Advance Power Electronics and Control
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Lecture – 27
VSI and CSI -I & MLI

Welcome to our lectures on advanced power electronics and control. Today, we are going to start out very important topic that is voltage source, inverter in water and current source inverter followed by actually multilevel inverter. So these are the three few modern entities of the power electronic circuits and it has got huge importance because most of the drives are essentially actually are AC drives further required are separate dedicated AC supply.

And that can be fed through VSI and that can be fed through CSI and to cater the need of the higher voltage and lower power issues that when high power factor low THD we will go for the multi-level inverter. So we will see that what are the topological aspect what are the advantage and where it can be applied. So as we have discussed in our previous class.

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Current Source Inverters (CSI)

- For the VSI, as the full form denotes, the output voltage is constant, with the output current changing with the load – type, and/or the values of the components.
- But in the CSI, the current is nearly constant. The voltage changes here, as the load is changed.

The VSI as the full form denotes is a output voltage is constant called stand with the output current changing with the load types or values or the component. So ultimately it will be something like the current may be the characteristics of the grid and on the other hand, CSI is a current source inverter so current is a nearly constant and voltage changes according to the load we see that actually.

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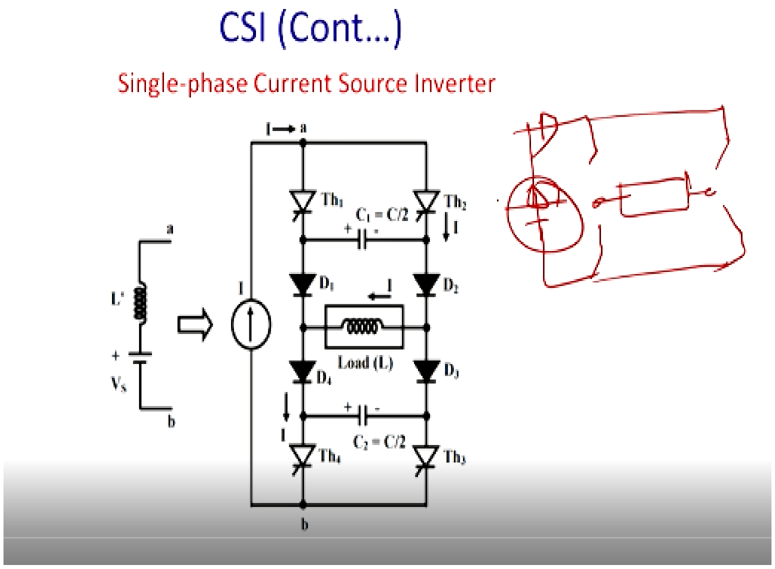

This is a single phase realisations of the current source inverter that the simple realisations can be done by basically essentially load can be connected here and with the pole is available here and with the so current at this point here it has to be a current source this is an available change so you can connect these two switches. So current will flow like this and you can connect these two switches current will flow like this to the load.

So and will imply the auxiliary if you use the thyristor then we apply the auxiliary method of commutations once this thyristor is triggered current will be through this and if you wish to change the direction of the current into the load not here not at the point A point a will always see that actually current is sinking and current view is always see that current is leaving. So what will happen then you have to trigger this thyristor.

As you triggered this thyristor this auxiliary commutations comes into the picture automatically current will wipes out and this capacitor will charges its polarity from this point to this point and thus actually what will happen the current through this thyristor will fall below the holding current and ultimately current will take this path and similar case will happen to the lower thyristor also.

So essentially what you if you wish this actually a current source in order to be realized so you can connect this switch and this switch current will flow like this but you know since putting off this thyristor is a very big challenge so for this we required to have some kind of mechanism and here it is applied the auxiliary commutation to achieve this and ultimately you know we can assume that it is a pure inductor.

And we may have a realize this current source with an older source with the in finite theoretical in finite inductance or practically you might take the L/R ratio near around actually 10 then you can have that realization. So it can be 1 millinery and 0.01 ohm resistance. So it is a challenge generally so that accordingly we can design we can have different values of combinations so that this L/R ratio you required to have an 110 second.

So because these power electronics circuits operates in terms of the milliseconds so compared to that you can say that 10 second is infinity that is a catch on it.

