Introduction to Electrical Engineering

Course Code: EE 103

Department: Electrical Engineering

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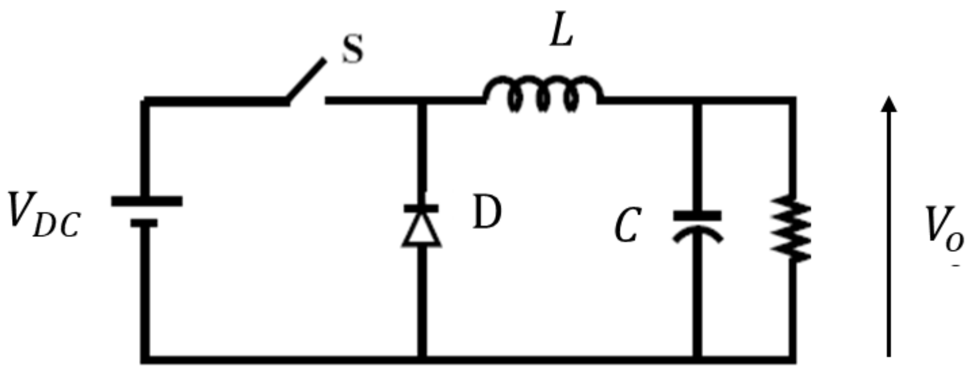
Review:

DC-DC Conversion: **Buck Converter**



L → filter inductor
C → filter capacitor
'V_O' is assumed to remain constant

Switch 'S' is switched at a very high frequency

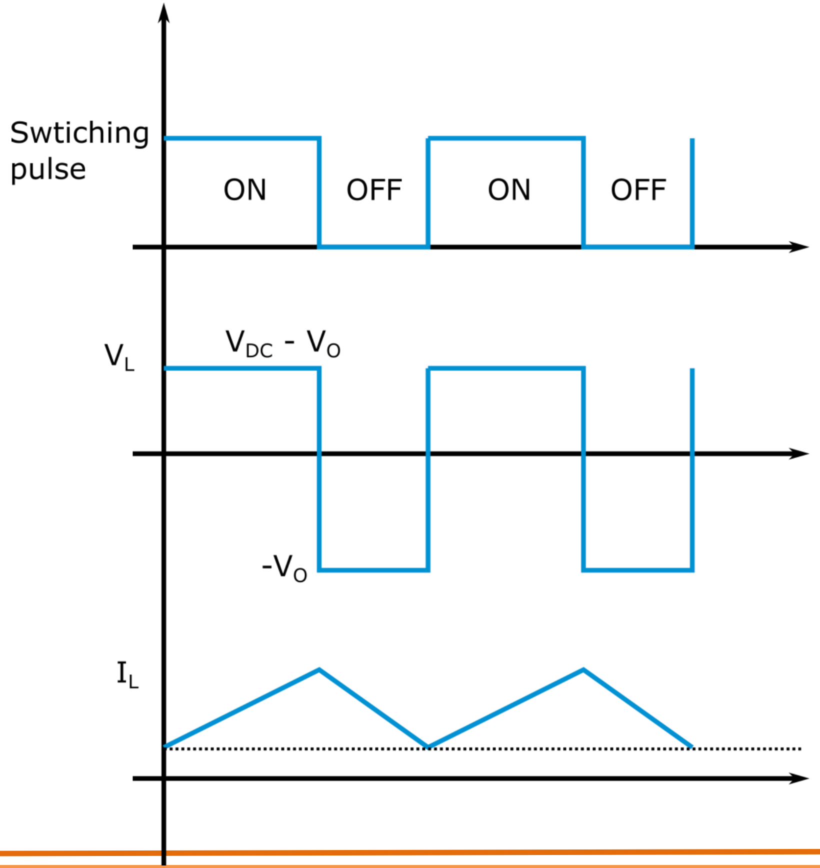
- S is ON for DT second
- S is OFF for $(1-D)T$ second

Average voltage across L = 0

$$\therefore (V_{DC} - V_o)DT = V_o(1-D)T$$

$$\Rightarrow V_o = DV_{DC}$$

→ Buck Converter, Output < Input

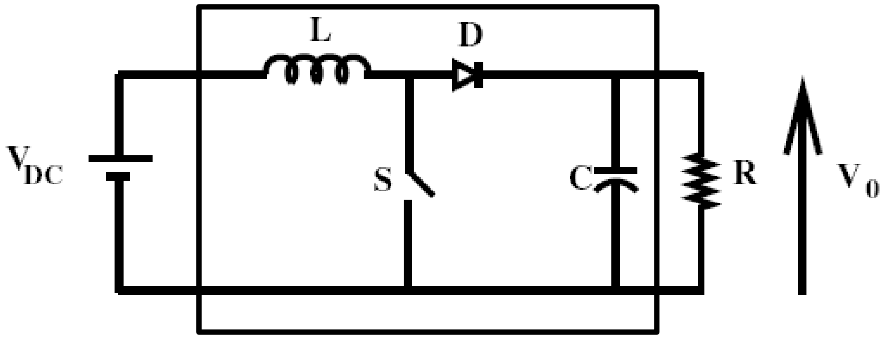


DC-DC Conversion: Boost Converter

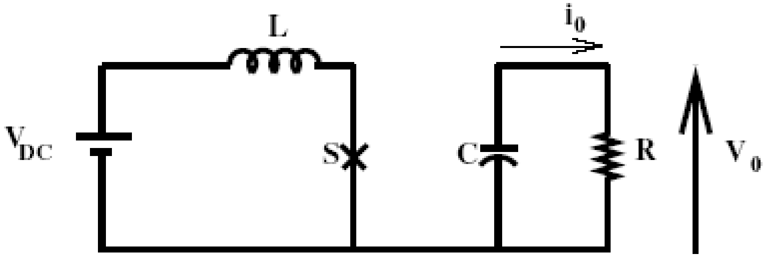
Following circuit is a boost converter
L → filter inductor
C → filter capacitor
'V_O' is constant and ripple free

Switch 'S' is switched at a very high frequency

- S is ON for DT time
- S is OFF for $(1-D)T$ time
- T is switching period,
  $T = \frac{1}{f_{sw}}$, f_{sw}: switching frequency



