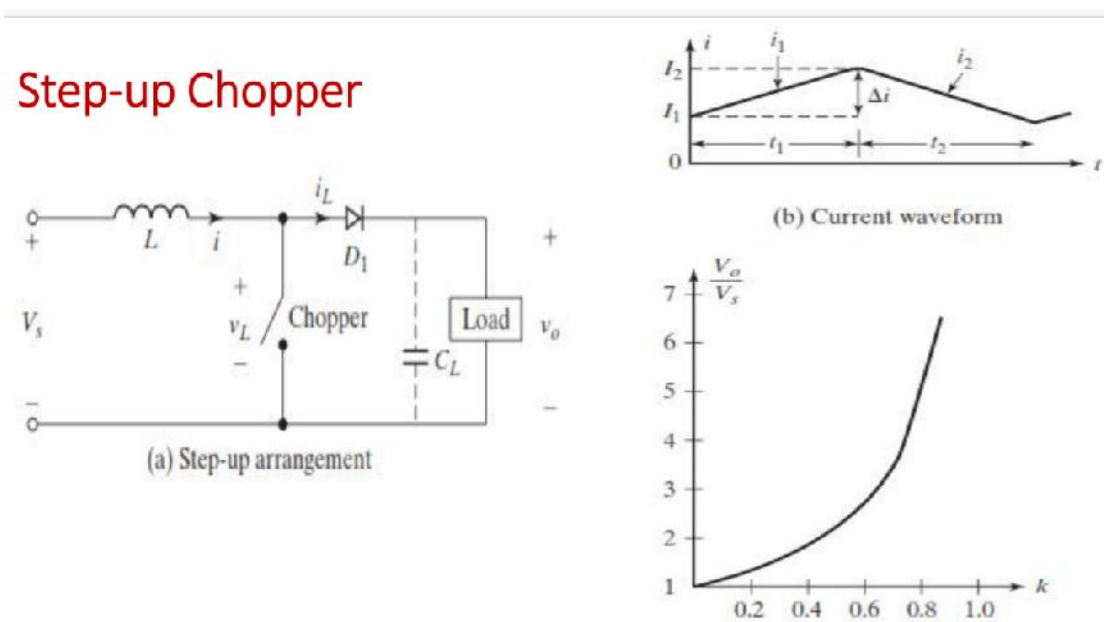
Scheme of Evaluation
Internal Assessment Test 3

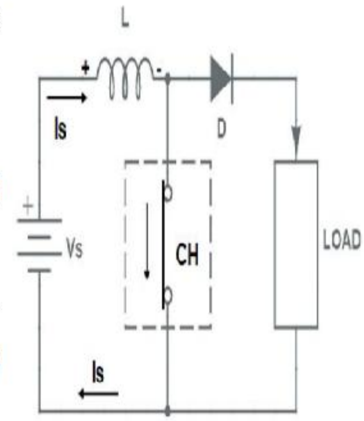
Sub:	Power Electronics							**Code:**	18EE53
Date:	25.01.2022	**Duration:**	90mins	Max Marks:	50	**Sem:**	V	**Branch:**	EEE

Note: Answer Any Five Questions

Question #	Description	
1a	**Explain the operation of step-up chopper. Draw the relevant waveform. Derive an expression for average output voltage.** ➢ Step-up chopper is a static device whose average output DC voltage is greater than its input DC voltage. ➢ A converter can be used to step-up a dc voltage and an arrangement for step-up operation. When switch SW is closed for time t, the inductor current rises and energy is stored in the inductor L. ➢ If the switch is opened for time t1, the energy stored in the inductor is transferred to load through diode D and the inductor current falls	1
		1

Mode 1: Switch is ON

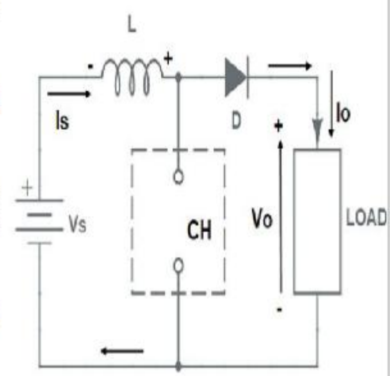
- When chopper (CH) is switched ON, the current will flow through the closed path formed by supply source Vs, inductor L and chopper CH. 1
- During this period, no current will flow through the load.
- Only source current i_s will flow and the value of load current i_o will be ZERO during the ON period.
- Also, during the T_{ON} period, energy is stored in the inductor L. 1
- This energy storage in L is essential to boost the load output voltage above the source voltage.
- Therefore, a large value of L is essential in a step-up chopper.



Mode 2: Switch is OFF

- When the chopper CH is switched OFF, the current through the L can not reduce instantaneously rather it decays exponentially.
- Due to this behavior of L, it will force the current through the diode D and load for the entire time period T_{OFF}.
- Since, the current through the inductor L tends to decrease, the polarity of the emf induced in inductor L is reversed as shown in above figure.
- As a result, the voltage across the load becomes equal to the sum of source voltage and emf induced in inductor.
- Thus, the output voltage exceeds the source voltage V_s.
- The load / output voltage may be written as below.

$$V_0 = V_S + L(di/dt)$$



		Average Output Voltage Equation When the converter is turned on, the voltage across the inductor is $$v_L = L\frac{di}{dt} \Rightarrow di = \frac{v_L}{L}dt = \frac{V_s}{L}t_1$$ and this gives the peak-to-peak ripple current in the inductor as $$\Delta I = \frac{V_s}{L}t_1$$ The average output voltage is $$v_o = V_s + L\frac{\Delta I}{t_2}$$ $$\Delta I = \frac{V_s}{L}t_1$$ $$t_1 = kT$$ $$= V_s\left(1 + \frac{t_1}{t_2}\right) = V_s\left(1 + \frac{kT}{(1-k)T}\right)$$ $$t_2 = (1-k)T$$ $$= V_s\frac{1}{1-k}$$ $$v_o = V_s\frac{1}{1-k}$$ *K value can be changed from 0 to 1.*	1
1b		**A step-up chopper has an input voltage of 220V and output voltage is 640V. If the non-conducting time of thyristor is 100µsec. Calculate the pulse width of the output voltage. If the pulse width is halved, for constant frequency operation. Calculate the new output voltage.**	

