Power Quality Improvement Technique

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Lecture – 19
VSI and CSI

Welcome to our NPTEL lectures on the Power Quality Improvement Technique. Today, we are going to discuss the first part which is voltage source converter and current source converter. We have discussed in detail about the voltage source converter and its predominance in the different kind of drives applications.

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Power Quality Improvement Technique

VSI and CSI

But we should also visit CSI, current source inverter and also it can be applied to the different kind of volt current mitigation technique and it is perfectly suitable for the STATCOM and the shunt active power filter.

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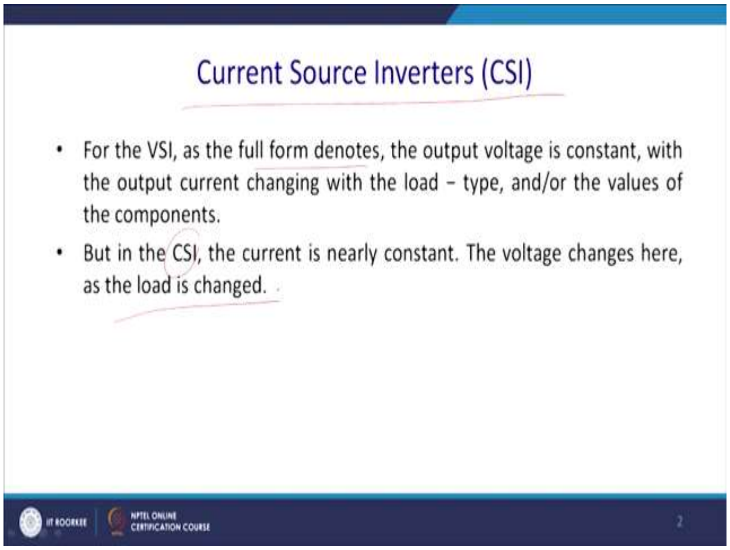

Current Source Inverters (CSI)

- 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.

So, but problem is that we do not have current source. We have a voltage source. So, for voltage source inverter, as the full form denotes the output voltage is constant with the output current, change with the load type or any other values of the component. In CSI, it is just reversed and the current is nearly constant and the voltage will change according to the load. So, that voltage will be whatever the load you connect it to. Otherwise it will give a constant current.

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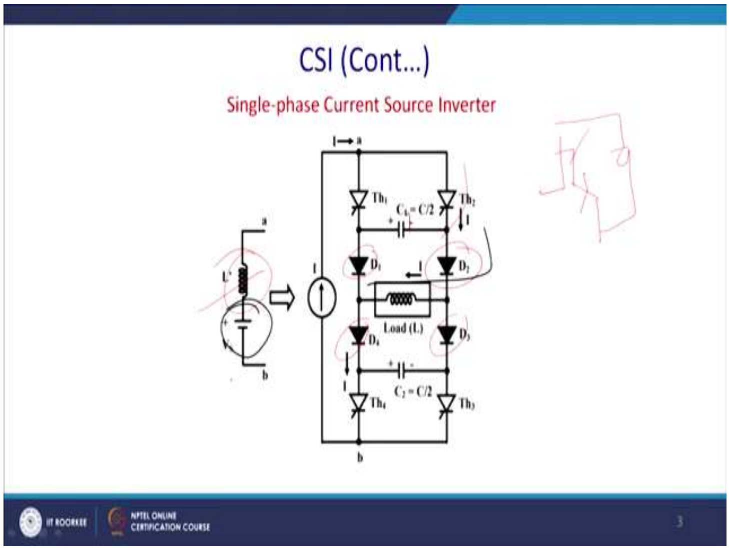

CSI (Cont...)

Single-phase Current Source Inverter

So, this is the how, it will be realized. Please understand when you have made VSI, depending on the load, you generally have a bi-directional switch. Generally, switch conducts for the positive half cycle and you required to have a bi-directional current flow and unidirectional voltage flow. But here we require a unidirectional current flow and this diode will ensure that whether unidirectional current flow has been achieved.

So, this is the current and ultimately you flow like this and you turn it on, this thyristor automatically turns on. It is an auxiliary commutation which you have studied into your power electronic circuit. So, ultimately once you turn on, this current will go through this because of this capacitor and so current will transfer to the Th_2 unless this given a trigger. So, this current will flow, so this will be the value of the current.

So, you will get a bi-directional CSI inverter. And how you realize it? Very simple. You will have a DC source. With the DC source, you will have a very large inductor. This is the challenge. Getting a very large inductor and unless you get a very large inductor, you cannot make a constant current source. But you see that it is inherently short circuit protected. You always have a short circuit protection and all those issues. Your problem of the leg short in a VSI.

So, you can have a return, you can have more reliability on it. At least it does not have a short circuit condition. So, and current is unidirectional, current can flow in one direction and it should give an alternative path to flow for the bi-directional in nature. So, this construction of CSI is quite simple and also operation of the CSI is also simple, but only challenging task is that you know you require a very high value of inductor to make a constant current source. But you can ask that.