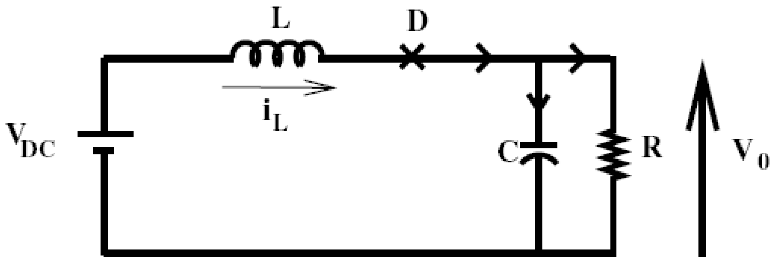
S is ON



$V_L = V_{DC} =$ Constant

→ I_L increases linearly
→ $I_o = -C\frac{dv_o}{dt} = \frac{v_o}{R}$

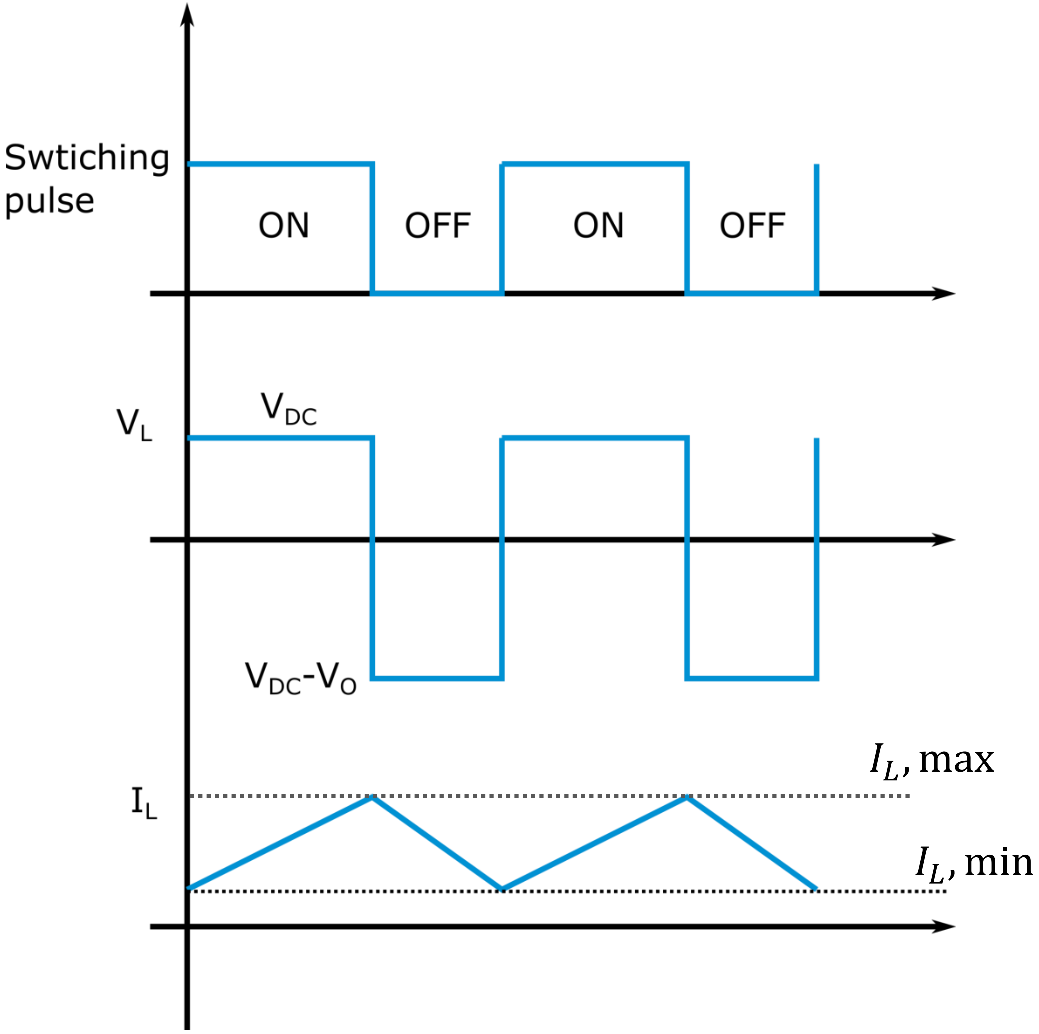
S is OFF



$V_L = V_{DC} - V_o =$ Constant

→ I_L decreases linearly
→ $I_L = C\frac{dv_o}{dt} + \frac{v_o}{R}$

DC-DC Conversion: Boost Converter



Assume i_L is continuous, and steady-state is assumed

Average voltage across L = 0

$$\therefore (V_{DC})DT + (V_{DC} - V_o)(1 - D)T = 0$$

$$\Rightarrow V_o = \frac{1}{1 - D} V_{DC}$$

➔Boost Converter, Output > Input

Precaution: Boost converter output should never be open circuited! (why??)

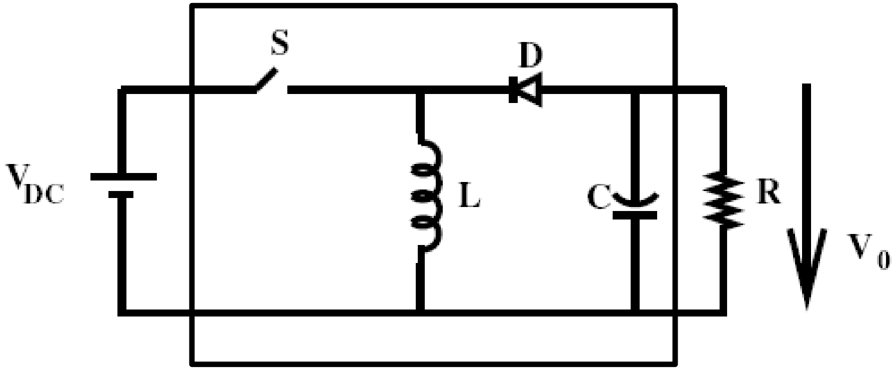
DC-DC Conversion: Buck-Boost Converter

This converter can be regarded as cascade connection of Buck and Boost converters

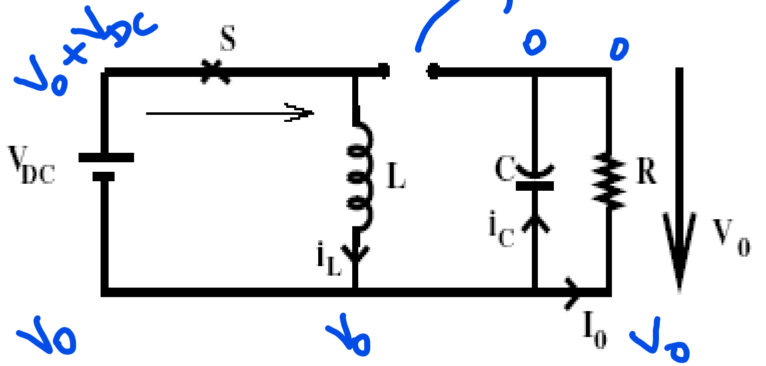
L → filter inductor

C → filter capacitor

'V_O' is constant and ripple free



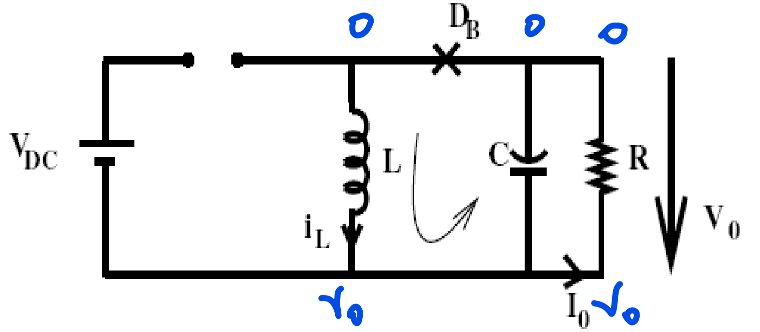
D is reverse biased



$$\boxed{V_L = V_{DC} = \text{constant}}$$

→ I_L increases linearly

→ $C\dfrac{dv_o}{dt} + \dfrac{v_o}{R} = 0$



$$\boxed{V_L = -V_o = \text{constant}}$$

→ I_L decreases linearly

→ $\boxed{I_L = C\dfrac{dv_o}{dt} + \dfrac{v_o}{R}}$

Assume i_L is continuous,

Average voltage across L = 0

$$\therefore\ (V_{DC})DT = V_o(1-D)T$$

$$\Rightarrow\ V_o = \frac{D}{1-D}V_{DC}$$

?

?

