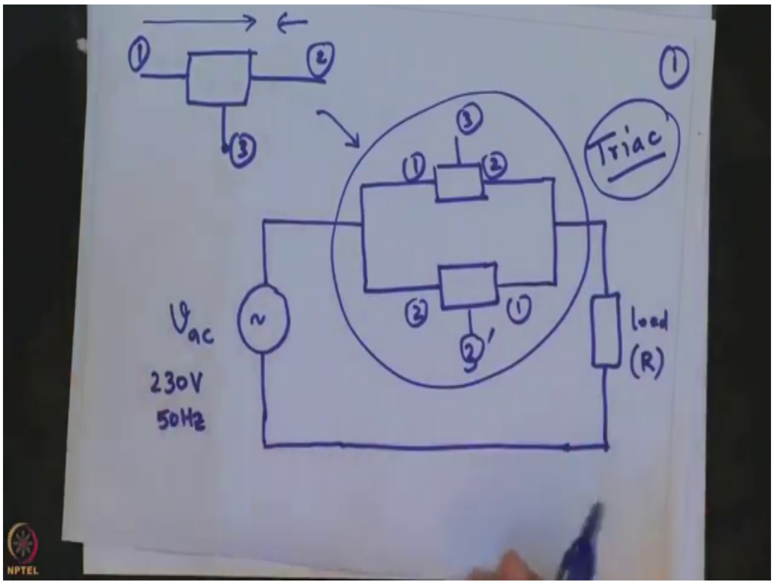

So, first of all our controllable device, the special device which I introduced calling the two terminals the regular terminals as 1 and 2 before between which the currents would flow and a third terminal which is marked as 3, and it is this terminal which is called the control terminal and it is to this terminal we apply the control signal and that is when the device this device starts to begins to operate, begins to conduct.

We assume that this device is capable of withstanding, a large negative voltage between terminals 1 and 2 we also assumed that the resistance offered by this device as the current flows from 1 to 2, terminal 1 to 2 is 0. So, we are just considered an ideal device, and also we assume that the current cannot flow from terminal 2 to 1, it can just flow from 1 to 2. So, it is a unidirectional device.

Now, let us say that we have this kind of device with us, and we connect it in the following manner. So, let us say we have this primary form the primary form of power which is the AC in this case. And let us say we are taking it from the 230 volts, 50 hertz you know the mains supply that we get very commonly from the wall socket. And what I do is that let us say in one of the lines let us in the top lines, I connect this special device I use two of these and the way I connect them is anti-parallel. So, what I have here is this device this is terminal 1, this is terminal 2 and this as terminal 3 and the other branch that we have made here. Let us say this device is again input but now it is the other way round. So, here 2 is basically connected here, terminal 1 is here, so this devices as you can see has been reversed in the direction in which it can conduct and it has again the terminal 3. Let me call it as 3 dash the control terminal.

And these are connected here terminals 2 and 1 or the two of these controllable devices they are connected, and let me just put some load that I want to drive which has a need for a variable AC supply to be applied across it. So, it is that low. For simplicity for now just assume that this is just a simple R load, simple R load. Now, such an example where you would need a variable AC supply to be applied to a load could be for example, a room heater or it could be a dimmer you know where the lights for example, in the on the theater and the stage, people try to dim it or maybe make it bright. So, they apply a variable AC to it, these are, so there are many examples of this.

So basically because we will see later because, this supply is going to be full of harmonics. So, basically, we try to operate only crude type of AC loads with it not very sophisticated because otherwise they would have to take all the harmonics and their life would reduce, ok. So, such is a situation you know what I have shown here in this diagram. So, this is my diagram. Now, let us see what happens, how this would work and what we will get across the load. Are we really going to get a variable AC supply across the load that we have actually started you know that was over basically our objective, ok?

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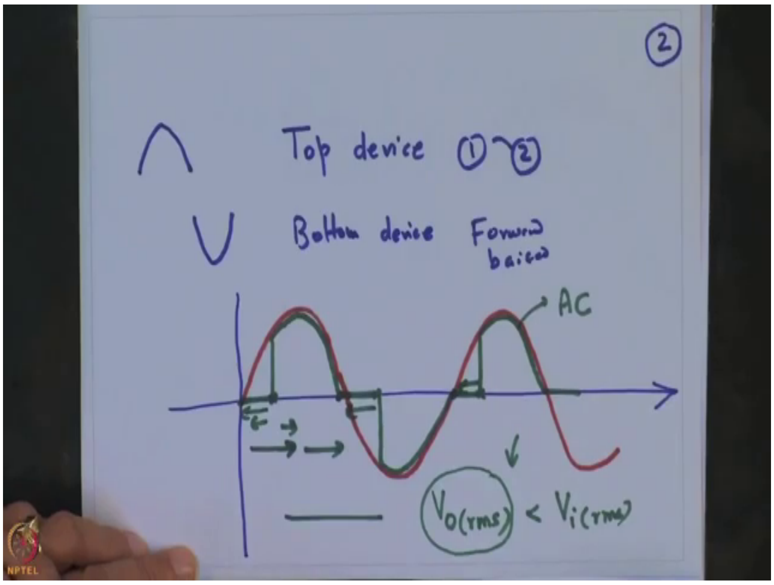

Now, when the AC supply on the input side is positive like this, we will find that the top device, will have a forward bias across terminals 1 and 2. When the input AC supply is negative at that time the bottom device, that is going to be forward biased, which means that during the positive half of the AC cycle that we are applying as input. The top device is ready to conduct and when the voltage applied the AC supply voltage at the input is negative during the negative half, the bottom device is ready to conduct is ready to conduct. But as I told you I must supply a control signal to the corresponding control terminals 3 and 3 dash. Now, let us look at this with the help of the waveforms.