So, this is perfectly suitable for this or the shunt active power rectifier, where you require to inject a current into the parallel to the load so that it can deliver this kind of configuration.

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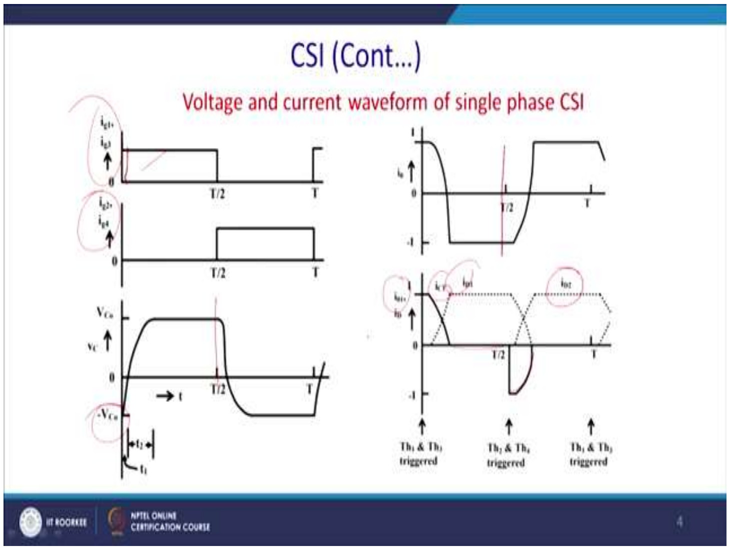

CSI (Cont...)

Voltage and current waveform of single phase CSI

Let us come to the basics first. Applications, we will talk about in STATCOM or in active power filter and V_{g1}, i_{g1} and i_{g3} have been gated. So, current will flow through it with the constant value and thereafter i_{g2} and i_{g3} are been gated.

So, then this kind of pulse will be there and please go back. This is the voltage across this capacitor and it will be having a negative voltage initially. Initially, it will be charging and it will be close to hold it plus V_{CO}. It will hold till the other thyristor has been triggered. It will continue to do that and ultimately the load current will have little charging and discharging profile that will come into the picture.

And this is the i_{a1} and the diode, this is the current of i_{C1}, that is a capacitor current and it will be 0. Again, when you tilt the T2 and T4 have been triggered, again it will bounce back and go like this. And this is the i_{D1}. Current has to be unidirectional here because diode cannot allow current to be bi-directional. So, current will flow like this, there after the diode D2 will conduct. For the small durations both the D1 and D2 diode conducts. Let us see this figure. So, here both will conduct while charging the capacitor.

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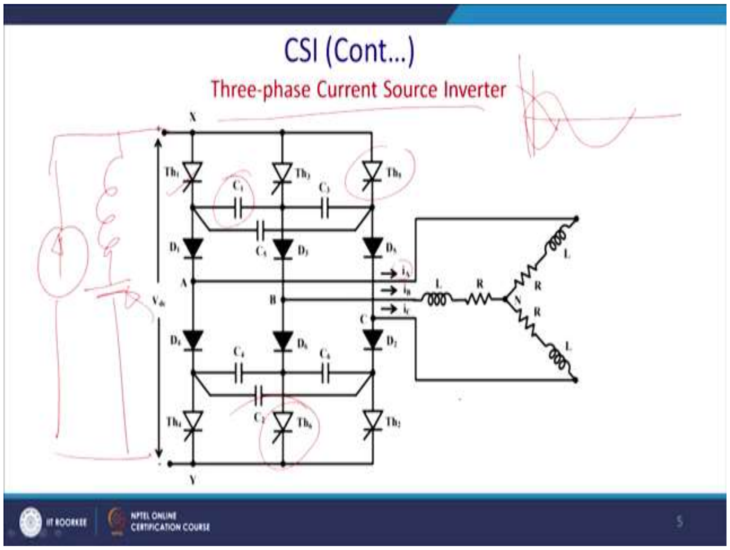

CSI (Cont...)

Three-phase Current Source Inverter

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So, this is the three phase realizations of this circuit, of the CSI. So, you required to provide the auxiliary commutations to make it three-phase. So, you can do that. So, this is C1, C2 and C3. These are the capacitors that will ensure that whether auxiliary commutation have been achieved. Essentially what you will do? You will have an inductor followed by this V_{dc} and that can be considered as a current, constant current source. So, this is the overall figure.

So, this V_{dc} is essentially this and since there is no losses across it, we can assure this voltage. We legitimately take this voltage to be V_{dc}. Thus, you can fit the current i_A, i_B, i_C with the RL load or any kind of load and this is a CSI operation. So, you want that a 30-degree operation. If you have sin 30 means, if you please recall your three-phase waveform and at sin 30 ‘A’ and ‘C’ makes the crossover and ‘B’ is the most negative phase.

So, to mimic it, T_1 and T_3 will be triggered and T_6 will be triggered and there you will have this, there you will have this current which will flow like this. So, students are requested to simulate this circuit and with the thyristors and they should get familiar with the 120-degree mode of conduction and 180-degree mode of conduction.