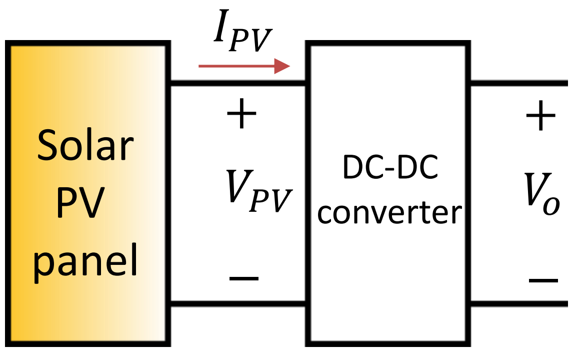
➔ Output is negative w.r.t the common point

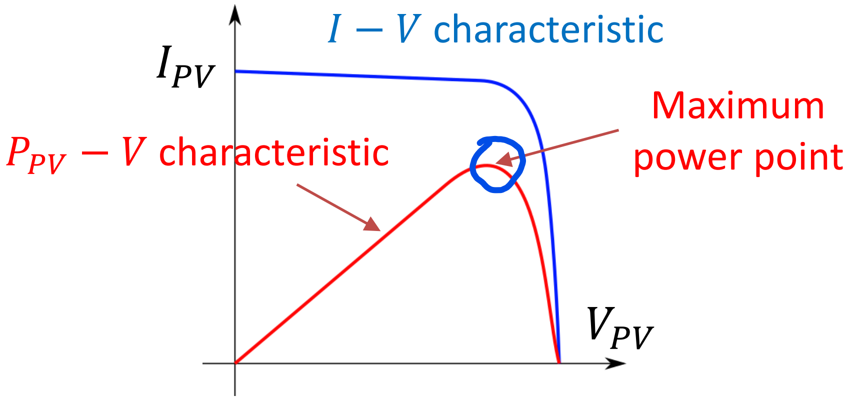
➔ Output can be less than or more than the input depending on the value of D

➔ Assignment: Sketch the waveforms of current through the inductor and voltage across it..

Important applications of DC-DC converters

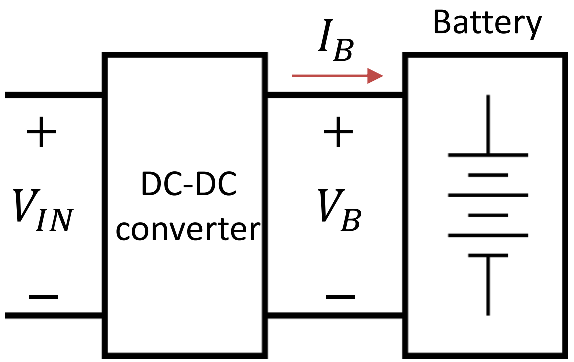
- In solar energy harvesting for maximum power tracking





- This "maximum power point"(MPP) varies continuously depending on the environmental conditions
- The DC-DC converter ensures that the PV is operated at MPP

- Battery charging



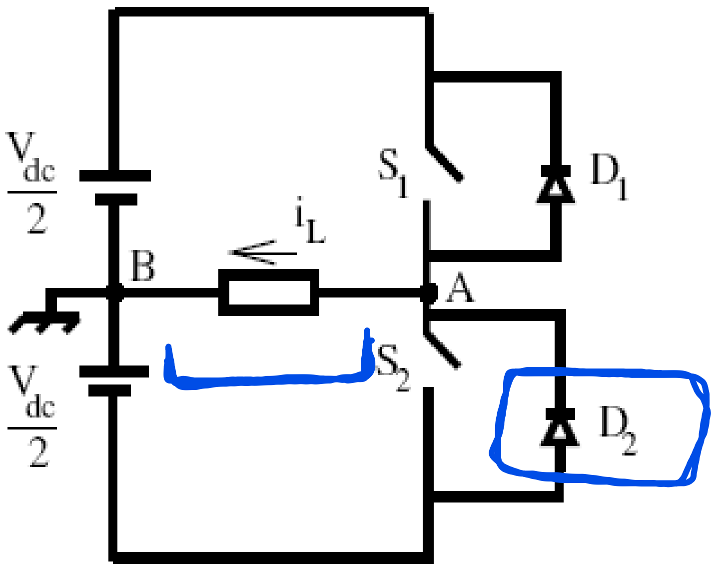
- Up to 85%, the battery is charged with constant current (CC)
- Beyond this level, it is charged with constant voltage (CV)
- This scheme of battery charging is termed as (CC-CV) charging
- A DC-DC converter is essential to perform such charging

DC – AC conversion

DC – AC conversion

Need for DC-AC conversion:

- Electric motor speed control
- Power source during grid failure
- Solar inverter
- Uninterruptible power supplies



Voltage source inverter (VSI)
Basic block: Half-bridge

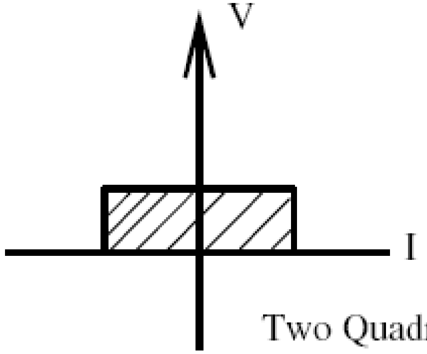
In VSI, input is the voltage source and it is constant. The current through the VSI can reverse
So… are there other types of inverters??

?

Requirement of the switches used in VSI:

- It should block the reverse voltage across it
- It should allow the current to flow in both directions

→ Connect a diode in anti-parallel to a switch



Two Quadrant Converter

DC – AC conversion: Half bridge

$\tau = \frac{L}{R}$

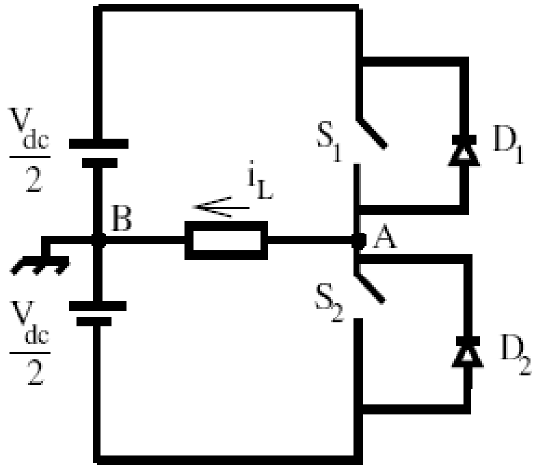
In VSI, switching signals S_1 and S_2 are always complementary