1b) $V_s = 220V$; $V_a = 640V$; $T_{OFF} = 100\mu sec$

Step-up-chopper:

$$V_a = \frac{V_s}{1-K}$$

$$640 = \frac{220}{1-K}$$

$$640 - 640K = 220$$

$$-640K = 220 - 640$$

$$K = 0.656$$ 1

$$K = \frac{T_{ON}}{T_{ON}+T_{OFF}} = \frac{T_{ON}}{T}$$

$T_{OFF} = 100\mu s.$

$$0.656 = \frac{T_{ON}}{T_{ON} + 100 \times 10^{-6}}$$

$$T_{ON} = 191\ \mu sec.$$ 1

Pulse width is halved,

$T_{ON} \Rightarrow$ half

Constant frequency; T is constant

$$T = T_{ON} + T_{OFF}$$

$$T = 191\mu s + 100\mu sec$$

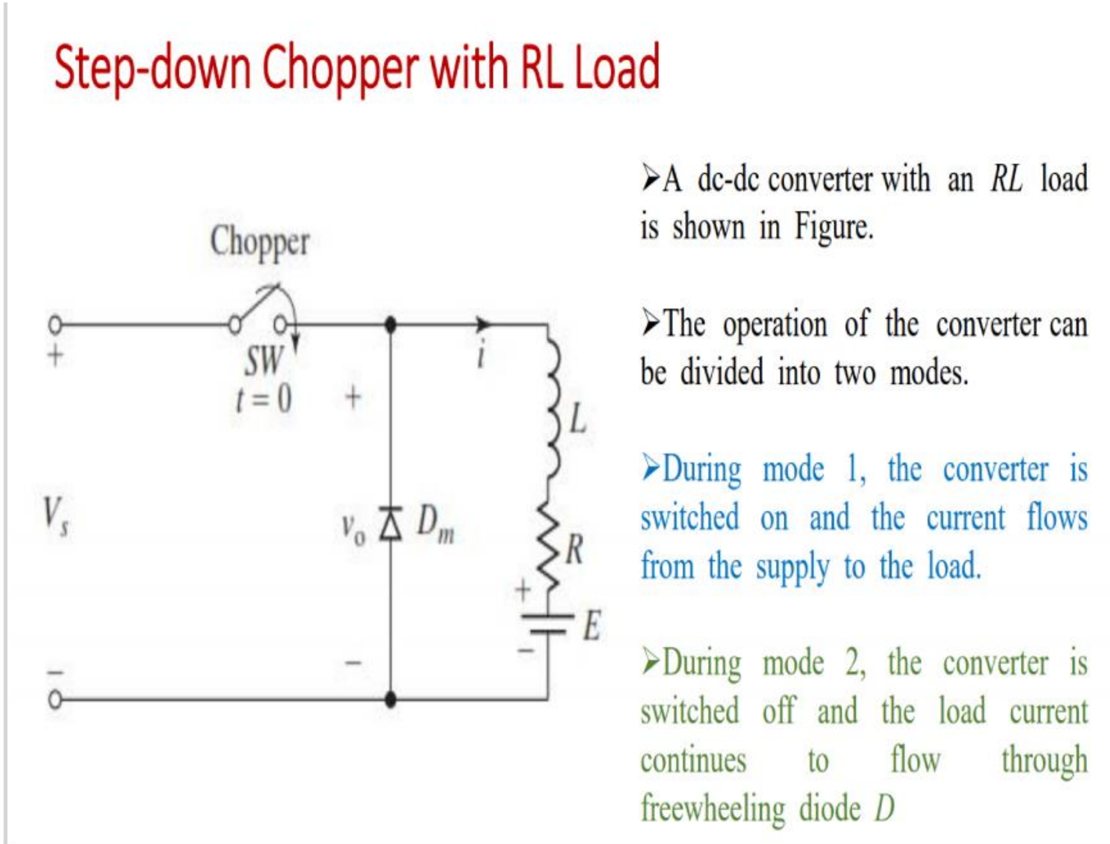
$$T = 291\mu s$$ 1

T_{ON} is half; $T_{ON} = \frac{191}{2} = 95.5\mu s.$

$$K = \frac{T_{ON}}{T} = \frac{95.5}{291} = 0.328$$ 1

New o/p Voltage. $V_a = \frac{220}{1-0.328} = 327.38V$

2a		**Explain working of step-down chopper. Draw the relevant waveform. Derive an expression for average and output rms voltage.**	1



Modes of Operation

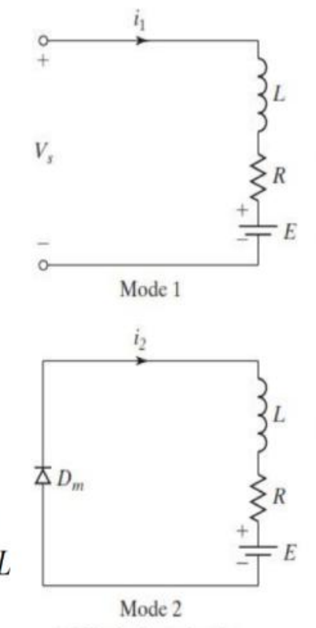
Current may be

- Continuous
- Discontinuous

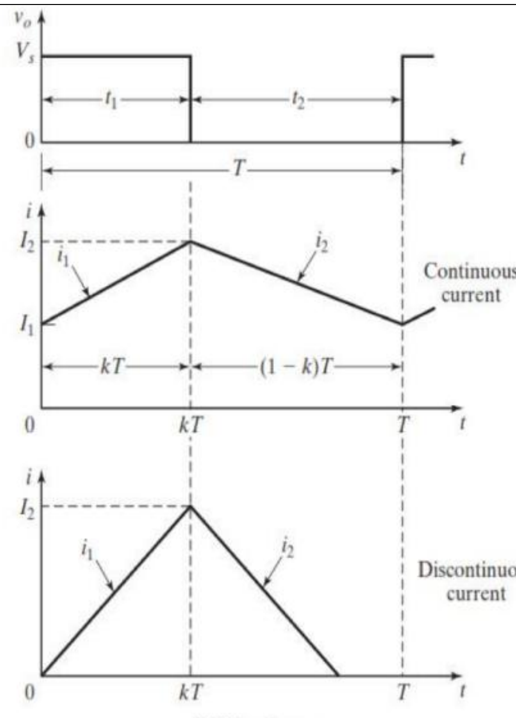
Assumption

load current rises linearly.

