Power Quality Improvement Technique
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Lecture – 20
Multi Level Inverter

Welcome to our NPTEL lectures on Power Quality Improvement Technique. Today, we shall discuss about the Multi Level Inverter that required to be used for STATCOM, as well as this shunt active power filter, also UPQC and also the series booster and other issues. So, we shall start our discussion with the multi level inverter and why multi-level inverter? So, this will be our content of discussion. We required to cover it within two lectures for half an hour a slot.

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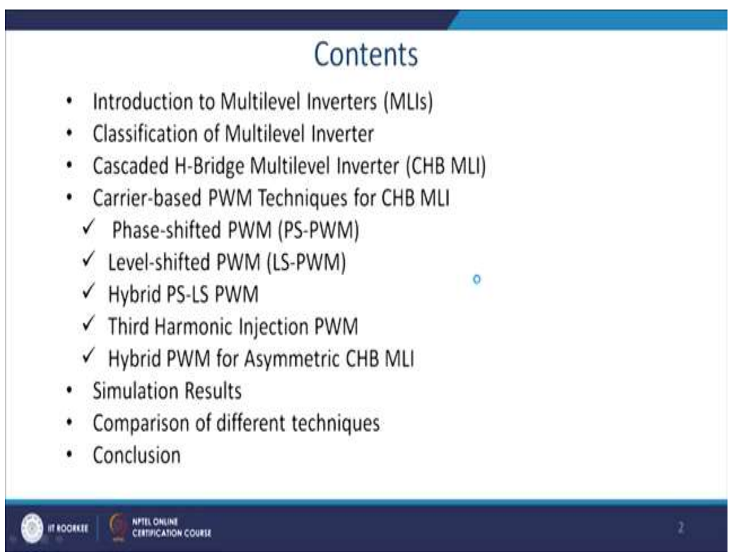

So, first of all we will talk about the introduction to the multi level inverter, classification of the multi level inverter, cascade H-bridge multi-level inverter, carrier-based PWM technique for CHB MLI that is cascade high cascade H-bridge and MLI stands for the multi level inverter. Thereafter, we shall discuss about different carrier technique that is suitable for those kinds of multi-level inverter.

These are the phase shifted PWM, level shifted PWM, hybrid phase shifted and level shifted PWM, third harmonic injection, thereafter asymmetric PWM for asymmetric cascade hybrid, cascade H-bridge and then we shall show some simulation studies on it and we will compare the different kind of technique and then conclusions.

So, these discussions have to be linked with our application part. That we will take next. That is UPQC as well as the shunt active, series and shunt filters, active filters and why you require the multi-level inverter for it?

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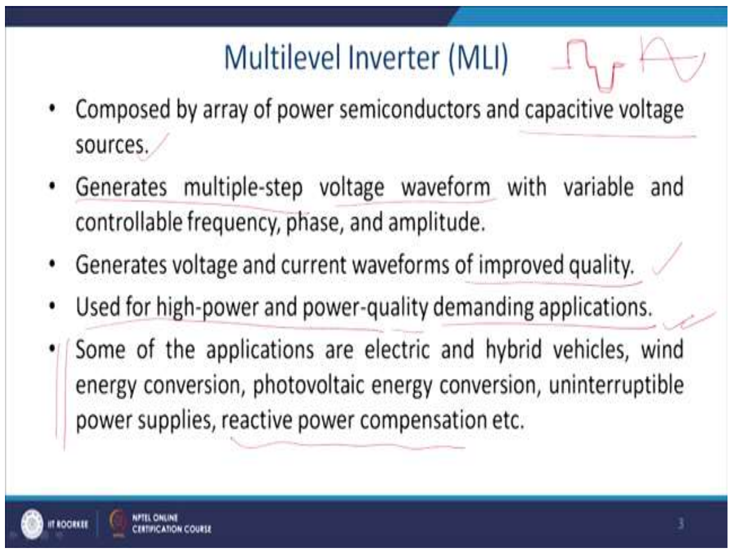

This is an multi-level inverter and it is essentially composed of array of the power semiconductor and the capacitor voltage sources. Array of power semiconductor is generally the diode clamp multi-level inverter. We shall see little later and the capacitor voltage sources are the capacitor come multi level inverter. What does it do?