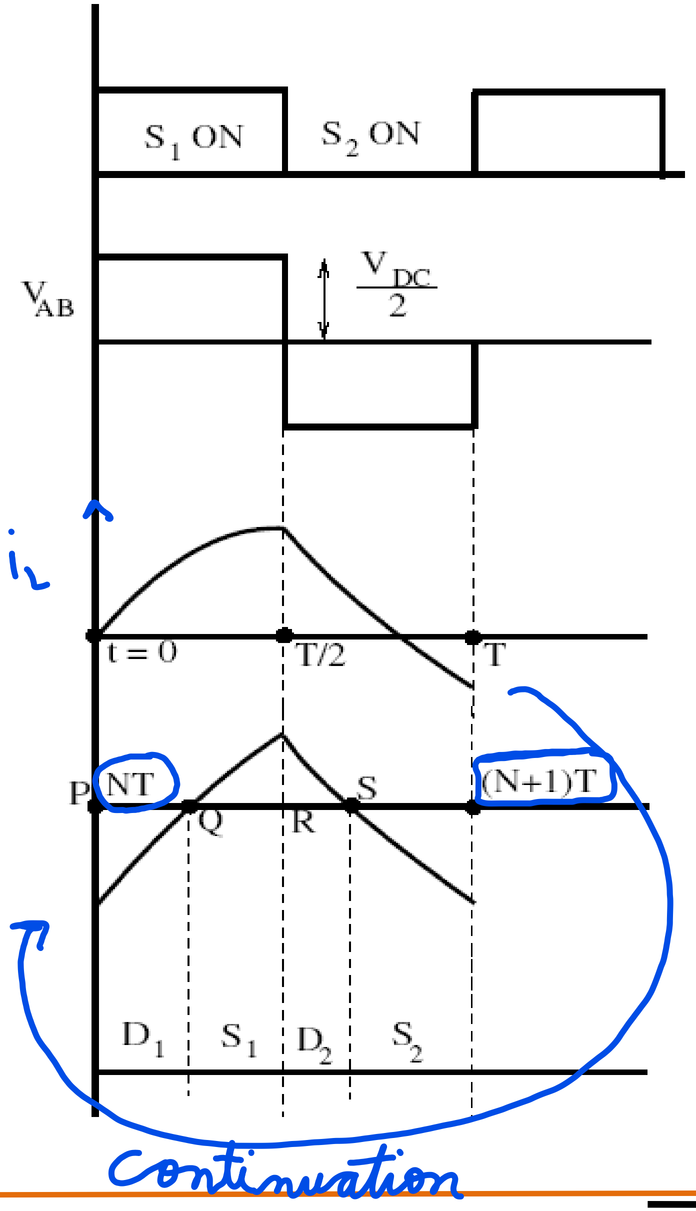
S_1 is ON → for $\frac{T}{2}$ duration, $V_{AB} = \frac{V_{DC}}{2}$

If load is $R - L$, Current $i = \frac{V}{R}(1 - e^{-\frac{t}{\tau}})$

S_1 is OFF → for $\frac{T}{2}$ duration, $V_{AB} = \frac{-V_{DC}}{2}$

Current, i will decay and become negative





Observations:

Time for which S_1/S_2 is ON will determine the frequency of V_{AB}, i.e. the output

→ If $\frac{T}{2}$ = 10 ms, f = 50 Hz

= 100 ms, f = 5 Hz

DC – AC conversion: Half bridge

At steady state,

During the duration P-Q: Voltage applied to the load is +ve

And i_L is –ve (i flowing from B to A)

➔ Diode, D_1 is carrying i

In Q-R: 'V' and 'I' are +ve

S1 is carrying 'I'

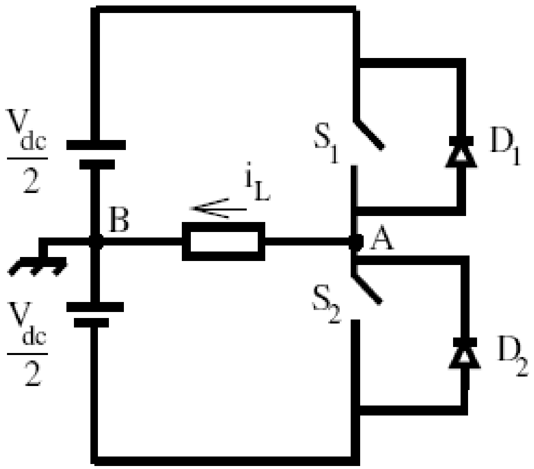
In R-S: 'V' is –ve and 'I' is +ve

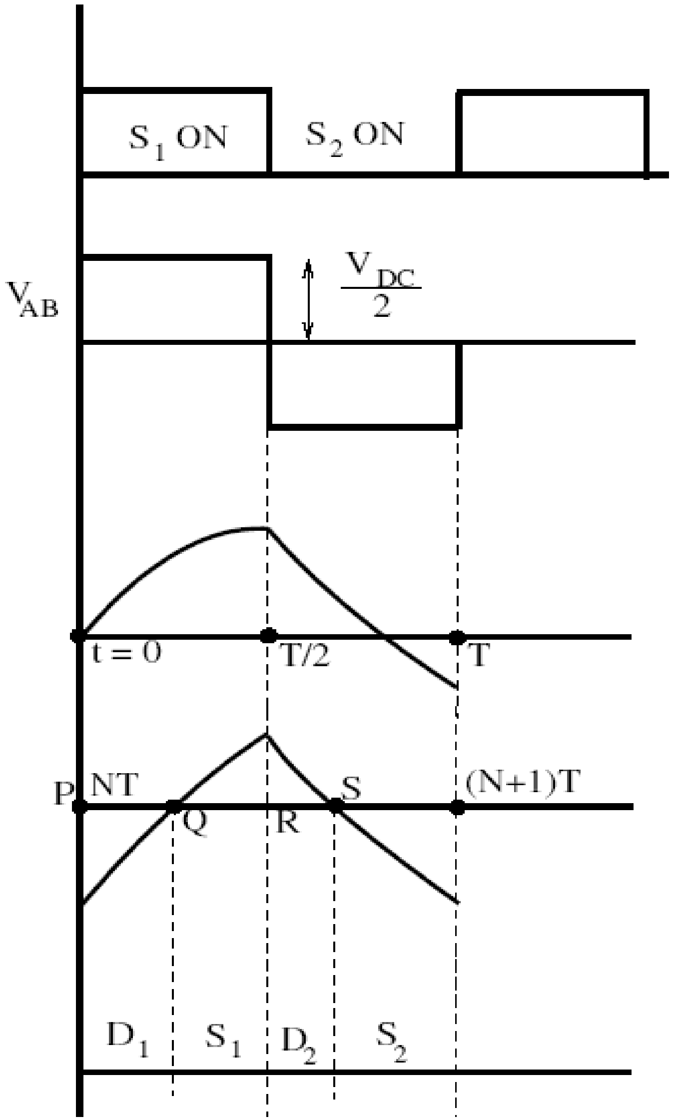
D2 is carrying 'I'

In S-T: 'V' and 'I' are –ve

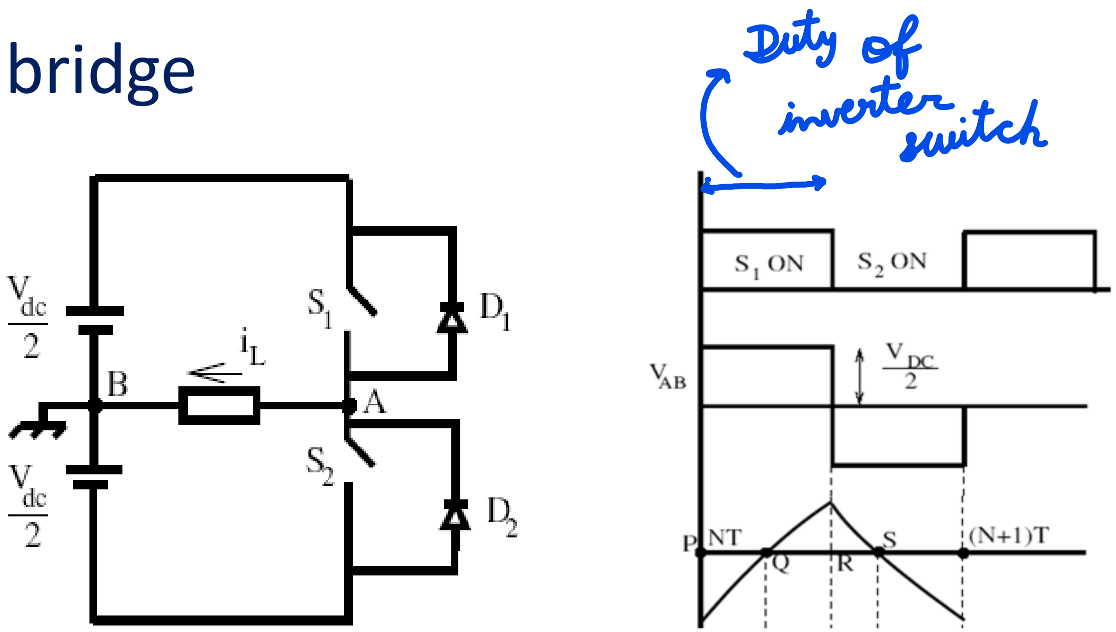
S2 is carrying 'I'

If load is purely resistive, is the diode required?? ?