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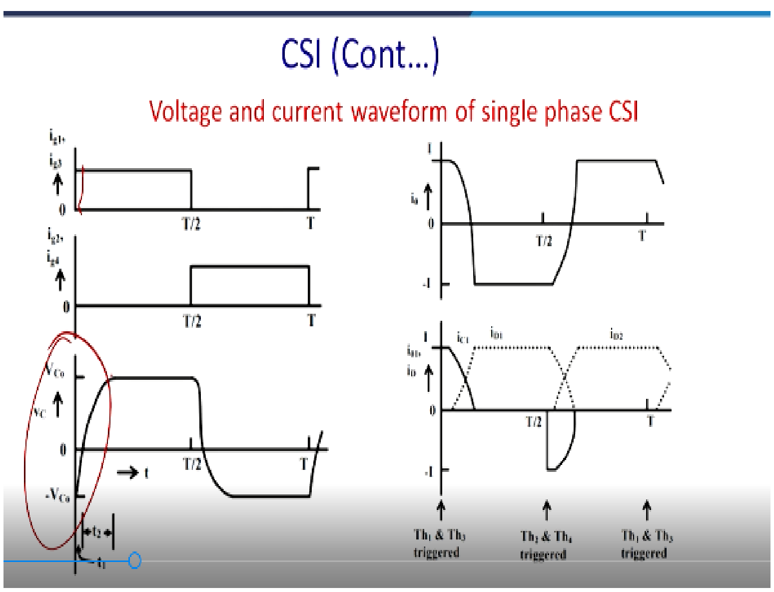

So you will give are triggering pulses if it is a thyristor it will be restricted to here so we need not have to give a continuous pulses otherwise if you have an actual GTO and all those things to make GTO in a turn on stage it is advisable to give him to give a little bit of a positive current or this has been manifested and if you have a IGBT and other devices also you know actually you have to give a continuous pulses.

And you will see that actually the voltage across the voltage that is connected in between the thyristor 1 and thyristor 2 and also the thyristor 3 and thyristor 4 will actually change like this for the positive negative VC02 positive VCO and this charging time and high current will definitely flow. So accordingly current also will see the sequence of there and a load current initially will change after an interval of time

so thereafter actually once this voltage changes thereafter it will be a steady state for the operation then you initiate this physically the changes there will be a delay thereafter again the same cart will be actually utilised. So this is the current through the capacitors and the diode so diode will have this kind of former here at this instance essentially another sequence of the thyristor Th2 and Th4 are triggered then here at this junction this are triggered and so on.

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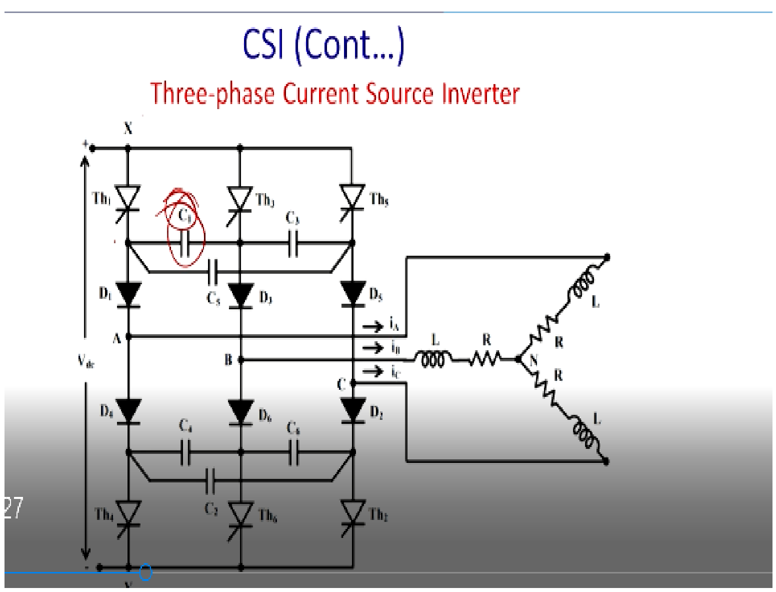

So this is the operation of it of course you can have a 3 phase realisations of it an you require it to connect capacitor in all the individual lines so you require AB BC CA all those things in so that actually makes the system little bulky because you required to have a huge capacitor and if it is a power rating is quite high the insight of the capacitor also become large and we have a calculation.

Which you have done into the while you were studying in a basic power electronic circuit that is auxiliary commutation. So accordingly the value of C can be designed and the calculated. So according otherwise we have to design the value of the C properly otherwise their might be a commutation failure and if the commutation failure occurs it will fail to work properly. So one of the basic advantage of the CSI is that actually you require a switch with a diode.