It generates the multi-pulse steps. Instead of the two steps when you have switching on you have positive V_{dc} and you are switching off you have minus V_{dc}. Instead of that you can have a multi steps. Voltage waveform with variable and controllable frequency phase and amplitude. Thereafter, it generates voltage and current waveform of improved power quality.

If you are using it for mitigating the current harmonics then it can precisely track the voltage or current required to be injected and moreover the switch rating of those devices is going to be reduced and generally cost of the switch is proportional to the square of the voltage. For this reason multi-level inverter is gaining an attention. Apart from that when you are feeding adjustable speed drive with a multi level inverter and we have seen the effect of the source capacitor, that will mitigate the problem of the mainly this reactive power which is affected most.

So, once you use this multi-level inverter, since harmonic content will be less and thus you will have a solution. We have found a solution with the multi-pulse converter. Now, we try to find a solution with the multi level inverter applied to the drives as well as applied to the banded method like you know when we are in a bus. Then you got a maximum power quality problem.

You connect that device and it will mitigate that problem. That is UPQC Unified Power Quality Conditioner or if your problem is related to you ensure that you are giving a good quality voltage. But you have a problem with the current then you will generally go for the shunt compensations and shunt compensation has to be filled up by shunt active power rectifier or compensator or shunt active power filter.

It can have varied operations. You can have an active rectifier and that can be made to the shunt active power filter anytime, because topologically they are not different. Once you take it, power to the grid and conversion of active power filter to the charging a battery then it becomes active rectifier and once you feed the power, you only try to compensate the harmonic part of it. Then it becomes a active rectifier.

Use for high power and power quality demanding applications. Because nowadays it is the problem of the induction machine mostly and the synchronous machine all of which is constant frequency machine. Since your supply voltage is constant, these machines will run close to its synchronous speed. But when you require to have a variable frequency operation you require an adjustable speed drive.

If it is a scalar then you require a V/f control. If it is a vector then you require a flux-oriented control or the direct torque control. In all those cases if you use multi level inverter then you can supply high quality power to the drives or the machines. Then sine wave is a best suitable for your machine because rate of change of voltage is low and it has a least impact on the insulations of the machines, but when you are giving this kind of voltages, in steps it got a very high dV/dt and thus the machine’s lifespan decreases.

We have discussed all those things in introduction. So, to reduce it we will be feeding the multi-level inverter. So, it has many applications. It is not been contained to the power quality only. So, some applications are the electric and the hybrid electric vehicle, wind energy conversion, photovoltaic conversion, uninterrupted power supply, reactive power compensations, shunt active power filter compensation, UPQC compensation and so on. So, practically we are living in the age of the multi-level inverter.

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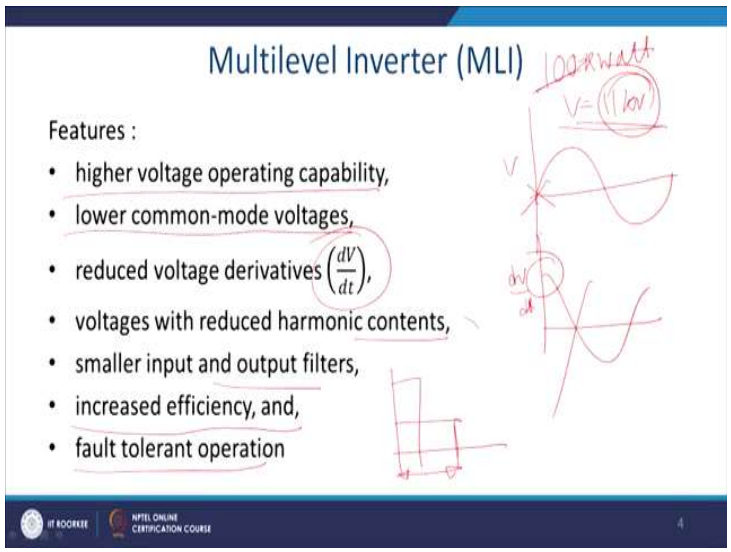

So, features: higher voltage operating capability. It is because of the stress across the switch it has been lowered. Lower common mode voltage. We shall see that. Common mode voltage is between these two legs. This is a differential voltage and another is to with the central of the capacitor.