DC – AC conversion: Half bridge vs Full bridge

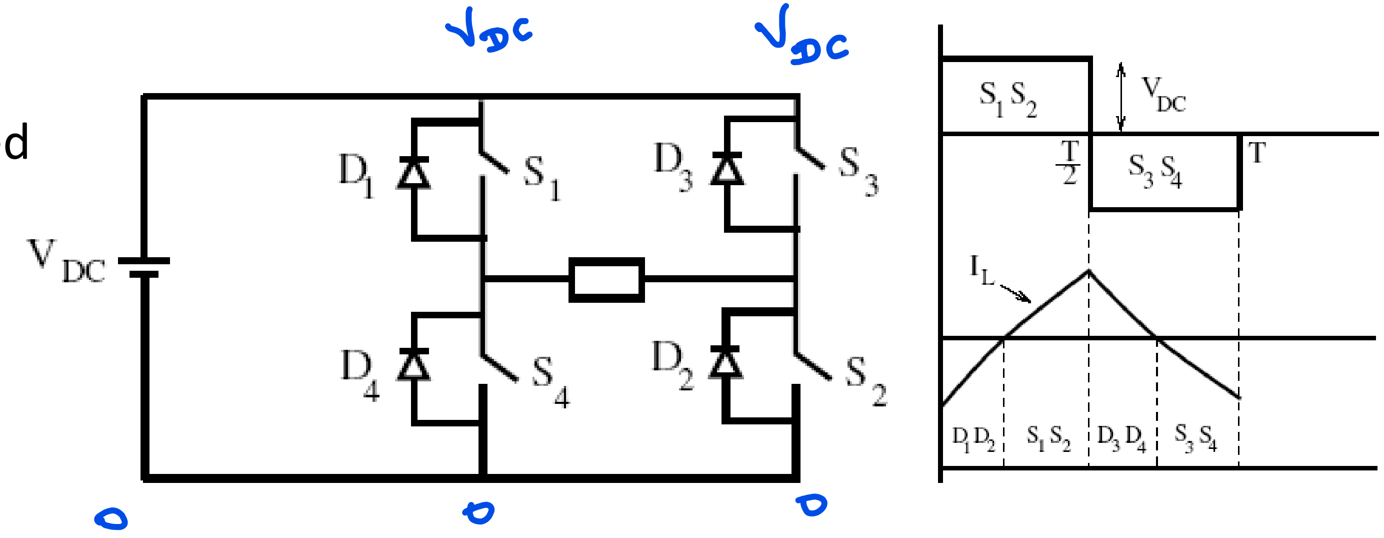


Limitations of Half Bridge

- Input is V_{DC}, but Output is $\frac{V_{DC}}{2}$
- Requires the center point of the DC source

Instead, use a Full Bridge

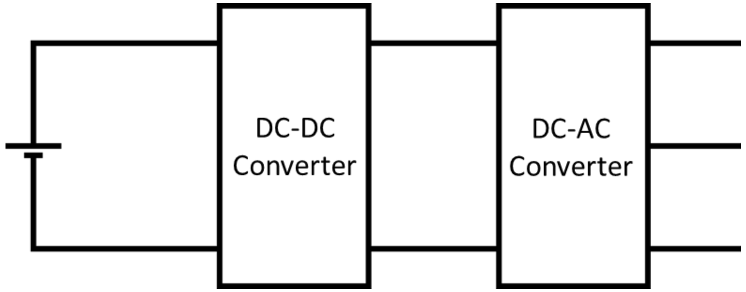
- In Full bridge, two devices conduct at a time
- Center point of DC source is not required
- Input is V_{DC}, and Output is V_{DC}



DC-AC Conversion: Varying the Voltage

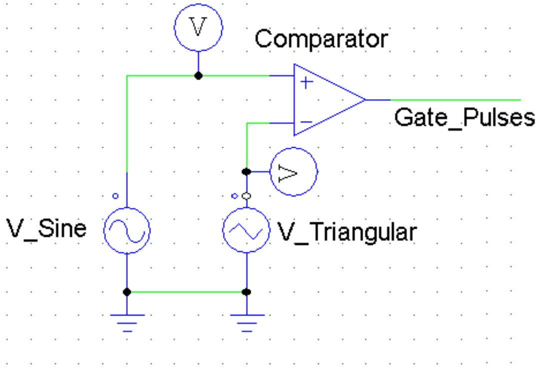
- Frequency variation can be obtained by changing the value of 'T', the time period
- How to vary the voltage value?

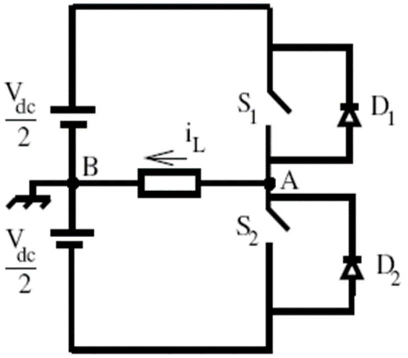
- A straight forward approach: Vary the input DC supply of the inverter (DC-AC Convertor) using a DC-DC converter
- In this method, the efficiency of the system is $\eta_{dc-dc} \times \eta_{dc-ac}$
- Also, the device count is high → low reliability
- Here, the switches are allowed to conduct for 180° (50% of T)