So it makes the current unidirectional. So that is a one of the biggest advantage and will inherently it is a short circuit protected because current essentially has been controlled and this is the realisation of the 3 phase and after all it is all the same you can actually eliminate this to capacitor you can think of. So there is a 2 block it can we can add another leg and connect the capacitor in between thus it essentially becomes a 3-layer level CSI.

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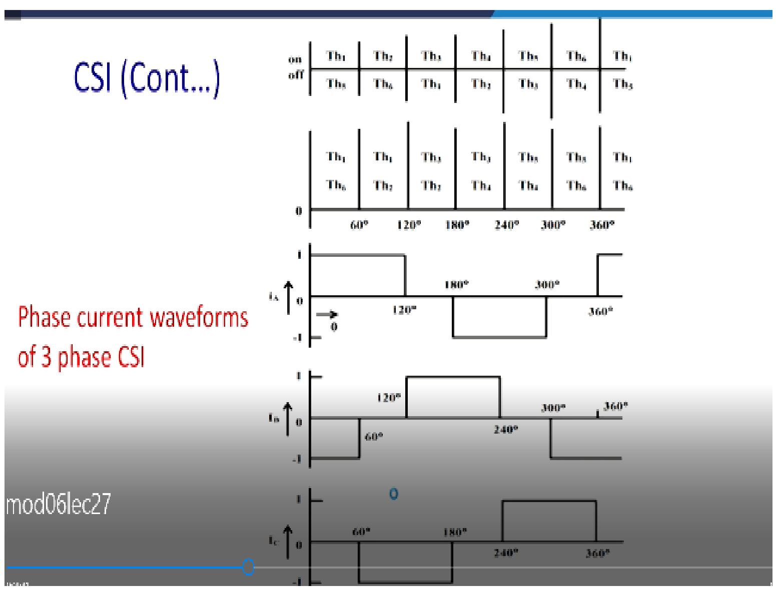

Now here we have to actually have a sequence so we have to have a sequence that is on and off sequence please see that actually what are the name Th1 Th3 Th5 and Th4 and Th6 Th2 so 1 3 5 4 6 2 this is a sequence and if you basically subtract so you always get 3 that is a catch here so it will start after 180 degree mode of conduction and individually will conduct at the layer of 60 degrees.

All those things what you have studied into the 120 level 10 degree or 180 degree inverter same is followed here so initially you can see that thyristor stage 1 is on and from the lower site thyristor T6 is conducting. So essentially you get initially let us see so thereafter thyristor T1 T2 thereafter T3 T2 and so on the sequence will appear and we will have around 120 degree mode of current it is not a voltage.

This is the basic difference between what you have studied discussed in 120 degree mode of conduction for this inverter that was VSI now in this case it is CSI and all those things is followed but only difference is that you will have a current into the system.

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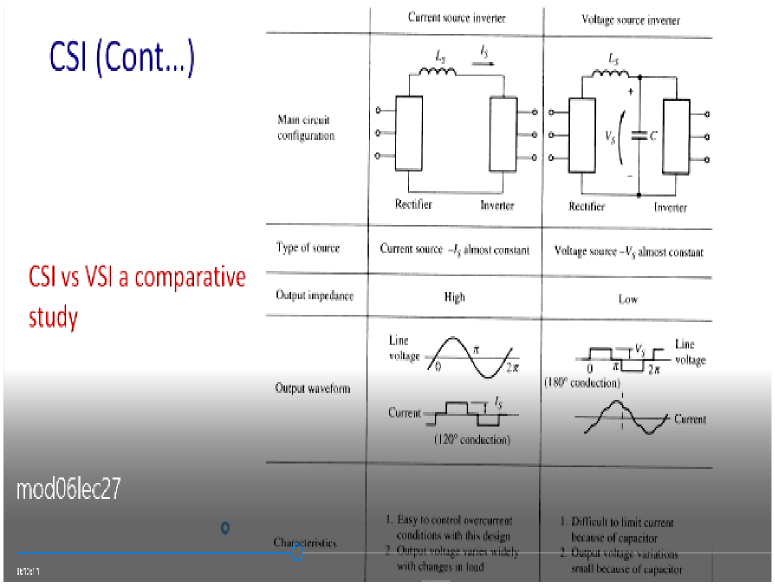

Now what are the difference between VSI and the CSI. So essentially if you can see that the first wave form in case of the CSI you definitely will generate you have got a Mains by rectifications maybe as a PWM technique or other so that power quality issues are being addressed thereafter you will have to put a huge inductance and that will make this current almost ripple free. That is what I was saying L/L ratio should be around 10 and thereafter you put the CSI.