The reduced dV/dt. That is what I was saying. When you have a sine wave, if you differentiate you get 'cos'. So, your 'sine' curve is this and you have a maximum dV/dt at the 0 crossing that is 'cos'. If you draw, this is voltage if you draw the dV/dt. Essentially you get a 'cos' waveform, and when your voltage is less you have got a maximum dV/dt and when you have a maximum voltage you got '0' dV/dt.

So, that is the beauty of a 'sine' wave when you fit and that enhances it but best substitute or weightful substitute for the machines of a proper sine wave because it will enhance the lifespan of the machine. Voltage with the reduced harmonic content. It is because what you want. You want maybe as particular voltage, 42 volt let say. Your DC bus voltage is 100 volt.

Essentially you will manage the volt area balancing because you can apply only 100 volt till this time and you will say that this area and this area are equal. Ok. It is equal and that is what the average will be done. But problem lies since they are exactly instantaneously not equal. These inequalities will be fill up by the harmonics and for this reason harmonic content will be more.

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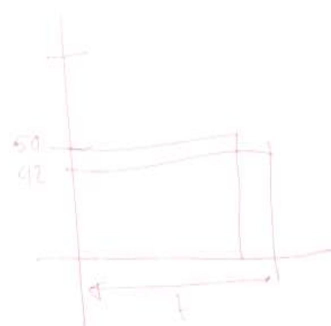

Instead of that let us take a whiteboard. Instead of that if you have multi level inverter where you can apply 50 volt as well as 100 volt. Then if you require a 42 volt you will be applying 50 volt for these durations and thus you will be having a very close area. This area and this area instantaneous difference of the voltage will be very close and for this reason definitely you will have least harmonic.

So, let us go back and since you will be pushing out the higher order harmonic. 5th, 7th and all those harmonics can be eliminated. Which we have eliminated also in case of the multi pulse converter. But there the solution was very bulky and suitable for the very high powered drives and mostly these are the thyristor driven drive and you require a power in the range of the mega Watt.

But here it is in a sub 100 kilo Watt or around 100 kilo Watt level and for this reason this drive is been preferred. Because you know if you have 100 kilo Watt motor drive, so of course, you expect that you will be feeding the voltage in the range of the 11 kv as simple as that. Because you cannot feed 100 kilo Watt motor drive from a 440 volt. The reason is pretty simple.

You cannot have this much of the current to be flown into the system and thus you require this much of a big copper wire and also the losses and other issues. So, that voltage also will be in that range to have an optimal operation of it. So, for this reason we require to increase the voltage level. As I told you that cost of this device rating is a square of the voltage rating.

So, definitely it makes sense to use a lower level device and thus reduce the device rating and go for the multi-level inverter, even though component counts are more. Thus, it increases efficiency and fault tolerant operation. That is also possible. Mostly it is the features of the capacitor clam inverter. We can find the redundancy.

If some switch is not working, but that particular voltage can be generated to the combinations of the other switches. So, that is the redundancy or the fault tolerant capacity can be incorporated into the multi level inverter. So, these are the few features of the multi level inverter.

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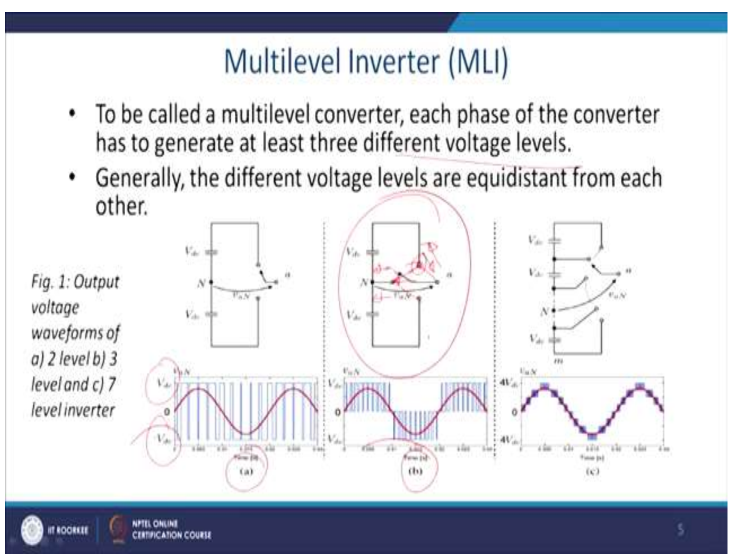