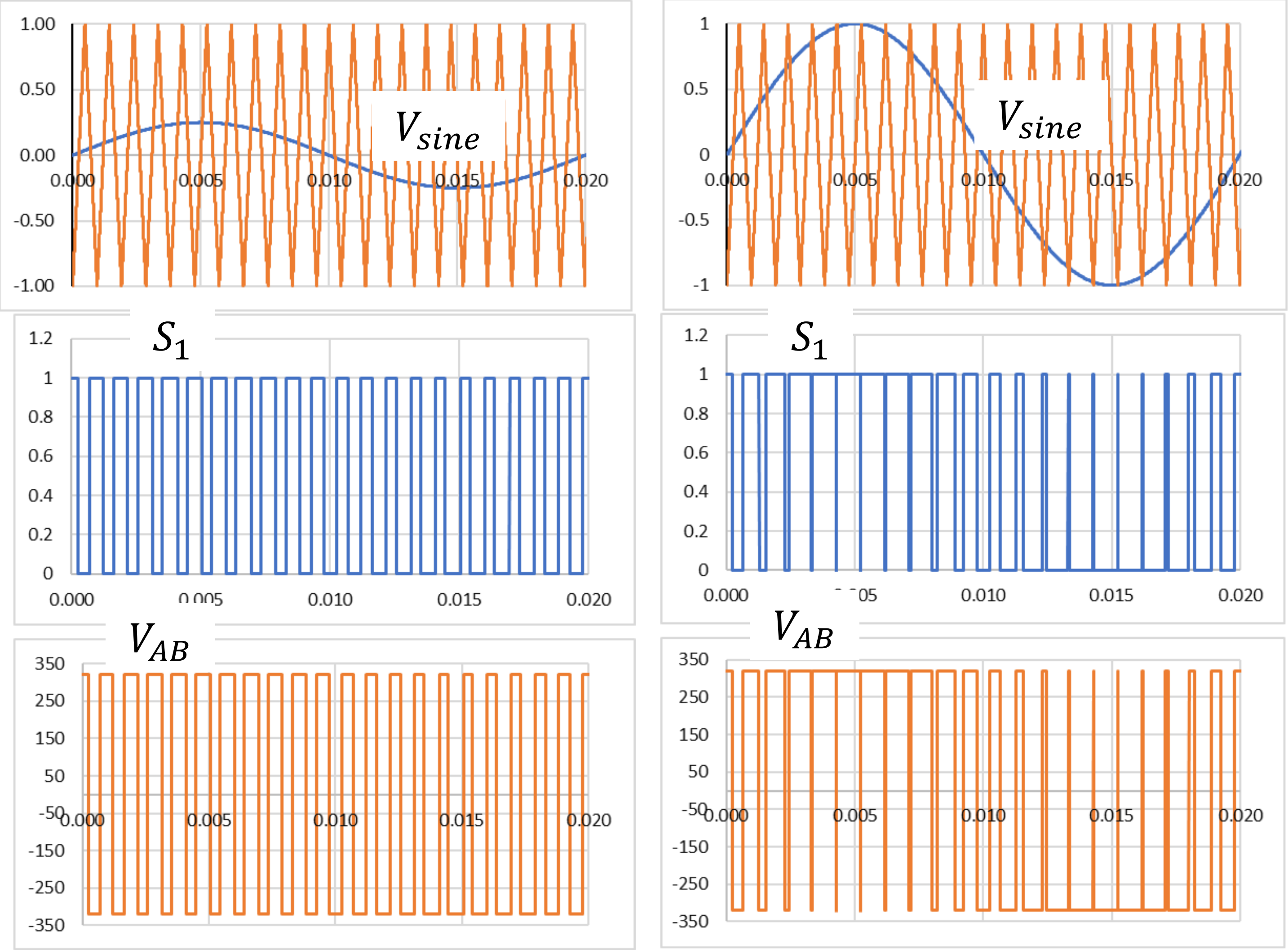


- Instead, keep the DC input to the inverter fixed and vary the duty of the inverter switches
- This scheme is known as Pulse Width Modulation (PWM)

Sine Pulse Width Modulation: Switch Gate Pulse Generation





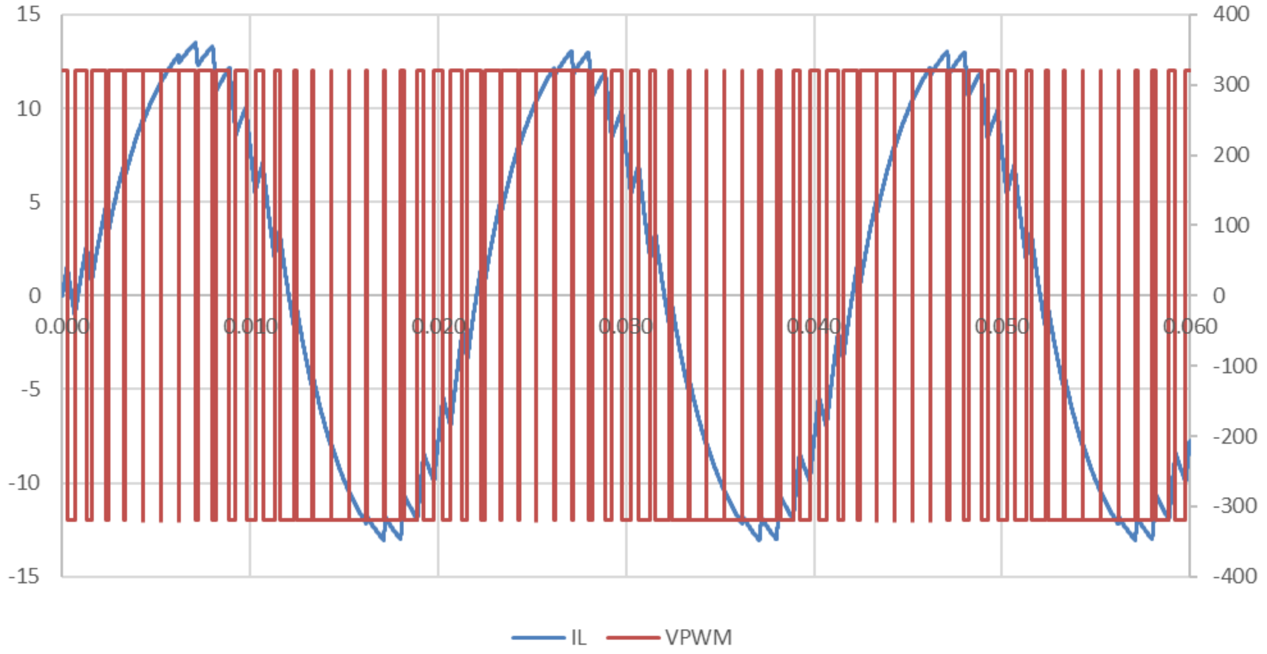


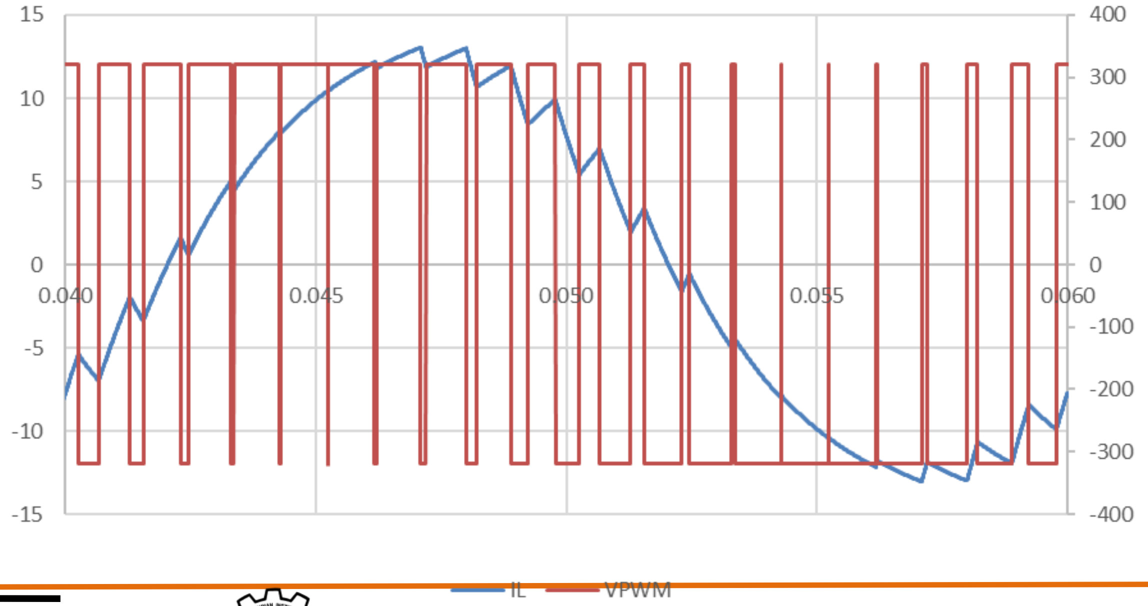
- A sinusoidal voltage (50 Hz) is compared with a triangular wave (High frequency)
- The obtained output is given as gate pulses to the corresponding switch