For the VSI, I want same task to be performed by them with the CSI and since voltage is going to be a square wave. But what I essentially wanted to have a current profile and then its harmonic spectrum. This I left for the student. Please let us be assured that questions will be from this part of the chapter.

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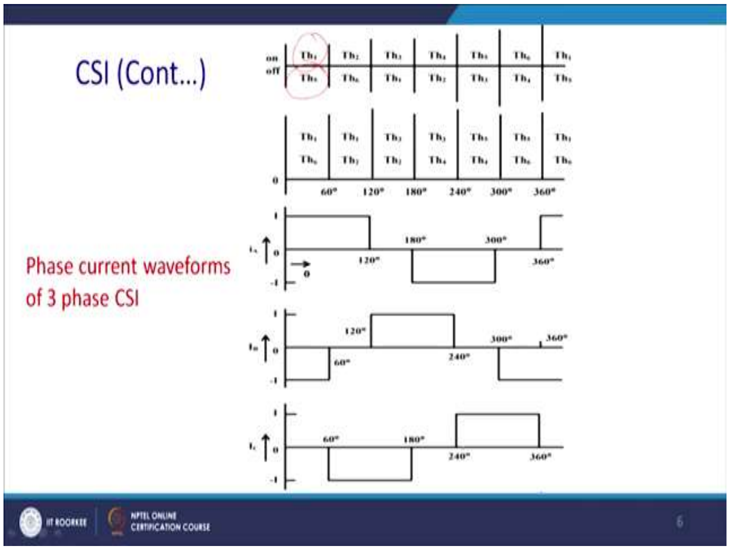

CSI (Cont...)

Phase current waveforms of 3 phase CSI

So, this is the characteristics of Th_1 on and off. So outgoing thyristor was Th_5 and then Th_2, Th_3 and so on. Accordingly, Th_1 and Th_6 will conduct. It is for the 120-degree mode of conduction. So, this is i_A. This will be a square wave. This is i_B, i_C that will be phase shifted by 30 degree and I have drawn for current. You require to draw for the voltage RL load.

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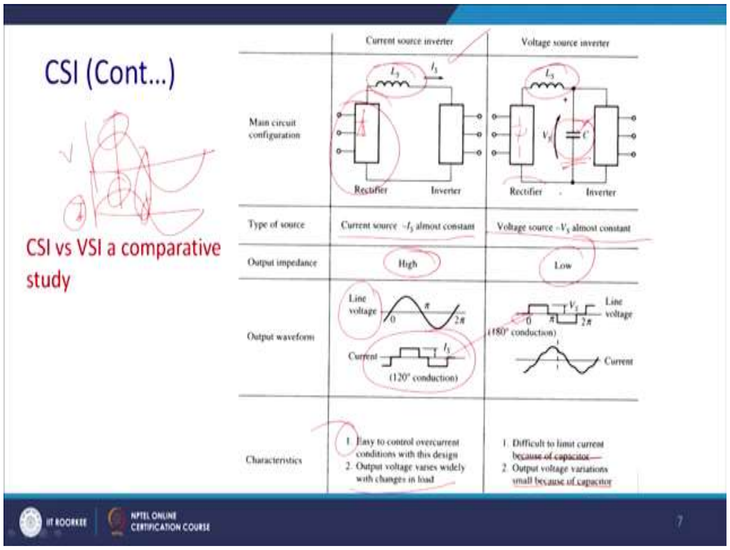

CSI (Cont...)

CSI vs VSI a comparative study

	Current source inverter	Voltage source inverter
Main circuit configuration		
Type of source	Current source $-I_S$ almost constant	Voltage source $-V_S$ almost constant
Output impedance	High	Low
Output waveform		
Characteristics	1. Easy to control overcurrent conditions with this design 2. Output voltage varies widely with changes in load	1. Difficult to limit current because of capacitor 2. Output voltage variations small because of capacitor

Now, what are the difference of the current source inverter and the voltage source inverter? One is that you know you got a rectifier generally or if you have a battery or the solar panel having constant relation in temperature then we could have considered them as a current source. Then you have a huge inductor. This is the one of the detrimental parts of the CSI. Otherwise CSI has a huge advantage, but it is bulky as well as costly.

Then in case of the VSI generally you have a rectifier. Rectifier will be followed by its inductance, that value is quite less because you will have a 300 Hertz ripple. 6-pulse ripple for this 6-pulse converter. If you have a multi-pulse converter which we have discussed and this ripple will be considerably low and here you would required to feed it from the capacitor. why? Because of the two tasks.

Please understand it that even if it is feeding a resistive load. This is a voltage and this is a current. Here even though you have given a constant voltage and you are converting it into the AC, you are fetching maximum power that leads to discharge it somewhere. This energy will come and this will be feeding from this capacitor. Same way at the 0 crossing, you do not have any power output.

So, capacitor voltage will little swell up and it will be continued to be so and for this reason we required to provide a capacitor here. So, types of source: the current source, I_S is almost constant, voltage source is almost constant. We get a constant voltage source irrespective of the load that is our assumption and we manage it by the modulation. Output impedance is high. So that is the one of the problematic entities here. The output impedance is generally high, because of the high inductor and here it is quiet low.