Now, this is the example of it, multi level inverter. We call the multi level inverter each phase of the converter has to generate at least three different voltage level. Generally, this is the first one, you can see that. It generally generates plus V_{dc} and minus V_{dc}. We have discussed about the unipolar PWM, bipolar PWM. This is the bipolar voltages.

So, either this voltage sticks to plus V_{dc} or the minus V_{dc}. In that case there is a high dV/dt, for half bridge. It is V_{dc}. For the full bridge it is $2V_{dc}$. So, that is the rate of change of that or the difference of the volt, instantaneous difference of the voltage. Also rate of change of voltage is extremely high. So, for this reason you can generate this voltage and ultimately you can map the volt area curve and find out the sine wave in between.

And thereafter this is the 'b', this is a three level. Here you can see that in between there is a neutral midpoint of the supply voltage or it is not available. You have to split the capacitor and put the midpoint and generate the midpoint. Then what happened? You can connect plus V_{dc}, you can connect minus V_{dc} and also you can connect to the neutral point and thus you get a three level.

So, this is the generally the multi-level inverter or the three-level inverter. This is the multi-level inverter. You can have a different level and you can split this voltage like this and ultimately you generate this waveform. You can see that it has a very low dV/dt and though number of switches required will be more but it is very close to the sine wave and requirement of the filter will be reduced, low dV/dt and all those advantages will be there.

And since these switches has to block only the V/N, Vdc/N of this total voltage, the voltage setting of these devices also going to be reduced.

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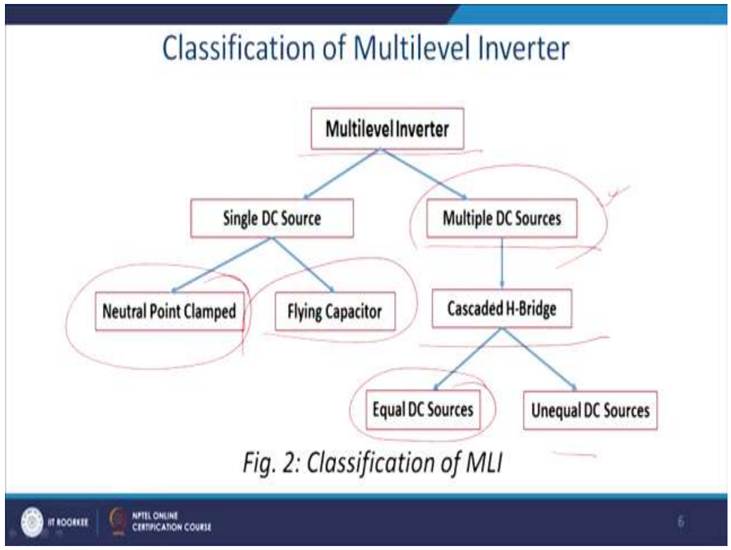

So, this is the classification of the multi level inverter. One it is a multi level inverter, so you can have a single DC source. These are mainly classified into the neutral clamp that is in a diode clamp and this is a flying capacitor. Also, it required a multiple DC source.

This is one of the disadvantages of this topology. So, you require more than single sources. All the sources required to be different and otherwise short circuit will happen. So, there is a research to provide say single source based multi level inverter for cascade H-bridge. But that we are not discussing here. We are taking the simple conclusion of it.

This is a one of the solutions we look for in a solar cell. Where a solar cell can individually generate power and ultimately it can do the needful. So, thereafter this can be a cascade H-bridge multi level inverter. This is said to be that. All these DC bus may have a equal voltage or it may have a unequal voltage.

It can be a binary string also. That is very famous for the solar applications because you can step it up and you will give it like that and this cascade multi level inverter also used in the UPQC, a shunt active power filter and many other applications also. Because ultimately you can. You just require a difference of dc bus voltages to compensate a different level of voltage.