. So, what I have drawn is the input AC supply this is the input AC voltage which is having 50 hertz or 50 hertz which is applied. Now, as I told you just now, when the AC input is positive during the positive of the top devices ready to conduct. Now, let us assume that at is it is at this point, where I give the control pulse to the terminal 3. Now, what will happen? As far as the load is concerned what will it observe. It will observe the corresponding part of the input AC supply voltage, ok. So, what will it see? Let me just draw it. This is typically what it will see.

Now, let us move on to the next half which is the negative half of the input supply voltage AC supply voltage. Now, by symmetry let us say approximately here is where I give the control pulse to terminal 3 dash. So, if you look at the previous you know our diagram here. So, I gave the during the positive half I applied the pulse to 3 and now, I am saying I will apply the pulse to 3 dash when the input supply voltage is negative.

So, when I do that now, this device will conduct the lower the bottom device will conduct; and what will the load see? What voltage will appear across the load? It will be something like this. Now, I again in the next half cycle which is the positives half cycle, I again give the control pulse to terminal 3 at this point and I again get this kind of voltage across the load. So, if you see carefully this waveform the green waveform and if I could maybe make it a little dark, and also a bit and also continuous. Then what we observe is that in this kind of circuit which we are calling as an AC voltage controller AC to AC, but AC of one level to the AC of another level, ok.

So, what we mean by this is that if you see this green waveform, the green waveform is as you can see both positive and negative, so it is AC. But if you do a root mean square if you try to find out the root mean square value of the AC voltage which is in green you will find that that if I just say because it is appearing at the output across the load if I just denoted by V o; so V o rms is going to be much less than or less than the input supply rms voltage. Now, it is very easy to see that as we move this point at which I am triggering or I am controlling the corresponding devices into conduction if I just move these if I shift these points left or right, I am going to vary I will be able to vary the rms voltage that appears across the load. So, this is how I am going to control the voltage that will come across the load.

So, what would be the, typically what should be the control point or what should be the trigger point to the control pulse or to the control terminal if I want to get the maximum rms output voltage across the load. The answer is that I should make this almost here 0. So, it there should be no delay from this point up to the point I trigger of the control terminal, likewise here, so it should actually move all the way up to this point this point you should move all the way here. And as I need less and less rms voltage at the output across the load I can keep on going on the right side. And you can see that if actually we were to trigger at this point, particularly for an ideal resistive case you will find that we will actually end up with a 0 voltage across the load. Now, this is a principle which is very very commonly used in today’s fan regulators.

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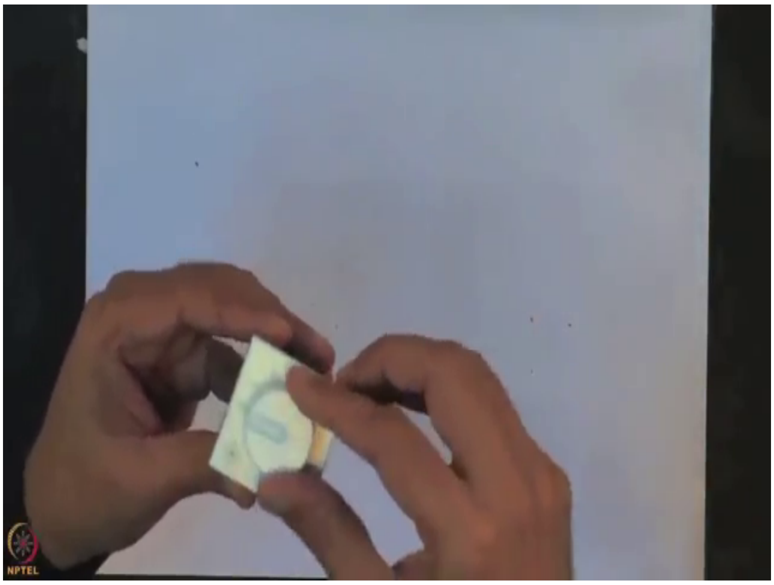

So, I will just show you one fan regulator. Today a modern fan regulator which is used in almost all the households, ok; so, you can see this there is a there is a knob here which you can move and it has all these gradations 0 1 2 3 4 and so on and 5 which is the maximum. So, what it does is, now inside this; now what I want to do is I am just trying to apply a different rms AC voltage to the fan that is what I am doing with this regulator.

Now, in the earlier ones, in the earlier regulators that we used the big ones, we were just using a resistive potential divider system and as I probably mentioned in one of my earlier lectures you actually end up release dissipating lot of power when we use that kind of an arrangement to control the speed of the fan but now these modern fan speed regulators they have nothing but as you can guess now, from the various things which I am saying that it is going to I have something like you know this arrangement inside. So, if you see here there is this arrangement of this very special three-terminal device which is connected in a specific way, and later on I will tell you that this is called this device is called a Triac, it is called a Triac

And we will see what is its structure, but the principle is going to be somewhat what I have already told you, this is what. So, basically our fan regulator modern fan regulator today it actually uses a circuit like this one which is shown here, here which is shown here and just by wearing this knob you are basically controlling the that delay at which you are tricking the control terminals, the various control terminals. So, you can see that if you are at 0 your delay is maximum you have taken it all the way to the right side at 180 degree point, and when you want to increase the speed you try to bring that control point the trigger point towards the left more left. Then you go to 2, more left then you further increase the output AC rms voltage, you further increase and this is the maximum you can get. So, actually here you are applying the full blast of the input voltage across the fan.

Having reviewed the AC voltage controllers and all the other basic types of power electronic converters, from the next time we will now get a bit formal and look at some other details of polychronic systems.

I thank you for your attention.