So, for line voltage you essentially get a sinusoidal one that is what I wanted you to draw and current with what you have drawn is a 120-degree mode of conduction and you will get this staircase waveform. On the other hand, if you have a 180-degree mode of conduction, it will be same for the line voltage, but current will have a ripple and it will be close to sinusoidal because of the effect of the filter. If you are feeding a RL kind of load. Where the most of the machines are essentially RL kind of load. Thus, you expect that this kind of current waveform and what else? The characteristics.

So, this is the one of the major benefits of it. Easy to control the overcurrent condition with this design. So, there is no short circuit condition. Output voltage varies widely with changing load. This is one of the drawbacks also because if you keep this constant, since current is constant the voltage whatever will depend on it. It will depend on the load.

Output small voltage variation because of the capacitor. Capacitor will maintain the DC-link voltage of this device.

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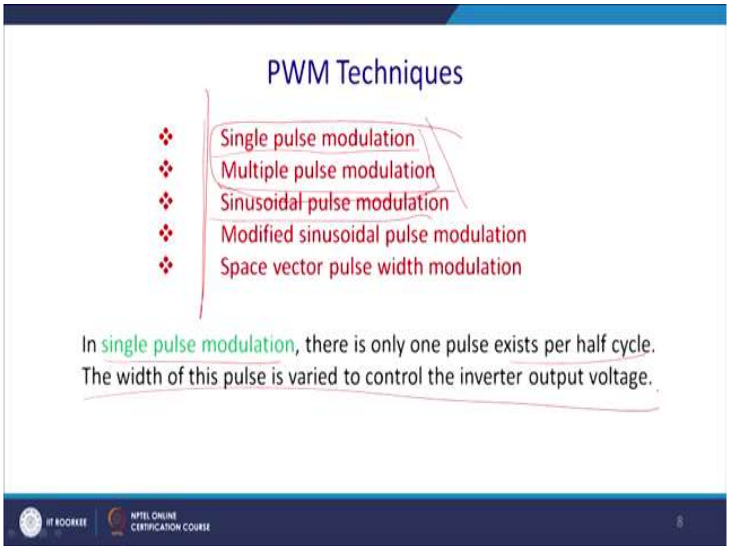

PWM Techniques

- Single pulse modulation
- Multiple pulse modulation
- Sinusoidal pulse modulation
- Modified sinusoidal pulse modulation
- Space vector pulse width modulation

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

Now, we required to design the suitable control strategy for it. we have a this much of the PWM technique for the multilevel inverter. That we will discuss later. Thereafter, we will discuss the PWM technique for the multilevel inverters also. So, now let us concentrate on the basic PWM and when it is operated. What was in previous case analysis? How this will generate the harmonics?

So, you have a single pulse modulation and you have multi-pulse modulation and the sinusoidal pulse modulation. We will be covering these two entities here and others has been covered in the other lectures. So, let us talk about the single pulse modulation. So, there is only one pulse exists per cycle and by this way you can eliminate one harmonic. Like when you are playing guitars. You touch in a particular note and that it creates the particular, eliminates at particular note, particular harmonics from the system. Same way the width of the pulse varies to control the inverter output voltage.

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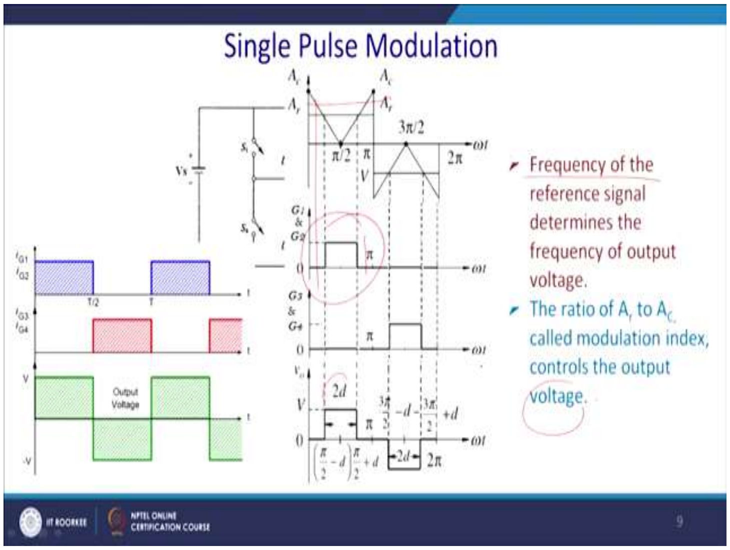

Single Pulse Modulation

- Frequency of the reference signal determines the frequency of output voltage.
- The ratio of A_r to A_C called modulation index, controls the output voltage.

So, this is a case where you can have a triangle waveform and once you have switched it on, you get this kind of pulse. You have a phase shifted triangular wave. So, this and this and this. So, you get a waveform and you change the DC level. You get more amplitude of the voltage. In that way you can control. Ok? So, frequency of the reference signal determines the frequency of the output voltage.