And there is a change in the current configuration that switch should be current flow should be unidirectional and for this reason you have switch followed by the diode it essentially makes this current unit directional. So this is the combination of the CSI and in case of the VSI essentially to ripple out this volt to ripple LC will axle out the filter for this reason but this size of this inductor will be quite low.

And you have to put a bulky capacitor to actually maintain that DC voltage was there. So you require almost a constant deceivers for this reason we require a bulky capacitor here. The source current IS has term specified that it should be all it is almost constant and this source voltage that is voltage appeared across this capacitor is almost constant. Here since this actually current is constant so or this an its output impedance is very high.

So you required to have a impedance matching and in this case it should be very low so it can sustain different high load current. Output waveform so line voltage will be sinusoidal depending on the load pattern it will lead or lag whatever maybe but you will have current will have a square kind of wave form. Just reverse if it is 120 degree or 180 degree here I have shown it for the 180 degree mode of conduction.

You will have this actually square kind of line voltages and ultimately this inductor ultimately this you mostly it is fitted to the diodes kind of applications inherits the characteristics of the low pass filter thus line current oil be almost sinusoidal in nature. So one of the biggest advantage is that easy to control over current condition and design because current is already protected but we require difficult to limit current.

Because of the capacitor and ultimately we required to insert the short circuit or load protection. Output voltage varies widely with the change of the load that is a quite disturbing fact of the CSI. But output voltage variation is small because of that capacitor that will maintain the capacitor almost constant. So these are the few examples but mind it actually this will be fitted to the drive and drive essentially if you take a simple drive that is that can we actually BYF control.

So that is you make the flux constant and if you are feeding to a simple induction machine you know your torque slip characteristics will be actually in all the sleep or speed whatever just reverser actually it is sleep written it should be 1 here it should be 0 here it should be this and if it is a VA characteristics you can change to the actually synchronous speed by changing the frequency.

And mostly actually I assume that is a low torque you will be operating here and here. In VSI there is a biggest advantage you know why I am discussing drive you will find it out that you can operate the motor in this region essentially this region this region. These are essentially at this part of the torque slip characteristics are essentially the stable region but you know they will be disadvantage.

If you imply or drive you will find with the CSI it has to operate this part of the region and while actually the why is so actually that required a detailed study of the drives. So anyway so what we can conclude here CSI also if you reply in a drive required a control circuit require a complicated complex control system whereas VSI it is easy to control. So now let us talk about the PWM technique.

We have already discussed PWM rectifier now we shall discuss this PWM in case of the inverter.
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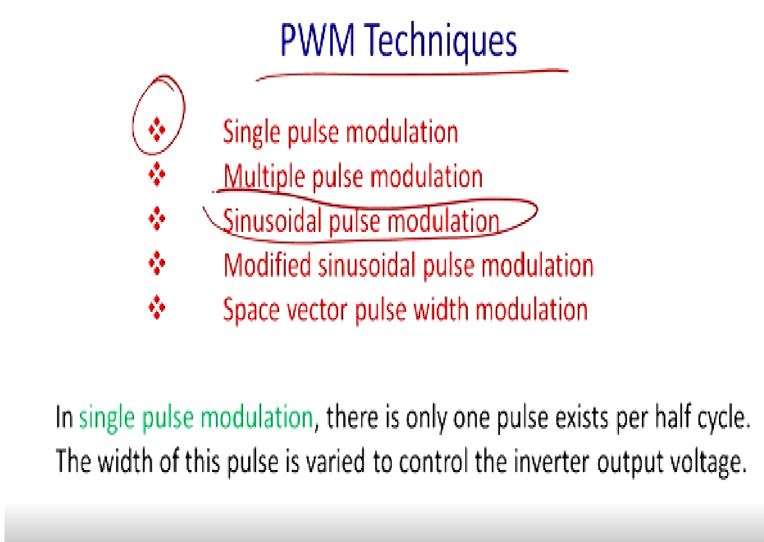

So simplest of this category are the single pulse modulation that we shall see that multiples modulation thereafter quite important phenomenon so that well try to cover this class today that is sinusoidal pulse modulation that is SPWM we should see that different variation of the sinusoidal pulse with modulation that is modified sinusoidal pulse with modulation then the space vector pulse with modulation.

In single pulse modulation there is only one pulse exist per half cycle the width of this pulse is varied to control that inverter output voltage.