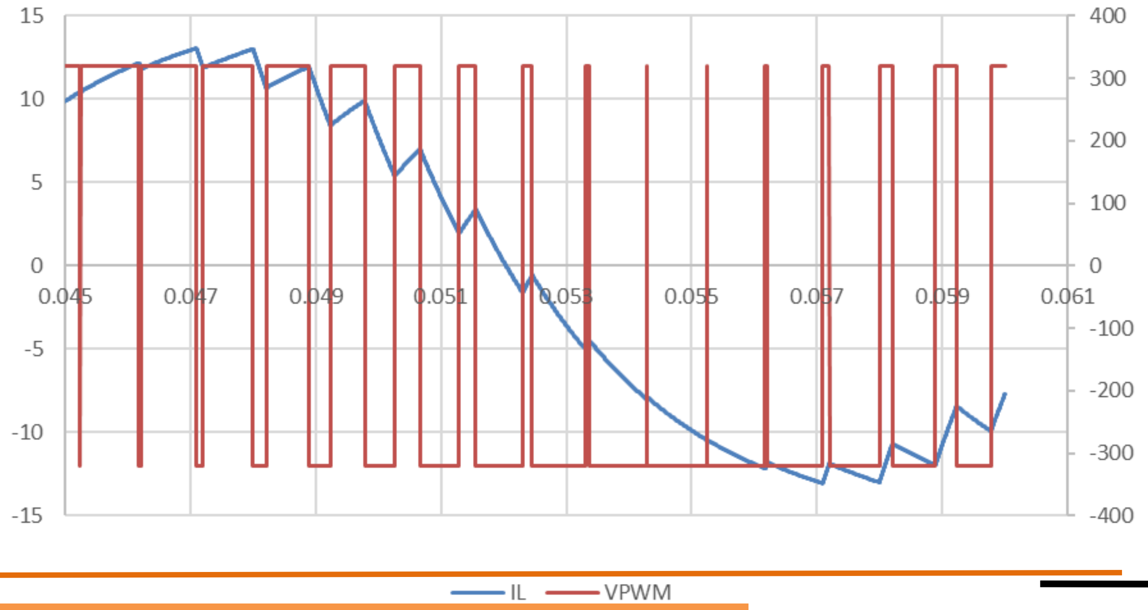
Sine Pulse Width Modulation

VSI feeding an $R - L$ load,
R = 10 ohm, L = 50 mH,
f_s = 1050 Hz

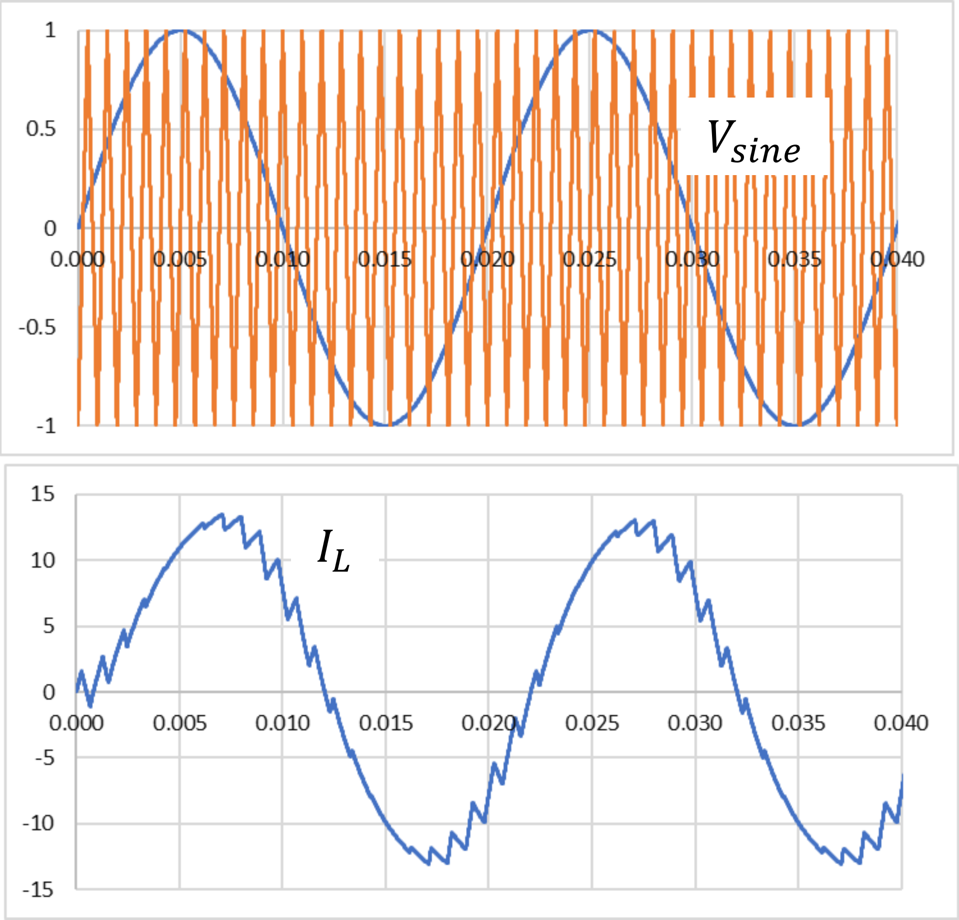
➔ It is possible to obtain sinusoidal current waveform