So, this this square pulse will have a frequency and the ratio of Ar to A_C is called the modulation index and controls the output voltage magnitude and thus you can have this duration of 2d. So, ultimately this duration is like this and in that way, you can see that duration of this different part of this 2π modulation technique. So, ultimately you get two square waves.

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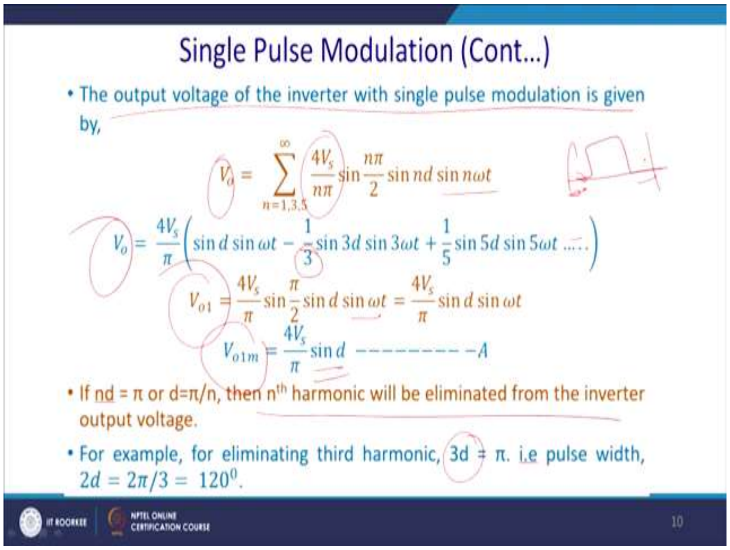

Single Pulse Modulation (Cont...)

- The output voltage of the inverter with single pulse modulation is given by,

$$V_o = \sum_{n=1,3,5}^{\infty} \frac{4V_s}{n\pi} \sin\frac{n\pi}{2} \sin nd \sin n\omega t$$

$$V_o = \frac{4V_s}{\pi}\left(\sin d \sin \omega t - \frac{1}{3}\sin 3d \sin 3\omega t + \frac{1}{5}\sin 5d \sin 5\omega t \;.....\right)$$

$$V_{01} = \frac{4V_s}{\pi}\sin\frac{\pi}{2}\sin d \sin \omega t = \frac{4V_s}{\pi}\sin d \sin \omega t$$

$$V_{01m} = \frac{4V_s}{\pi}\sin d \text{ ---------- } A$$

- If nd = π or d=π/n, then n^{th} harmonic will be eliminated from the inverter output voltage.
- For example, for eliminating third harmonic, 3d = π. i.e pulse width, $2d = 2\pi/3 = 120^0$.

Now, if you generate this kind of waveform then is what a square wave inverter is and thus the power quality problem comes here. For this reason, we require to have an analysis of it. The output voltage inverter with a single-phase modulation is given by V_0 and since there is an odd symmetry $\sum_{n=1,3,5}^{\infty} \frac{4V_S}{n\pi} \sin\frac{n\pi}{2} \sin nd \sin n\omega t$.

So, output voltage what essentially you will get is $\frac{4V_S}{\pi}\left(\sin d \sin \omega t - \frac{1}{3}\sin 3d \sin 3\omega t + \frac{1}{5}\sin 5d \sin 5\omega t \;....\right)$. Thereafter, minus 1 by 7, all those things will come and the magnitude $\frac{4V_S}{\pi}\sin\frac{\pi}{2}\sin d \sin \omega t = \frac{4V_S}{\pi}\sin d \sin \omega t$. Essentially what you got is the magnitude of this fundamental that is $\frac{4V_S}{\pi}$. So, depending on the sin d, magnitudes of the V_{01m} is going to vary.

So, if nd equal to π and d equal to $\frac{\pi}{n}$, then n th harmonic will be eliminated from the inverter. This is a simple logic. For example, to eliminating the 3rd harmonic 3d equal to π. That mean pulse width will be 120 degree. So, you have to shift like this. So, this duration is 30. This duration is 30 and this is 30, 30, 60 and this weight 2d equal to 120 degree and thus you can see that 3rd harmonic will be eliminated. By this method you can only eliminate one harmonic from the system.

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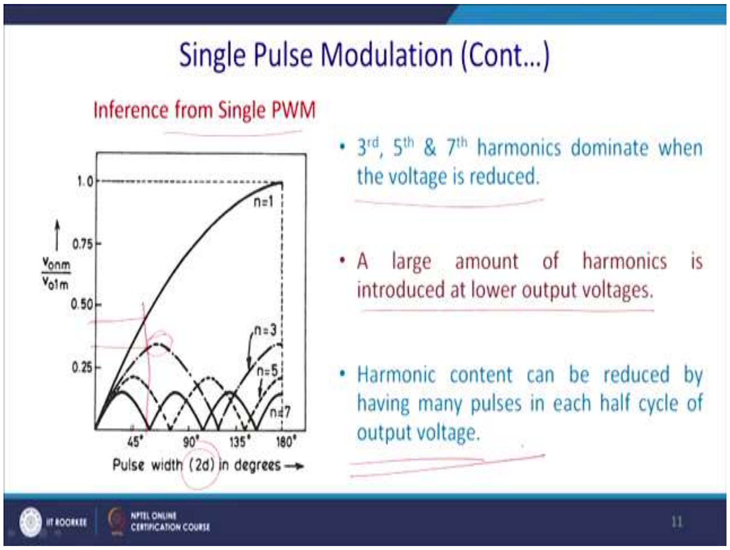

Single Pulse Modulation (Cont...)