However, the current flowing through an *RL* load rises or falls exponentially with a time constant.



(a) Equivalent circuits



(b) Waveforms

The load time constant $(\tau = L/R)$ i

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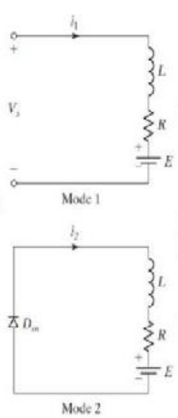

The load current for mode 1 can be found from

$$V_s = Ri_1 + L\frac{di_1}{dt} + E$$

which with initial current $i_1(t = 0) = I_1$ gives the load current as

$$i_1(t) = I_1 e^{-tR/L} + \frac{V_s - E}{R}\left(1 - e^{-tR/L}\right) \tag{5.19}$$

This mode is valid $0 \le t \le t_1 (= kT)$; and at the end of this mode, the load current becomes

$$i_1(t = t_1 = kT) = I_2 \tag{5.20}$$

The load current for mode 2 can be found from

$$0 = Ri_2 + L\frac{di_2}{dt} + E$$

With initial current $i_2(t = 0) = I_2$ and redefining the time origin (i.e., $t = 0$) at the beginning of mode 2, we have

$$i_2(t) = I_2 e^{-tR/L} - \frac{E}{R}\left(1 - e^{-tR/L}\right) \tag{5.21}$$

This mode is valid for $0 \le t \le t_2 [= (1 - k)T]$. At the end of this mode, the load current becomes

$$i_2(t = t_2) = I_3 \qquad I_3 = I_1 \tag{5.22}$$

		A step-down chopper with resistive load of 20Ω and the input voltage is 200V. When the converter switch is remains ON its volage drop is 1V and chopping frequency is 2Khz, if the duty cycle is 50% determine, 1) Average output Voltage 2) RMS output voltage 3) Chopper efficiency. 4) effective input resistance.	
2b		2b) Step down Chopper: $R = 20\Omega$; $V_s = 200V$; $V_T = 1V$. $f = 2khz$; $K = 50\% = 0.5$ i) Average o/p Voltage: $V_0 = KV_s = 0.5[200-1]$ $V_0 = 0.5 \times 199 = 99.5V$	1
		2) Rms o/p Voltage: $V_0 = \sqrt{K} \times (V_s - V_T)$ $= \sqrt{0.5} \times [200-1]$ $V_0 = 140.7V$	1
		3) Converter efficiency: $\eta = P_o / P_i$ $P_o = K\frac{V_s^2}{R} = \frac{K[V_s - V_T]^2}{R}$	1
		$= \frac{0.5 \times (199)^2}{20} = 990W$ $R_i = \frac{20}{0.5} = 40\Omega$	1
		$P_i = V_s I_s$ $= V_s \times \frac{V_s - V_T}{R_i}$ $P_i = 200 \times \frac{199}{40} = 995W$ $\eta = \frac{990}{995} = 99.5\%$	1

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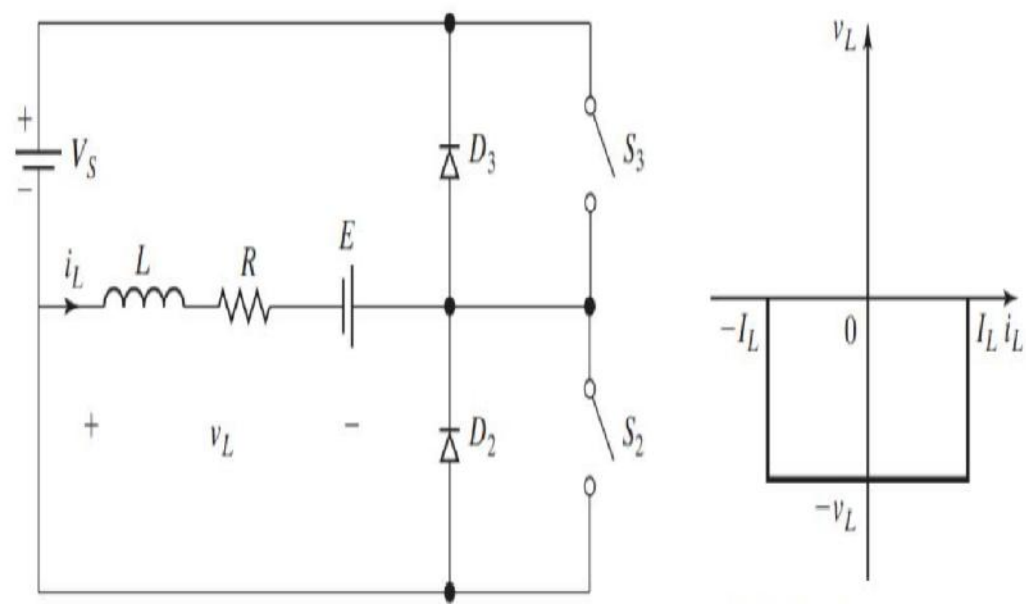
With circuit diagram and waveforms, explain the operation of class D chopper and Four quadrant chopper.

Class D Chopper
• The load voltage is always negative.
• The load current is either positive or negative
• S3 and D2 operate to yield both a negative voltage and a load current.
• When S3 is closed, a negative current flow through the load.
• When S3 is opened, the load current freewheels through diode D2.
• S2 and D3 operate to yield a negative voltage and a positive load current.
• When S2 is closed, a positive load current flow.
• When S2 is opened, the load current freewheels through diode D3.
• It is important to note that the polarity of E must be reversed for this circuit to yield a negative voltage and a positive current.
• This is a negative two-quadrant converter.
• This converter can also operate as a rectifier or as an inverter.
• The load voltage is always negative.
• The load current is either positive or negative
• S3 and D2 operate to yield both a negative voltage and a load current.
• When S3 is closed, a negative current flow through the load. • When S3 is opened, the load current freewheels through diode D2
• S2 and D3 operate to yield a negative voltage and a positive load current. • When S2 is closed, a positive load current flow.
• When S2 is opened, the load current freewheels through diode D3.
• It is important to note that the polarity of E must be reversed for this circuit to yield a negative voltage and a positive current.