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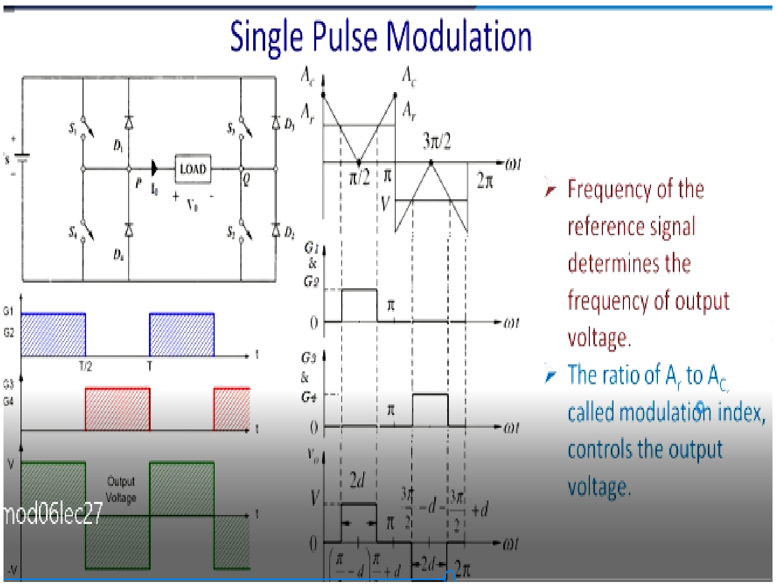

So see that what happened you close this switch and this switch then current will flow to this path and it is a VSI thus current is by directional so for this reason you will have an anti-parallel diode to be placed with each of the circuit. Anyway so we shall see later how the diode and how diode conducts and current conducts. But let us now analyse that how what happened essentially if it is IGBT so you have to connect anti-parallel diode.

If it is MOSFET it comes with the body diode and if it is the GTO, you have to connect the anti-parallel diode. So G1 G2 given pulses and see that how it will generate pulses so generally you will have this inverted triangular wave form and it will start essentially it is just a phase shifted waveform and it will start from the costs wave form something like that and it will be actually Ar is the control signal you can vary this point.

And thus what happened the width of the pulse will change so you can and here since actually you have truncated this part and this part it will operate a unity power factor. So this is get pulses of G1 and G2 and this is a voltage of actually appear across the load When S1 S2 is conducting and thereafter this will be the voltage of the load if S3 S4 are conducting and the width of this pulse is considered to be 2d.

So the frequency of the reference signal determines the frequency of the output voltage. So it is the air that will actually generate the ratio of air to Ac called the modulation index and it is control the output voltage so this width will change and ultimately we will get a different values of the RMS values of this voltages.

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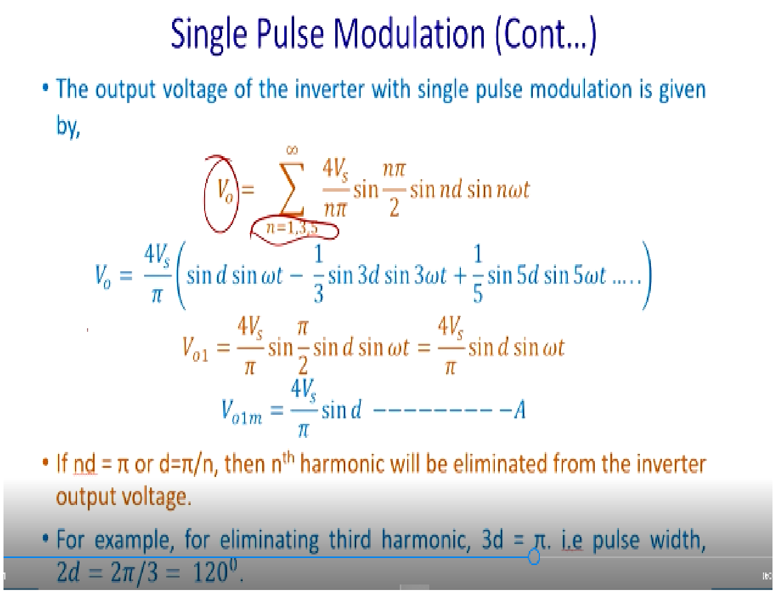

So we can analyse it so the output voltage of the inverter with a single modulations that can be calculated we have already seen so this value is 4 Vm/pi and these are the harmonic content so it is so far for output voltage we can see that that is Vs/pi 4 Vs/pi sin nd sin omega t -3rd harmonics 5th harmonics all the harmonic will be present due to the odd symmetry. So fundamental will be essentially is 4 Vs/pi sin d.