Inference from Single PWM

- 3^{rd}, 5^{th} & 7^{th} harmonics dominate when the voltage is reduced.
- A large amount of harmonics is introduced at lower output voltages.
- Harmonic content can be reduced by having many pulses in each half cycle of output voltage.

So, this is the case. Inference from single PWM. 3rd, 5th, 7th harmonic dominates when voltage is reduced. So, once your voltage is reduced, you are squeezing. So, a large number of harmonics is introduced for the lower amount of voltage strain, you can see that. This is a 180. This is a value of the 2d. If 2d goes to 180 degree, then there is a considerable amount of the other harmonic.

But if you come to this point of 45 degree, then you can see that this one corresponds to 3rd harmonic. 3rd harmonic is having a value of let us say 0.3 or 0.4 and this will have a value of 0.47. So, huge amount of 3rd harmonic is present and THD is more and the harmonic content can be reduced by having multiple pulses. For this system instead of a single pulse we required to go for the multiple pulse to mitigate this power quality problem.

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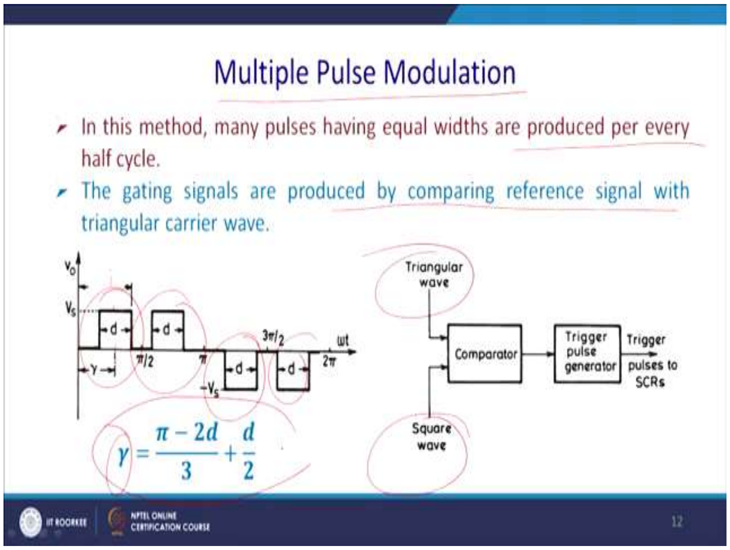

Multiple Pulse Modulation

- In this method, many pulses having equal widths are produced per every half cycle.
- The gating signals are produced by comparing reference signal with triangular carrier wave.

$$\gamma = \frac{\pi - 2d}{3} + \frac{d}{2}$$

Now, we have a multiple pulse. So, multiple pulse modulation in this method. Many pulses have the equal width are produced per half cycle. The getting signals are produced by comparing the reference signal with the carrier signal. So, this is a triangular wave, this is a square wave and there will be a comparator. So, comparator will give a trigger and it will on and off. So, you will you will have a 2d, d and d and d and so on.

So, this one $\gamma = \frac{\pi-2d}{3} + \frac{d}{2}$. So, this is the case. Now we can do the Fourier analysis of the circuit and we can see that how it will give lower THD.

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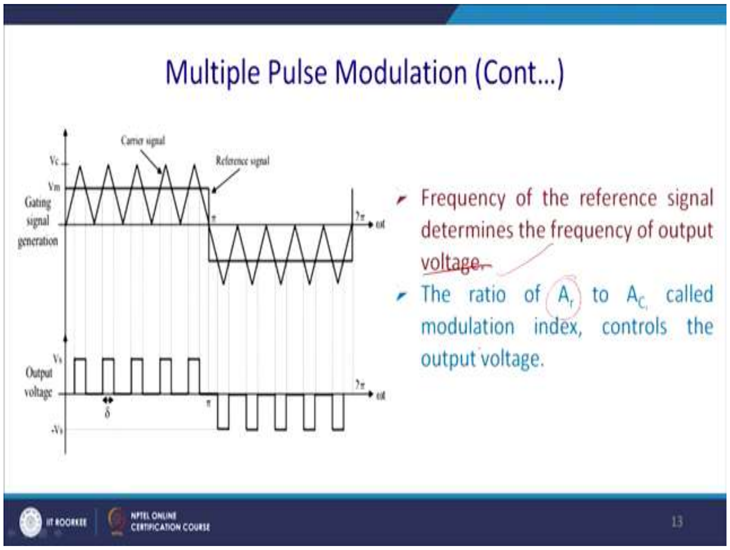

Multiple Pulse Modulation (Cont…)

- Frequency of the reference signal determines the frequency of output voltage.
- The ratio of A_r to A_c called modulation index, controls the output voltage.