So, all those applications are nowadays we prefer more than neutral clamp and the flying capacitor. It is because of the building block. You take a H-bridge. That will be a building block. You put them in different way and thus you can get any level. So, that is the one of the advantages. It is because of the brick structure. So, this cascade H-bridge multi level inverter is been preferred.

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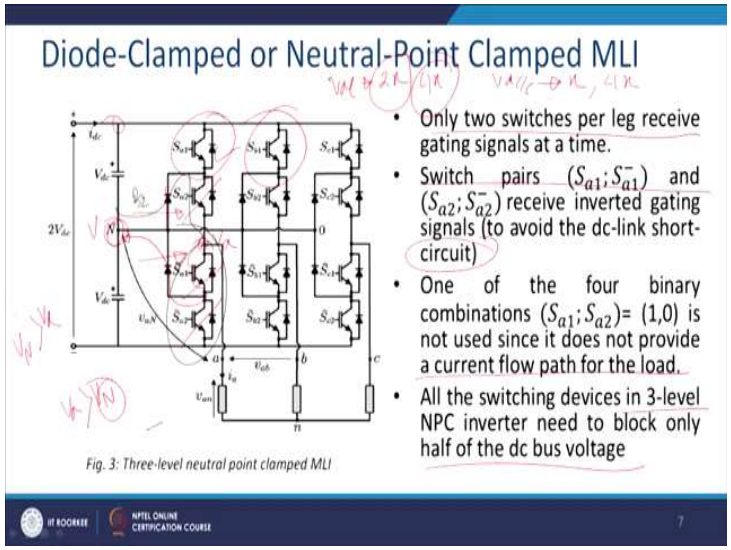

So, this is the diode clamp or the neutral point clamp, MLI. As I told you that this will have a neutral point to diode and how you will come out with this logic? Generally, what happen? If you go back here, this is the three-level inverter and that realization has been shown. Once you connect this switch at this point within that required to block the voltage of $Vdc/2$ and within that it required to block the voltage of V_{dc} and current can be bi-directional. That is the feature.

Same way when you put this switch here then also you are blocking the voltage of minus $Vdc/2$, plus $Vdc/2$ and the current can be bi-directional. Same way for upper one, it will be just replication of the reverse one. Just change in sign. So, how these features can be incorporated in this circuit?

Let us say that this point is a point of interest. We required to connect at the point V_{dc}. Once you connect this point, as you understand S_1 and S_2 both required to be shorted. So, both will be on. So, once they are on you get the voltage of $2V_{dc}$ or the $2V_{dc}$ let us say. Because we have considered that this voltage to be V_{dc} and this voltage to be V_{dc}. So, you are at this point you are getting $2V_{dc}$. Fair enough.

Now, if you want to connect this point here, this point to be connected here. So, depending on the polarity whether this voltage let us say Va is greater than V_N then you will trigger this device and this device. Previously, S_{1a} and S_2 was on and then S_2 and S_1 prime will be on. I can tell you a little later that as you have seen that this switch and this switch are complement. Ultimately your control circuit is quite easier.

So, just ‘not’ logic will work. They are not independent function. So, what happens? You will be getting this S_{a2} and S_{a1} prime. Depending on the which voltage is positive it will take the path. If $V_a > V_N$ then what will happen? So, ultimately this is on, this is on, this will go back like this. If the reverse happens, this voltage is more than this voltage. Generally, it happens in the negative half cycle, then if reverse happened, this is that V_N and it is greater than Va.

So, then essentially current is required to flow. Then current will flow from this point to this point through this diode D, S_{a2} and through S_2 and ultimately reach here. Similarly, other switches are followed and here just reverse will happen and you will get a current. Because if you want to connect by minus V_{dc} then you require to on S_{a1} prime and S_{a2} prime. So, in that way this voltage can be generated and you can connect.

So, thus we can brief out our discussions in this way. Let me again change the color of the pen to red. So, only two switch per legs receive the gating signals at a time. Switch pairs S_{a1} and S_{a2} receives inverted signals to avoid the DC link circuits. One of the four binary combination S_{a1} and S_{a2} is not used seen it does not provide the current path to flow the load. You can see that all the switching device in three-level neutral point clamp or the diode clamp inverter needs to block only the half of the DC bus voltage. Thus, you have a uniformity in the bill of material in abbreviation we call ‘bomb’.