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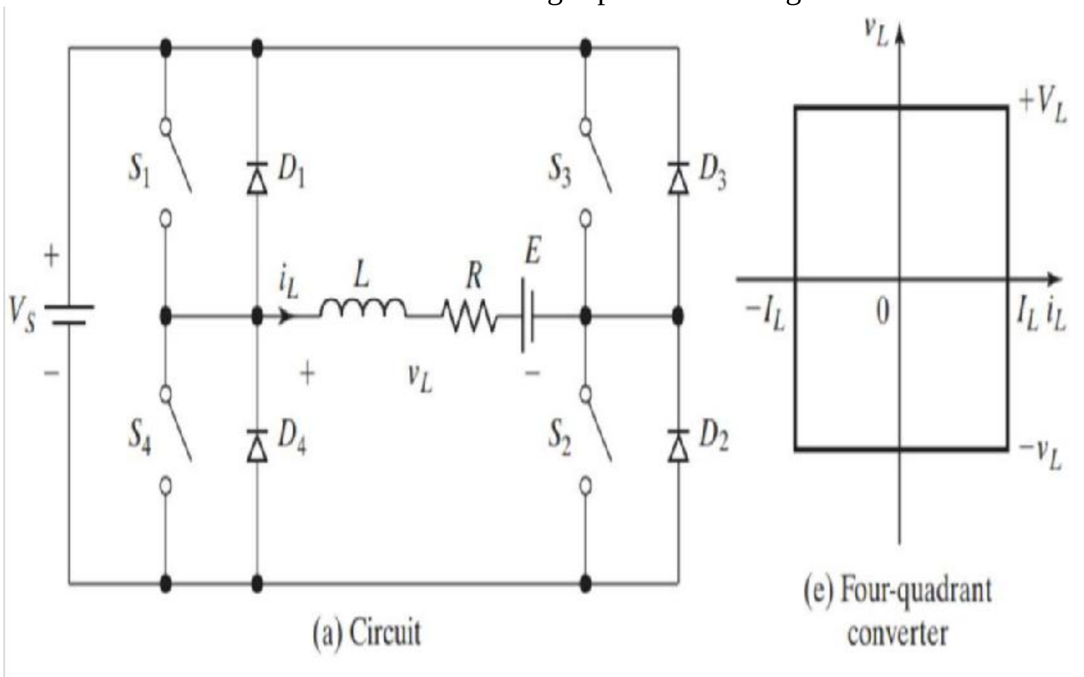
<table>
<tr><td></td><td></td><td>Four-quadrant converter / Class E Chopper
• The load current is either positive or negative
• The load voltage is also either positive or negative.
• One first and second quadrant converter and one third and fourth quadrant converter can be combined to form the four-quadrant converter.
• For operation in the fourth quadrant, the direction of the battery E must be reversed.
• This converter forms the basis for the single-phase full-bridge inverter.

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2</td></tr>
<tr><td>4</td><td></td><td>With the neat circuit diagram and waveforms, Explain the operation of single-phase full bridge inverter supplying resistive a load.

Single Phase Bridge Inverter
• Full bridge single phase inverter is a switching device that generates a square wave AC output voltage on the application of DC input by adjusting the switch turning ON and OFF based on the appropriate switching sequence, where the output voltage generated is of the form +Vs, -Vs, Or 0.
• A single-phase bridge voltage-source inverter (VSI)
• It consists of four choppers (Q1 D1, Q2 D2, Q3 D3, Q4 D4).
• When transistors Q1 and Q2 are turned on simultaneously, the input voltage Vs appears across the load.
• If transistors Q3 and Q4 are turned on at the same time, the voltage across the load is reversed and is -Vs.</td><td>2</td></tr>
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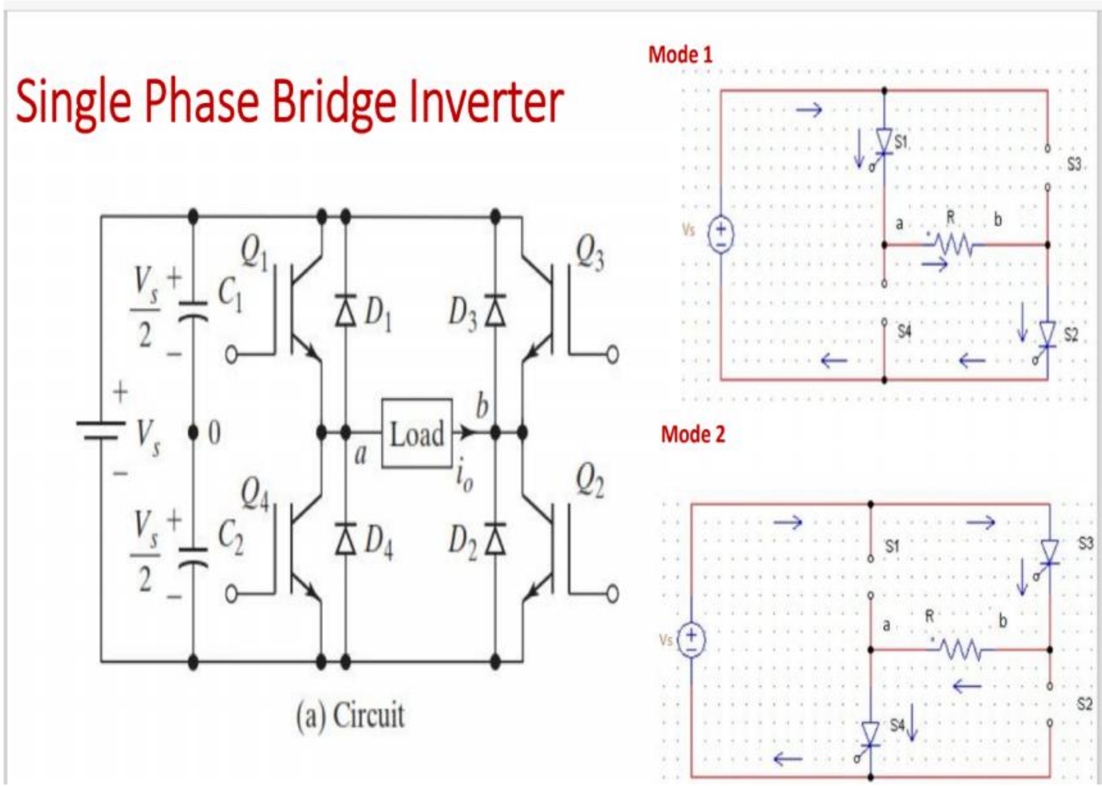