So, this is the case. So, you will get multiple pulses from there and the frequency of the reference signals determines the frequency of the output voltage the ratio of Ar and AC which is called a modulation index and controls the output voltage.

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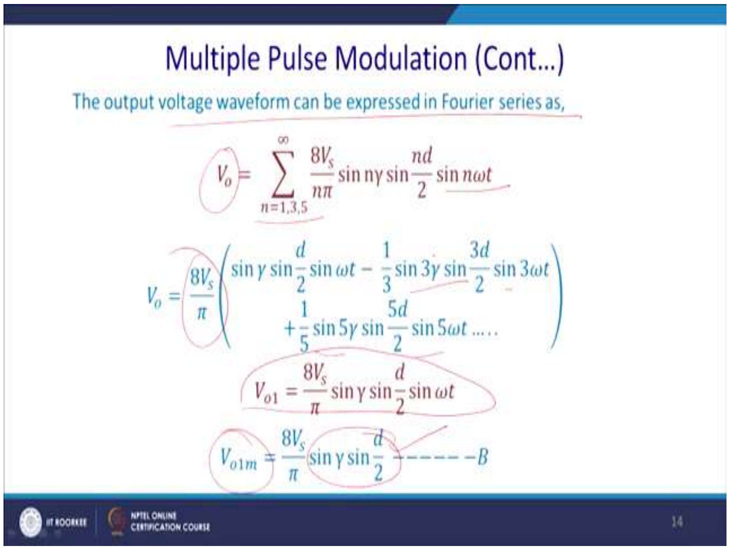

Multiple Pulse Modulation (Cont...)

The output voltage waveform can be expressed in Fourier series as,

$$V_o = \sum_{n=1,3,5}^{\infty} \frac{8V_s}{n\pi} \sin n\gamma \sin \frac{nd}{2} \sin n\omega t$$

$$V_o = \frac{8V_s}{\pi}\left(\sin\gamma \sin\frac{d}{2} \sin\omega t - \frac{1}{3}\sin 3\gamma \sin\frac{3d}{2}\sin 3\omega t + \frac{1}{5}\sin 5\gamma \sin\frac{5d}{2}\sin 5\omega t \ldots\ldots \right)$$

$$V_{o1} = \frac{8V_s}{\pi}\sin\gamma \sin\frac{d}{2}\sin\omega t$$

$$V_{o1m} = \frac{8V_s}{\pi}\sin\gamma\sin\frac{d}{2} \text{------} B$$

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Now, let us do the Fourier series analysis of it. The output voltage waveform can be express in the Fourier series where output voltage will be here. So, it will be $\sum_{n=1,3,5}^{\infty} \frac{8V_s}{n\pi} \sin\frac{nd}{2} \sin n\gamma \sin n\omega t$. Thus, you can extend it to $\frac{8V_s}{\pi}\left(\sin\gamma \sin\frac{d}{2}\sin\omega t - \frac{1}{3}\sin 3\gamma \sin\frac{3d}{2}\sin 3\omega t + \frac{1}{5}\sin 5\gamma \sin\frac{5d}{2}\sin 5\omega t \ldots.\right)$.

But here is a beauty you know, actually we can cancel few of the harmonics here and the fundamentals of this will be $V_{01} = \frac{8V_s}{\pi}\sin\gamma \sin\frac{d}{2}\sin\omega t$ and $V_{01m} = \frac{8V_s}{\pi}\sin\gamma\sin\frac{d}{2}$..... So, this will be the magnitude or the amplitude of the fundamental voltage and thus you can control the magnitude of the fundamental voltage by ‘d’ as well as by ‘γ’. So, there is the both controlling unit.

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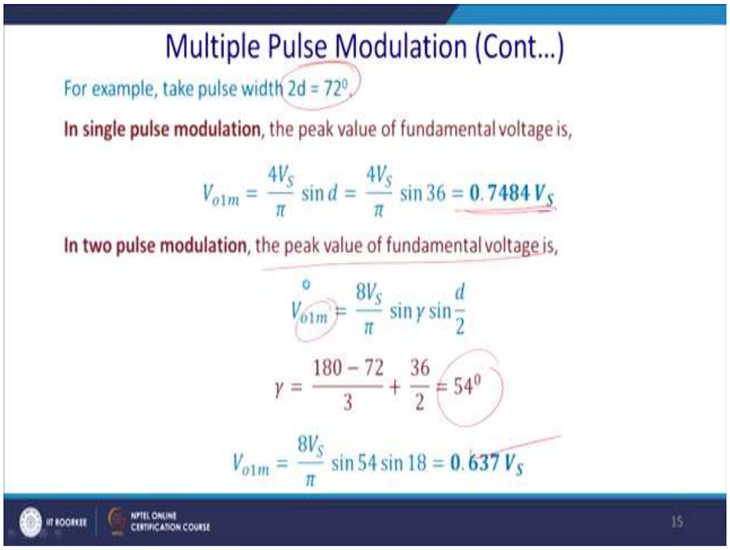

Multiple Pulse Modulation (Cont...)