So now there is an issue if nd=pi, then particular harmonic will be absent or d=pi/n then nth harmonic will be eliminated from this inverter in this configuration you can eliminate only one harmonic. Let us take the example of the you are feeding induction machine and you know actually 5th harmonic generally you know 3rd harmonics it is not really harmful the co phaser sir with the sinusoidal voltage and mostly you know for the higher rating it is a delta connected.

So it does not happen in a line lane but you know 5th harmonic is quite dangerous. Why it is dangerous because you know if you will see that actually 6th harmonic will be also co phaser but did not exist because of that even harmonic but what will happen you know so it is basically lagging so 5th harmonic will appear to be the negative sequence and thus will generate torque if it is component is low end high you know you got torque in negative direction.

Magnetic torque will be generating in the negative direction so what happened you know it will give a torque ripple into the machine and also it will be damage the machine or it may cause harm to the machine. So if you wish to eliminate this 5th harmonic then you can choose and you can eliminate that 5th harmonic. So but you can eliminate it only 1 harmonic here.

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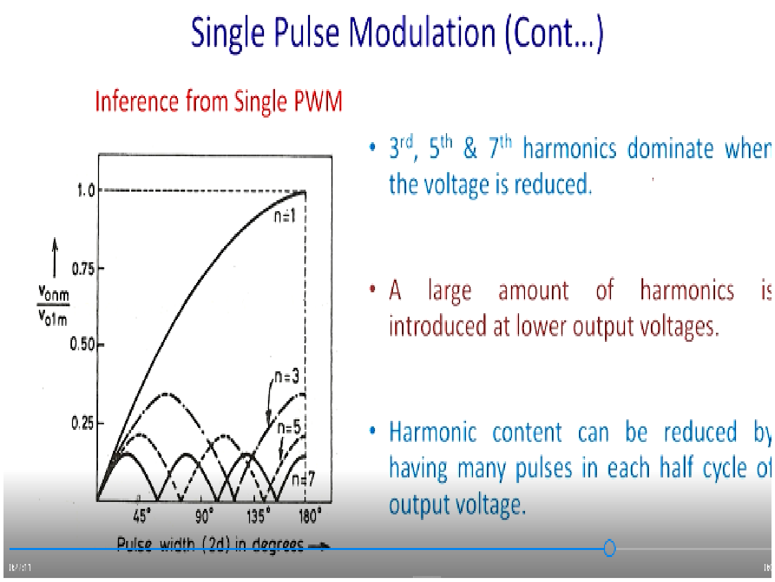

So this is something you can see how the strength of this actually harmonic changes and we are considering actually lower harmonics. The 3rd 5th and 7th are the dominating harmonic when voltage is reduced and you can see that larger mono harmonics introduced at lower output voltage if you actually increase the value of the d so magnitude you can see that initially when actually it is 45 degrees.

You see that there is a high amount of 5th and 7th harmonics are present. So this is a 3rd harmonic and this is the 5th harmonic and this is the 7th harmonic. Harmonic content can be reduced by having many pulses of each half cycle so that is called multi pole pulse with modulations.

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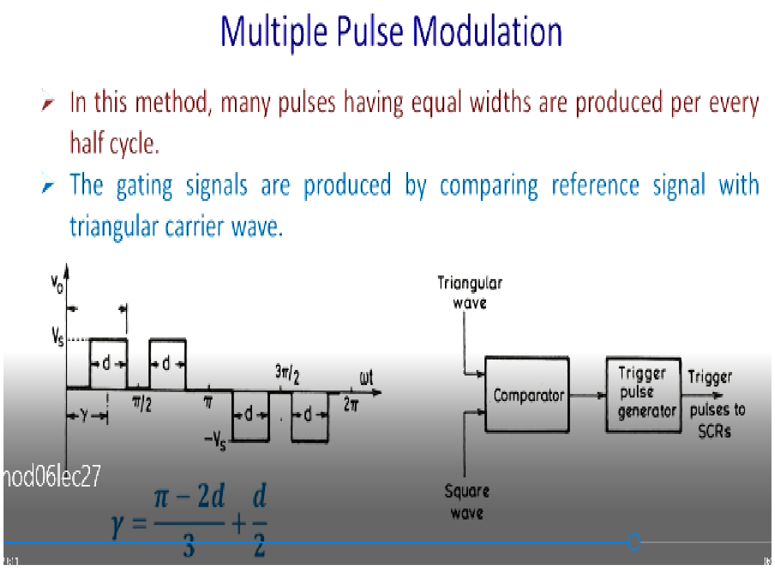

So see that what happened instead of the one single pulses you will have a number of pulses turn of pulses in 1 cycle. This method many pulses are having equal widths are produced in every half cycle and repeated in the negative half cycle. The gating signals are produced by comparing the reference signal with a triangular wave is almost same thing but we shall see that little change and thus you know actually you have a lambda.