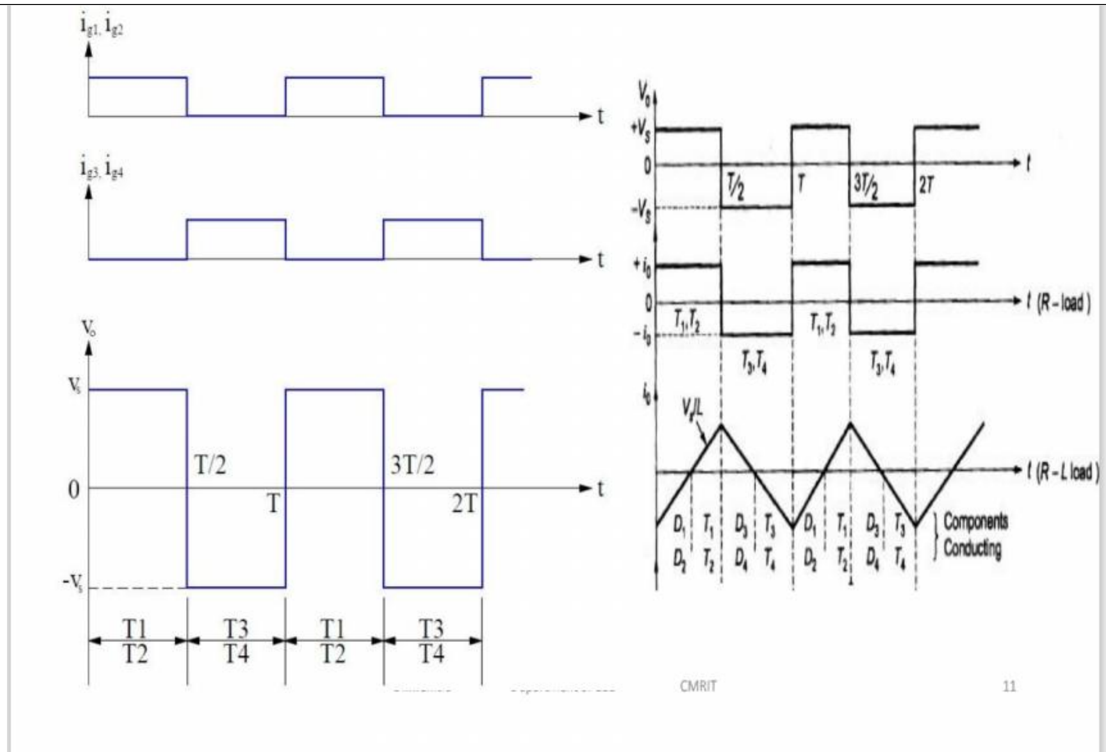
2

Mode 1 (0 to T/2):-

- During this mode switch S1 and switch S2 are ON and switch S3 and switch S4 are OFF From period 0 to T/2. 2
- Current flowing path during this mode is Vs – S1- a -R(load reistor) – b – S2 – Vs.
- Voltage across the load resistor is positive Vs. (Vo = Vs)

Mode 2 (T/2 to T):-

- During this mode switch S3 and switch S4 are ON and switch S1 and switch S2 are OFF From period T/2 to T.
- Current flowing path during this mode is Vs – S3 – b – R(load resistor) – a – S4 – Vs.
- Voltage across the load resistor is negative Vs. (Vo = -Vs)



2

Switching States of single phase full bridge inverter

Switch States for a Single-Phase Full-Bridge Voltage-Source Inverter

State	State No.	Switch State*	v_{ao}	v_{bo}	v_o	Components Conducting
S_1 and S_2 are on and S_4 and S_3 are off	1	10	$V_S/2$	$-V_S/2$	V_S	S_1 and S_2 if $i_o > 0$ D_1 and D_2 if $i_o < 0$
S_4 and S_3 are on and S_1 and S_2 are off	2	01	$-V_S/2$	$V_S/2$	$-V_S$	D_4 and D_3 if $i_o > 0$ S_4 and S_3 if $i_o < 0$
S_1 and S_3 are on and S_4 and S_2 are off	3	11	$V_S/2$	$V_S/2$	0	S_1 and D_3 if $i_o > 0$ D_1 and S_3 if $i_o < 0$
S_4 and S_2 are on and S_1 and S_3 are off	4	00	$-V_S/2$	$-V_S/2$	0	D_4 and S_2 if $i_o > 0$ S_4 and D_2 if $i_o < 0$
S_1, S_2, S_3, and S_4 are all off	5	off	$-V_S/2$ $V_S/2$	$V_S/2$ $-V_S/2$	$-V_S$ V_S	D_4 and D_3 if $i_o > 0$ D_1 and D_2 if $i_o < 0$

2

5

With the neat circuit diagram and waveforms, Explain the 180° mode of operation for three phase inverter. Give the expression for line and phase voltages for one cycle.

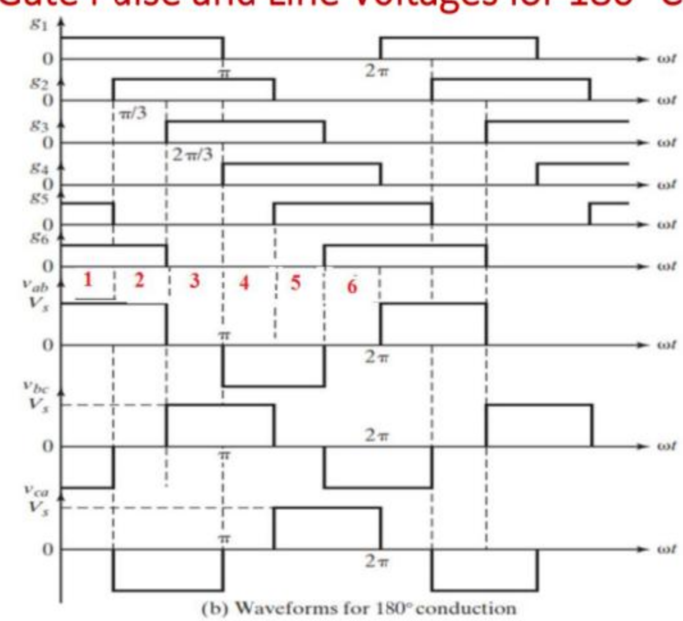
Three Phase Bridge Inverters

- A three-phase output can be obtained from a configuration of six transistors and six diodes.
- Two types of control signals can be applied to the transistors:
- 180° conduction or 120° conduction.
- The 180° conduction has better utilization of the switches and is the preferred method.
- This circuit topology is often known as a three-phase bridge inverter and is used in many applications, including renewable energy systems.
- The rectifier converts the ac voltage of the wind generator to a dc voltage and the voltage source inverter (VSI) converts the dc voltage into three-phase ac voltages to match with ac grid voltage and frequency.