So, you require to purchase all the IGBTs of the same rating and that gives you reduced component count of your bill of material and also as I told you that if you use the IGBT rating of V_{dc}, then cost was four times higher. Ultimately if this IGBT price of $Vdc/2$ is ‘x’ then the cost of the one leg is 4x. But if IGBT price of V_{dc} is 2 x, then 2 IGBT you require. It is again 4 x.

So, cost wise we do not have much problem but in terms of the benefit you get lower THD, lower value of the filters, cater longevity of your devices and so on. All those advantages.

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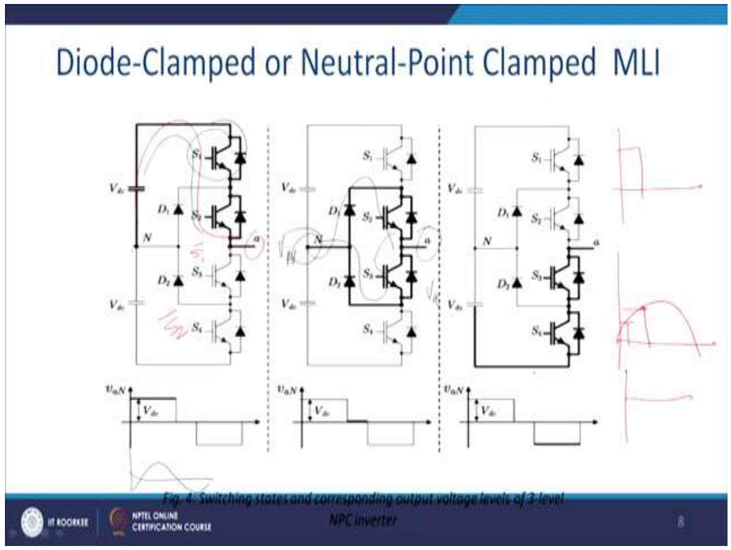

So, let us see that how does it work? That I try to explain here, that you know when we want that it will get V_{dc}, then upper two switches S_1 and S_2 will be closed or you can write S_3 as S_1 prime and S_4 as S_2 prime. For this diode clamp MLI you want this voltage as I told you. You close these two switches.

Now, it will be assignment for you, when there the voltage lead or lag. Let us say this is your voltage lead or lag means, once you connect you get a plus V_{dc}. But generally, what happens? Since you are tracking the sine wave you generally do not apply this high voltage at the beginning. So, generally you only have a half voltage here. From there onward you generally have this big voltage of V_{dc} and that will be applied.

For this reason, if you do not have extremely poor power factor generally it is in STATCOM and this is a challenge there. Otherwise voltage and current both will be positive. Only in STATCOM they are 90-degree phase shifted. So, there is a challenge because one voltage at this peak then current is 90-degree phase shifted. Otherwise you know current and voltage will be equi-directional and that generally happens.

But current and voltage, if current is positive voltage is negative then there is a big challenge because ultimately you apply this voltage. Ultimately V_{dc} will come here and we expect that current to flow this way. But if you wanted the current to flow in reverse, it will go to the diode. That is only for few cases. That is the direction of the current also, most of the cases.

Thus, you get a voltage and most of the cases if you have about this, you apply this voltage after 45 degrees. So, voltage and current will be in positive. Here there is a challenge. Ultimately this voltage you are applying is 0, or sometimes this voltage will be more. If it is a positive half cycles and you apply it, then you expect that this voltage is more. That means, $V_a > V_N$. Thus, what happen? The lower switch will conduct.

Previously, what happened? Thus, this will go out and this will come in and ultimately this will be the path to flow most of the cases. In negative half cycle what will happen? Mostly when this voltage is less, then upper switch will turn on and ultimately voltage will come from this to compensate or mitigate to the 0. So, this is the way of functioning and this is the same thing for the lower half cycles or the negative half cycles.

Thank you for your attention. I shall continue our discussion in our next class.