For example, take pulse width 2d = 72^0.

In single pulse modulation, the peak value of fundamental voltage is,

$$V_{o1m} = \frac{4V_S}{\pi}\sin d = \frac{4V_S}{\pi}\sin 36 = \mathbf{0.7484}\, V_S$$

In two pulse modulation, the peak value of fundamental voltage is,

$$V_{01m} = \frac{8V_S}{\pi}\sin\gamma\sin\frac{d}{2}$$

$$\gamma = \frac{180-72}{3} + \frac{36}{2} = 54^0$$

$$V_{o1m} = \frac{8V_S}{\pi}\sin 54\sin 18 = \mathbf{0.637}\, V_S$$

Now, for example, if you take 2d equal to 72 degree. The single pulse modulation index peaks will be you know V_{o1m} equal 74 percent. So, the 75 percent or 0.784 V_S. What essentially you get it here? It is little less. The two-pulse modulation peak for the same value you will get as $V_{01m} = \frac{8V_s}{\pi}\sin\gamma\sin\frac{d}{2}$. So, lambda is 180 degree minus 72 by 3 plus 36 by 2, it is 54. So, if you put this value, you will get 63 degree. Around 15 percent less you will get. Are you happy with that? That is a different question.

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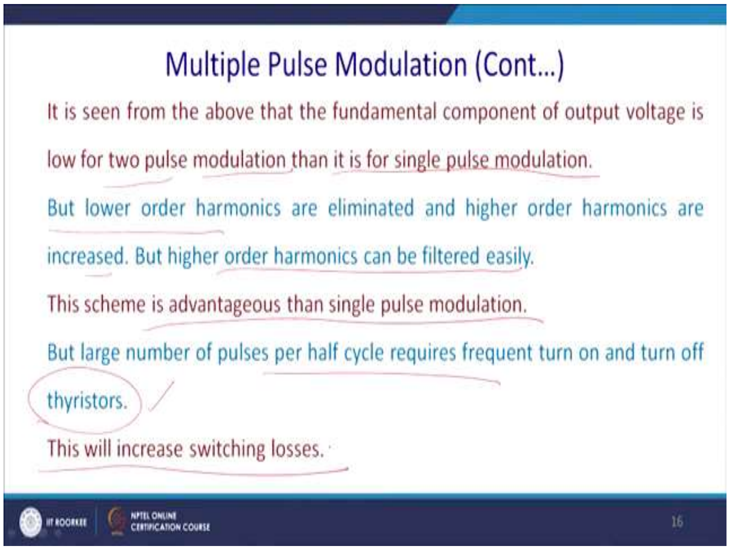

Multiple Pulse Modulation (Cont...)

It is seen from the above that the fundamental component of output voltage is low for two pulse modulation than it is for single pulse modulation.

But lower order harmonics are eliminated and higher order harmonics are increased. But higher order harmonics can be filtered easily.

This scheme is advantageous than single pulse modulation.

But large number of pulses per half cycle requires frequent turn on and turn off thyristors.

This will increase switching losses.

So, what we can conclude? There is a way to eliminate the multiple harmonics here. So, you can choose it such a way that the 3rd harmonic will be eliminated. So, ‘3γ’ can be 180 degree and also you can choose 5d by 2 is 180 degree. So, in that way or 7 d by 2 or any of the two frequencies you can eliminate by it. So, that is called selective harmonic elimination. That has been discussed in our class in detail.

So, what we can conclude now? It is seen that from the above fundamental component the output voltage is lower for the two-pulse modulation than it is for the single pulse modulation. Single pulse modulation, you get around 75 percent with the same duration. But there is a catch here. The lower order harmonics are eliminated and higher order harmonics are increased.

But that is not a big deal you know. Eliminating higher order harmonics are easy because designing a low pass filter essentially motor, power system all are low pulse filter and thus you get rid of those waves, but higher order harmonics can be filtered easily. So, for this reason, for the sake of compactness the size of the filter which will be bulky otherwise, if you use a single pulse module.

But if you use a multi pulse, you get a little less voltage, but your size of the filter will be less. The scheme is advantageous for this reason than the single pulse modulation. Ultimately you cannot feed in motor, you require to feed it to the filter. Designing a filter is a challenging job. But large number of pulses per cycles require frequent turn on and turn off of our thyristors. if you are using thyristors, then you require to have a commutation circuit. Then again it makes the system bulky and also it will increase the device.

It is also required to maybe switch from the thyristor to GTO or any turn on and turn off devices. Thus, what will happen then? Then we have to reduce the lower rating devices and moreover you will have more switching losses. So, we required to do some kind of compactness studies for it.

So, which one we will go for and that is what it is. This will increase the switching loss. This is the major disadvantage of it. Thank you for your attention. We shall continue to our discussions on this power quality issues. Today, I tried to cover the CSI and the VSI and the eliminatory PWM and its effects to the power quality.

Thanks.