1

2

Gate Pulse and Line Voltages for 180° Conduction



(b) Waveforms for 180° conduction

Thus, the resulting ac output line voltages are

Vs, 0, and -*Vs*

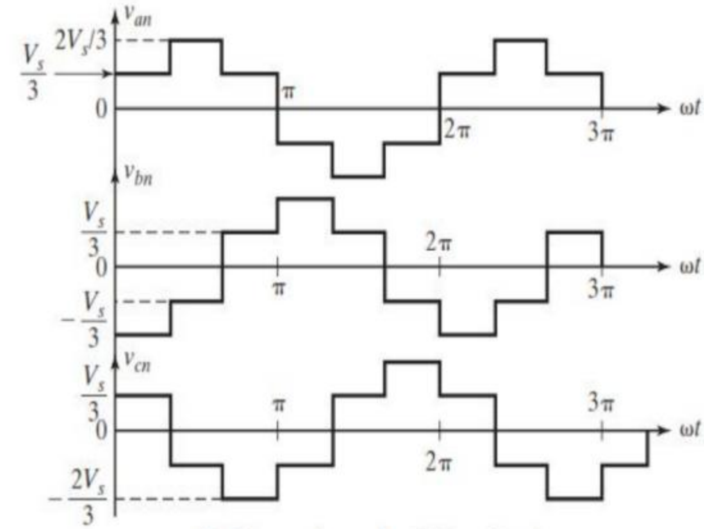
Vab – Q1 Q6 +Vs
& Q3 Q4 -Vs

Vbc – Q3 Q2 +Vs
& Q5 Q6 -Vs

Vca – Q5 Q4 +Vs
& Q1 Q2 -Vs

7

Phase Voltages for 180° Conduction



(b) Phase voltages for 180° conduction

- Phase voltages are step wave with step height Vs/3
- Line Voltages are quasi square wave with voltages Vs, 0, -Vs

15

2

Switching States for Three Phase bridge Inverter 180° mode

TABLE Switch States for Three-Phase Voltage-Source Inverter

State	State No.	Switch States	v_{ab}	v_{bc}	v_{ca}
S_6, S_1, and S_5 are on and S_3, S_4, and S_2 are off	1	101	V_S	$-V_S$	0
S_1, S_2, and S_6 are on and S_4, S_5, and S_3 are off	2	100	V_S	0	$-V_S$
S_2, S_3, and S_1 are on and S_5, S_6, and S_4 are off	3	110	0	V_S	$-V_S$
S_3, S_4, and S_2 are on and S_6, S_1, and S_5 are off	4	010	$-V_S$	V_S	0
S_4, S_5, and S_3 are on and S_1, S_2, and S_6 are off	5	011	$-V_S$	0	V_S
S_5, S_6, and S_4 are on and S_2, S_3, and S_1 are off	6	001	0	$-V_S$	V_S
S_1, S_3, and S_5 are on and S_4, S_6, and S_2 are off	7	111	0	0	0
S_4, S_6, and S_2 are on and S_1, S_3, and S_5 are off	8	000	0	0	0

2

Mode 1; From 0 to 60;

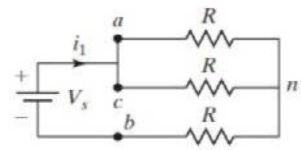
During mode 1 for $0 \le \omega t < \pi/3$, transistors Q_1, Q_5, and Q_6 conduct

$$R_{eq} = R + \frac{R}{2} = \frac{3R}{2}$$

$$i_1 = \frac{V_s}{R_{eq}} = \frac{2V_s}{3R}$$

$$v_{an} = v_{cn} = \frac{i_1 R}{2} = \frac{V_s}{3}$$

$$v_{bn} = -i_1 R = \frac{-2V_s}{3}$$



Mode 1

Mode 2; From 60 to 120;

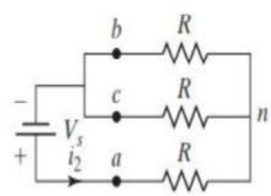
During mode 2 for $\pi/3 \le \omega t < 2\pi/3$, transistors Q_1, Q_2 and Q_6 conduct

$$R_{eq} = R + \frac{R}{2} = \frac{3R}{2}$$

$$i_2 = \frac{V_s}{R_{eq}} = \frac{2V_s}{3R}$$

$$v_{an} = i_2 R = \frac{2V_s}{3}$$

$$v_{bn} = v_{cn} = \frac{-i_2 R}{2} = \frac{-V_s}{2}$$



Mode 2

Mode 3; From 120 to 180;

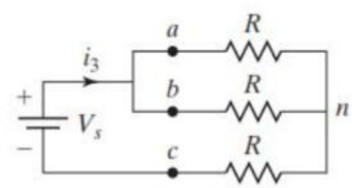
During mode 3 for $2\pi/3 \le \omega t < \pi$, transistors Q_1, Q_2, and Q_3 conduct