So lambda is given by pi-2d/3+d/2 this will be the actually the midpoint of this first pulse. So accordingly you can design and you can eliminate it.

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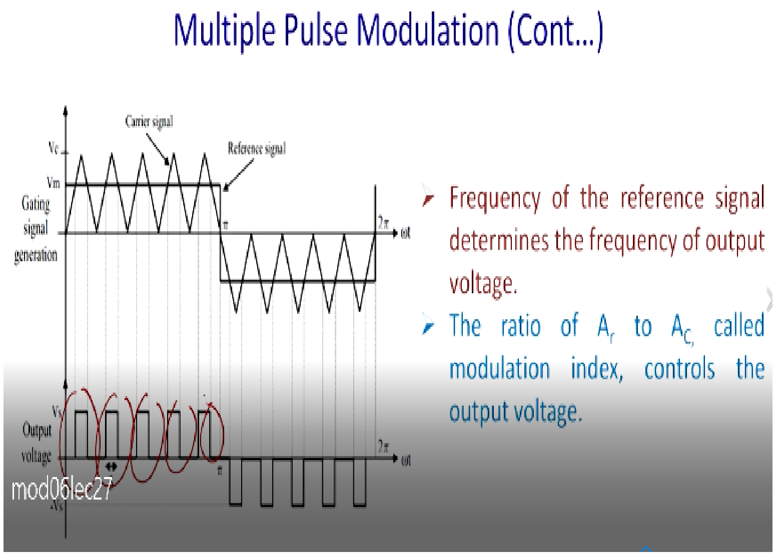

So you can see that there is a number of triangular wave and so this is a carrier wave so you can have constant with pulses of so many and thus what will happen you can see that it can have an you can eliminate more than 1 harmonic we shall see that the expression then we will come to the conclusion. Utility of the multiple PWM the frequency of the reference signal determines the frequency of the output voltage. That is the square wave the ratio of Ar and Ac are called a modulation indexing and controls the output voltage.

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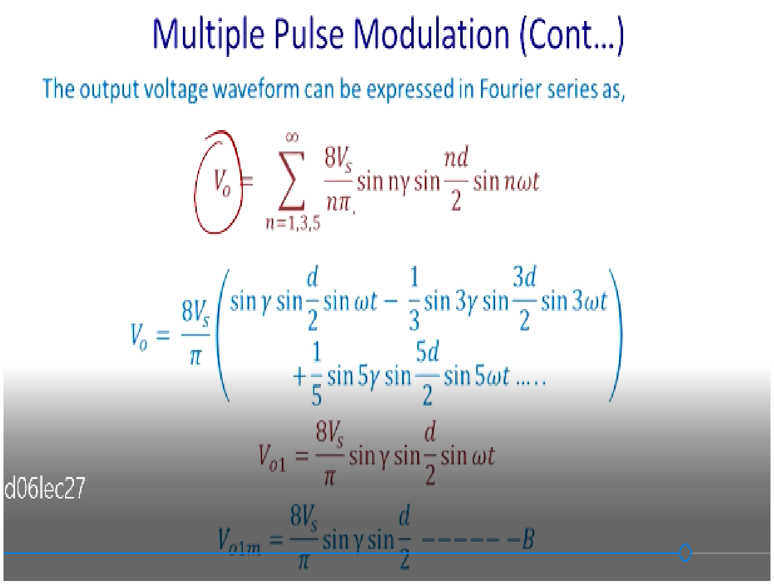

So in this case so output voltage will be actually again it will only order 1 will be present it I s8 Vs/n pi sin n lambda while lambdas expression has been given sin nd/2 sin omega t. So you can take 8 Vs/pi common so sin lambda sin d/2 sin omega t thereafter 3rd harmonic 5th harmonic and 7th harmonic and so on. So fundamentals will be 8 Vs/pi sin lambda sin d/2 so this is the actually the fundamental value of the voltages and maximum value of course you remove this sin omega t you get the but here what you get essentially this maximum magnitude is also a function of the lambda and d.