$$R_{eq} = R + \frac{R}{2} = \frac{3R}{2}$$

$$i_3 = \frac{V_s}{R_{eq}} = \frac{2V_s}{3R}$$

$$v_{an} = v_{bn} = \frac{i_3 R}{2} = \frac{V_s}{3}$$

$$v_{cn} = -i_3 R = \frac{-2V_s}{3}$$



Mode 3

2

		RMS output Voltage (Line – Line) & Phase The line-to-line rms voltage can be found from $$V_L = \left[\frac{2}{2\pi} \int_0^{2\pi/3} V_s^2 \, d(\omega t) \right]^{1/2} = \sqrt{\frac{2}{3}} V_s = 0.8165 V_s$$ $V_L = 0.8165 V_s$ The rms value of line-to-neutral voltages can be found from the line voltage, $$V_p = \frac{V_L}{\sqrt{3}} = \frac{\sqrt{2} V_s}{3} = 0.4714 V_s$$ $V_p = 0.4714 V_s$ **RMS Value of Fundamental Line Voltage & Phase Voltage** From v_{ab} Eq , the rms nth component of the line voltage is $$V_{Ln} = \frac{4V_s}{\sqrt{2} n\pi} \sin \frac{n\pi}{3}$$ which, for $n = 1$, gives the rms fundamental line voltage. $$V_{L1} = \frac{4V_s \sin 60°}{\sqrt{2}\pi} = 0.7797 V_s$$ $$V_{p1} = \frac{V_{L1}}{\sqrt{3}} = \frac{0.7797 V_s}{\sqrt{3}}$$ $V_{p1} = 0.45 V_s$	1
6		A single-phase full bridge inverter has a resistive load of 4Ω and dc input voltage is Vs = 24V. Determine 1. RMS output voltage at fundamental frequency 2. Output power 3. Average and peak current of each transistor 4. Peak reverse blocking voltage of each transistor 5. THD, DF, HF and DF of LOH	

6) $V_s = 24V$; $R = 4\Omega$.

1) Rms o/P Voltage @ fundamental frequency

$$V_{01} = 0.90 \times 24 = 21.6V.$$

2) O/P Power $= P_0 = V_s^2 / R = \frac{24^2}{4} = 144W$

3) Peak transistor Current $I_p = \frac{24}{4} = 6A$

Average current of each transistor

$$I_Q = 0.5 \times 6 = 3A.$$

4) Peak reverse blocking voltage of each transistor

$$V_{BR} = 24V.$$

5) THD

$$THD = \frac{1}{V_{01}} \sqrt{\sum_{n=2}^{\infty} V_{on}^2}$$

$$= \frac{\sqrt{V_0^2 - V_{01}^2}}{V_{01}} = \frac{\sqrt{24^2 - 21.6^2}}{21.6}$$

$$= 0.4843$$

$$THD = 48.43\%.$$

Distortion factor (DF)

$$DF = \frac{0.048 \times V_s}{V_{01}} = \frac{0.048 \times 24}{21.6}$$

$$= 5.33\%$$

HF & DF of LOH

3rd harmonics ; $n = 3$

$$HF = \frac{V_{03}}{V_{01}} = \frac{V_{on}}{V_{01}} = \frac{7.2}{21.6} = 0.3333$$

$$V_{03} = \frac{V_{01}}{3} = 7.2$$

$$HF_3 = 33.33\%$$

$$DF_3 = \frac{V_{03}}{V_{01} \times n^2} = \frac{V_{01}}{3 \times V_{01} \times 3^2} = \frac{1}{3^3} = 0.03704$$

$$DF_3 = 3.704\%$$

7a

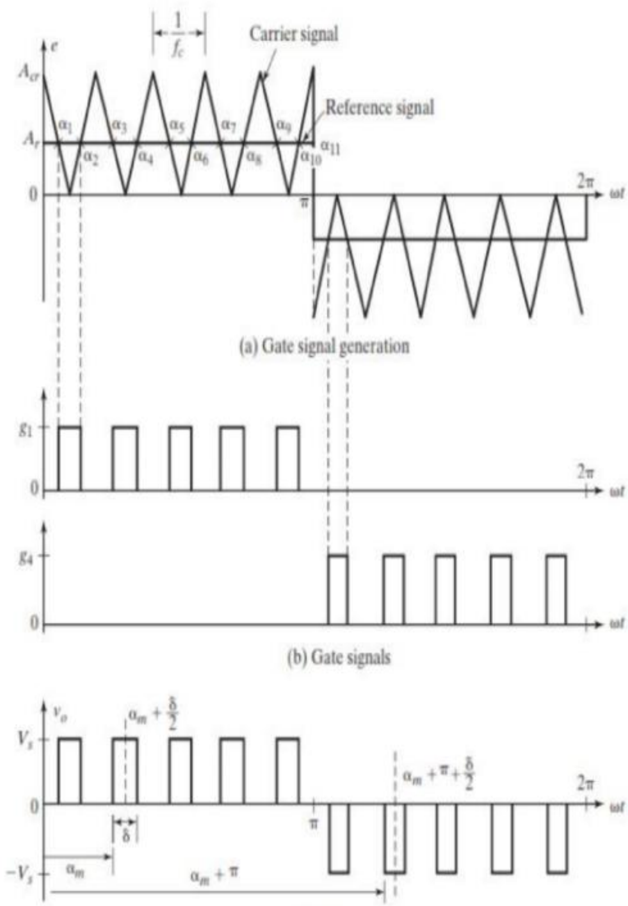
Explain the voltage control of single-phase inverter using 1) multiple pulse width modulation 2) sinusoidal pulse width modulation 3

Features of Multi pulse width modulation

- The order of harmonics is the same as that of single-pulse modulation.
- The distortion factor is reduced significantly compared with that of single-pulse modulation.
- However, due to larger number of switching on and off processes of power transistors, the switching losses would increase.
- With larger values of *p*, the amplitudes of LOH would be lower, but the amplitudes of some higher order harmonics would increase.
- However, such higher order harmonics produce negligible ripple or can easily be filtered out.

2. Multi Pulse Width Modulation

Output Voltage Vo = Vs (g1- g4)