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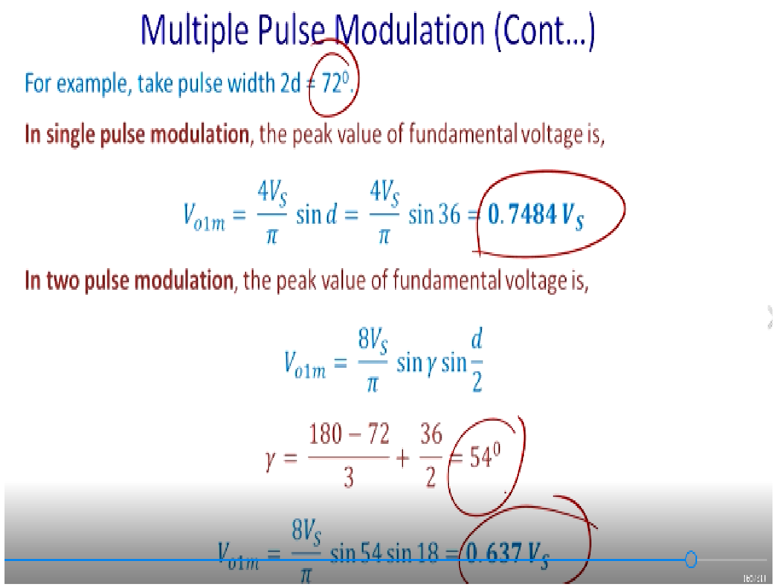

So for example you take that actually 2d actually 36 d=36 then actually you can substitute here and you get the value is around 75% and the 2 pulses peak to peak. Peak value of the fundamental 8 Vs/pi sin lambda sin d/2 so this value will be 54 if you make it 54 then this voltage will come down to 63%. So accordingly you can see that there will be a different voltages in a multiples converter.

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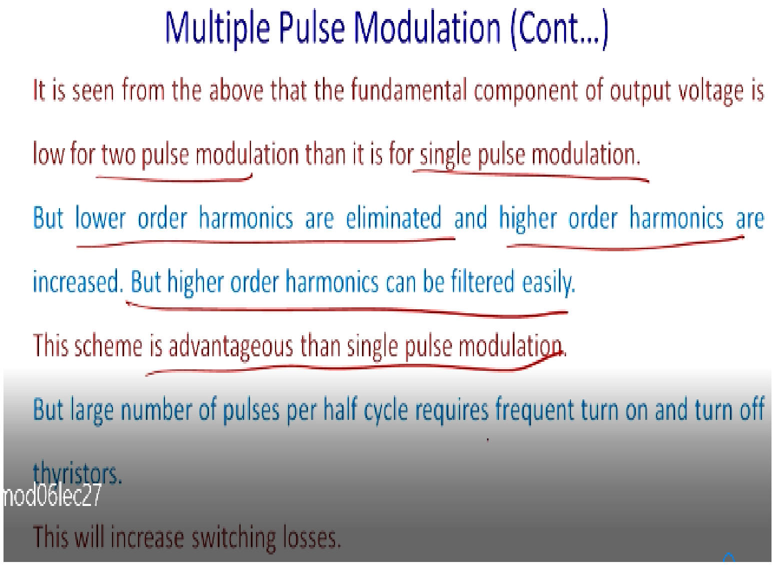

So from there what we can conclude it is seen from the above that the fundamental component the output voltage is low for the two pulse modulation than for the single pulse modulation. But what is the advantage of it we have to check it we can we get a lower value but lower order harmonics I eliminated and higher order harmonics are increased since our load essentially a low pulse filter.

So higher order already been eliminated by the load itself higher order our filters easily because and the filter size will also be less. The scheme is advantageous than the single pulse modulation. So it gives you the lower THD but large number of pulse per half cycle requires frequent turn on and turn off thyristors. and that require a commutation device and which is not possible and for this is solution lies with the more modern devices like GTO or the thyristors.

But we are now talking about again devices accessory devices so nowadays this is not at all a very big challenge and it will increase thus the switching losses. Now we shall discuss in our next class with a sinusoidal modulation and we shall checkout advantage of it over the multiples and the single pulse PWM converter. Thank you for your attention we shall actually continue with the sinusoidal pulse modulation in our next class.