Dr K Chitra

Sinusoidal Pulse Width Modulation

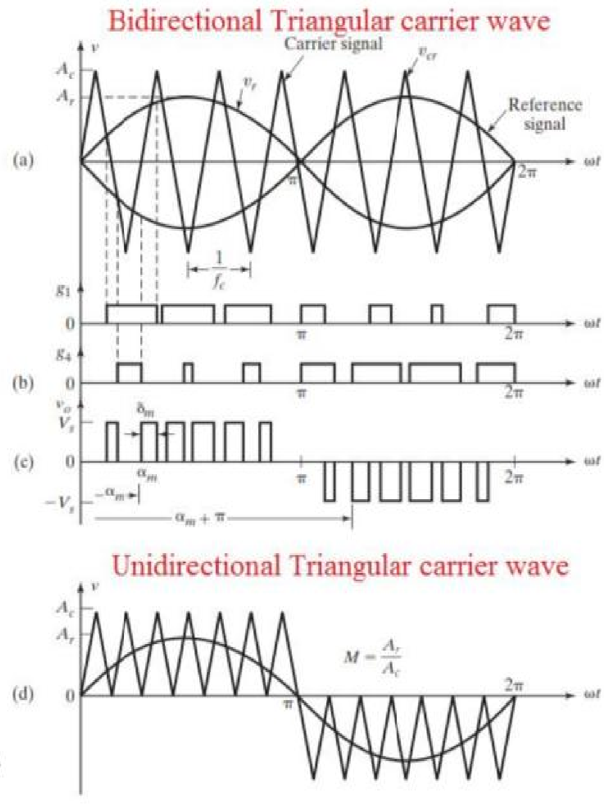
- Since the desired output voltage is a sine wave, a reference sinusoidal signal is used as the reference signal.
- Instead of maintaining the width of all pulses the same as in the case of multiple-pulse modulation, the width of each pulse is varied in proportion to the amplitude of a sine wave evaluated at the center of the same pulse.
- The DF and LOH are reduced significantly.
- The gating signals are generated by comparing a sinusoidal reference signal with a triangular carrier wave of frequency *fc.*
- This sinusoidal pulse-width modulation (SPWM) is commonly used in industrial applications.
- The frequency of reference signal *fr* determines the inverter output frequency *fo*; and its peak amplitude *Ar,* controls the modulation index *M, then controls RMS output voltage.*

Sinusoidal Pulse Width Modulation

✓Comparing the bidirectional carrier signal v*cr* with two sinusoidal reference signals *vr* and -*vr* shown in produces gating signals *g*1 and *g*4, respectively.

✓Unidirectional triangular wave if preferred

Output Voltage Vo = Vs (g1- g4)

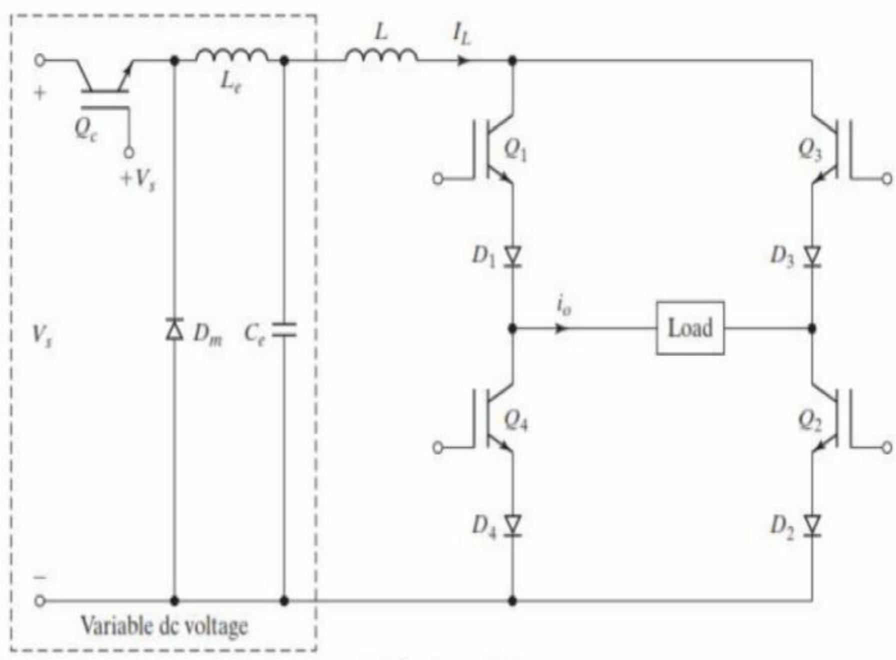


7b		**With the neat circuit diagram and waveforms, Explain the operation of current source inverter.**	1 2

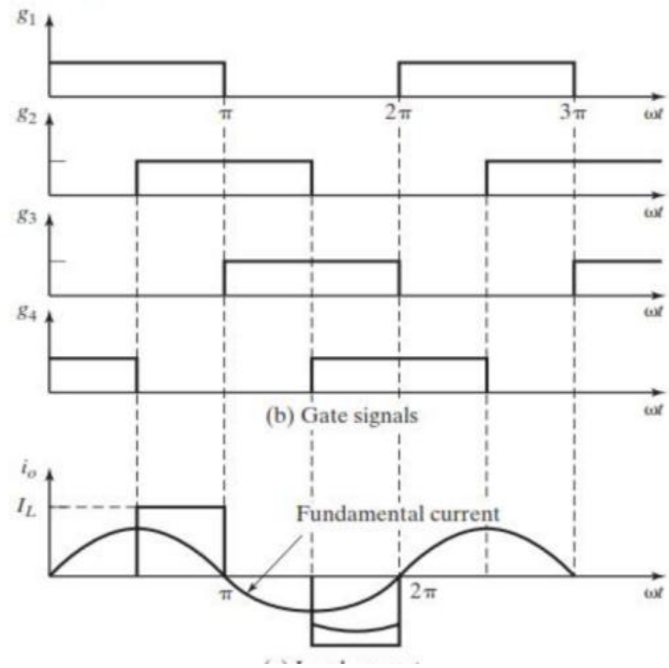
Current Source Inverter

- In VSI, the inverters are fed from a voltage source and the load current is forced to fluctuate from positive to negative, and vice versa.
- To cope with inductive loads, the power switches with freewheeling diodes are required
- In a current-source inverter (CSI), the input behaves as a current source.
- The output current is maintained constant irrespective of load on the inverter and the output voltage is forced to change.

Current Source Inverter (CSI) – Single Phase



Gate Pulse & Output Current Waveform



2

Current Source Inverter

- Because there must be a continuous current flow from the source, two switches must always conduct—one from the upper and one from the lower switches.
- The conduction sequence is 12, 23, 34, and 41.
- The switch states are shown in Table 6.6.

TABLE Switch States for a Full-Bridge Single-Phase Current-Source Inverter (CSI)

State	State No.	Switch State $S_1S_2S_3S_4$	i_o	Components Conducting
S_1 and S_2 are on and S_4 and S_3 are off	1	1100	I_L	S_1 and S_2 D_1 and D_2
S_3 and S_4 are on and S_1 and S_2 are off	2	0011	$-I_L$	S_3 and S_4 D_3 and D_4
S_1 and S_4 are on and S_3 and S_2 are off	3	1001	0	S_1 and S_4 D_1 and D_4
S_3 and S_2 are on and S_1 and S_4 are off	4	0110	0	S_3 and S_2 D_3 and D_2