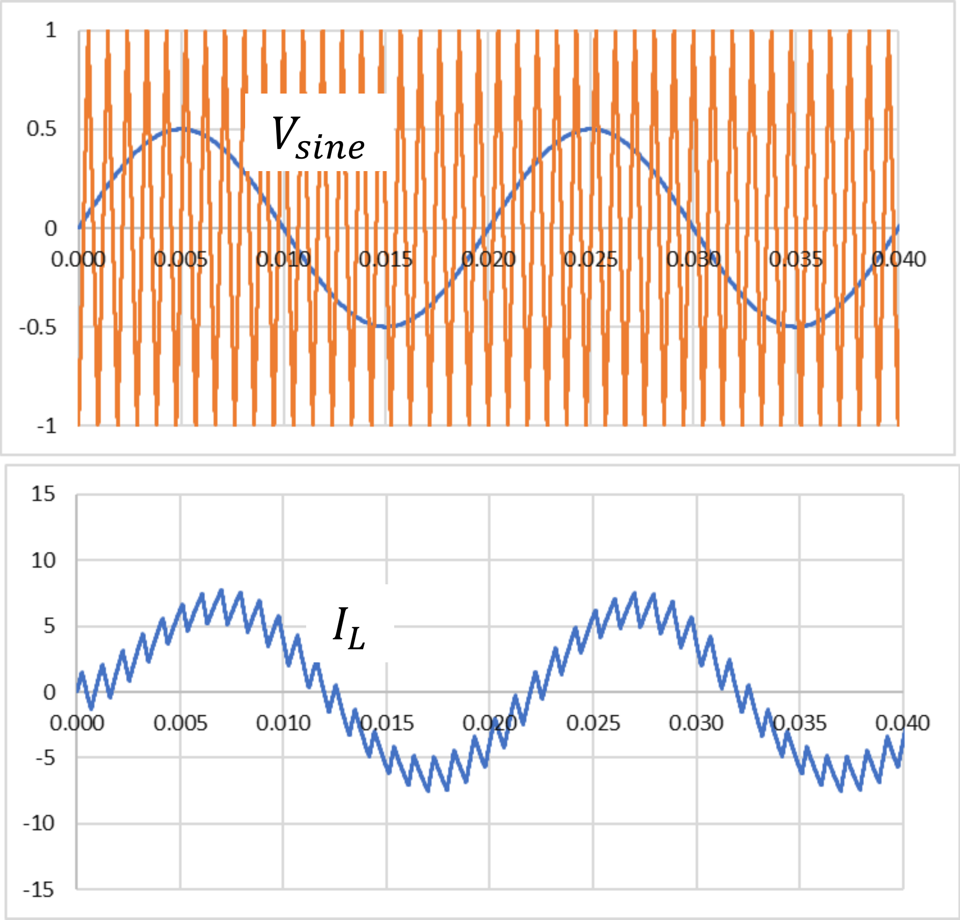






Sine Pulse Width Modulation: Variation of Load current with reference sine





Electrical Grounding/Earthing

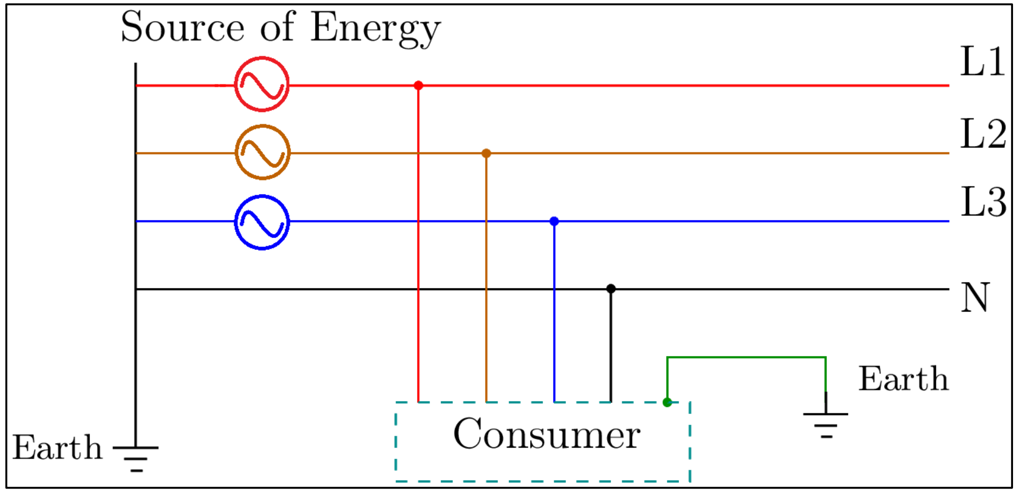
Ref: Prof. A. M. Kulkarni, EE334, Power Systems, Lecture: Safety, Three-phase neutral and earthing connections, Equipment classes, switches

Ground Path (Earthing)

- A ground is a return path for current
- A ground is also a point to which circuits may be 'referenced'

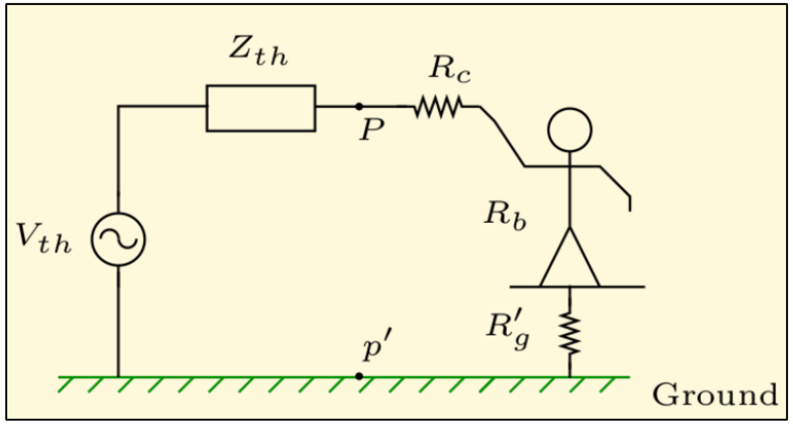
Can ground be a regular current path?

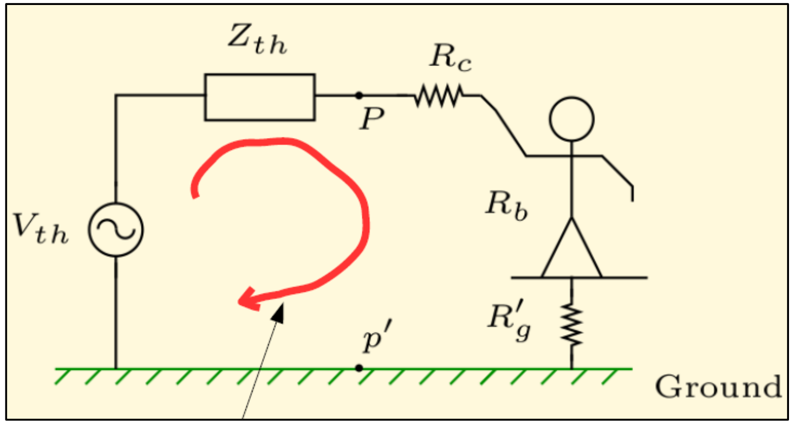
- Not generally used in practice
- For high voltage DC transmission, earth/sea are used as ground returns for short durations
- A few single-wire earth return systems are in existence
- Current can flow through ground during short-circuits



- A three-phase source can be viewed as three single-phase sources with one terminal common to all
- This common terminal is generally grounded to 'Earth'
- There is a return path from the consumer…

Safety





Z_{th} = Equivalent Impedance

$V_{th} = V_{\text{open-circuit}}$ at $P\,p'$

$R_c = R_{\text{contact}} \approx 500\,\Omega$

$R_b = R_{\text{body}} \approx 1000\,\Omega$

$R'_g = R_{\text{ground}} \approx 600\,\Omega$

- The entire power system is represented using a 'Thevenin Equivalent' network between points P and p'
- Depending on the impedance of the path, current flows through the 'person'

Source: Walter Weeks, *Transmission and Distribution of Electrical Energy*, Harper & Row Publishers 1980.

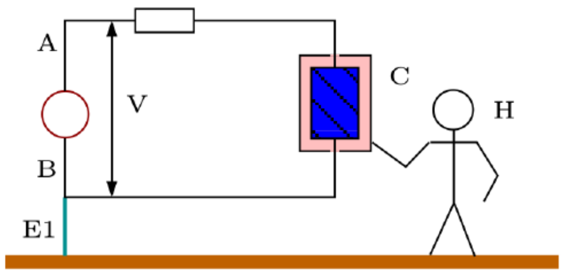
Effects of various magnitude of current through a person

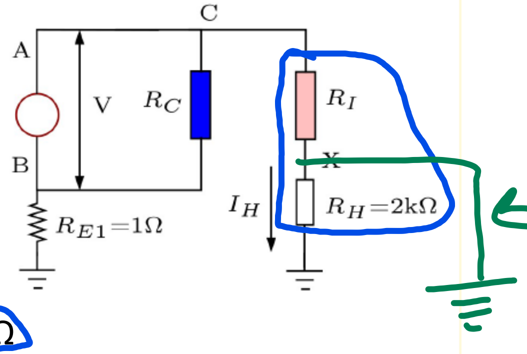
Sr No.	Effect	Current (mA)			
		Direct Current		60 Hz rms	
		Men	Women	Men	Women
1.	No sensation on hand	1	0.6	0.4	0.3
2.	Slight tingling. Perception threshold	5.2	3.5	1.1	0.7
3.	Shock- not painful but muscular control not lost	9	6	1.8	1.2
4.	Painful shock- painful but muscular control not lost	62	41	9	6
5.	Painful shock- let go threshold	76	51	16.0	10.5
6.	Painful and severe shock, muscular contractions, breathing difficult	90	60	23	15
7.	Possible ventricular fibrillation from short shocks:				
(a)	Shock duration 0.03 s	1300	1300	1000	1000
(b)	Shock duration 3 s	500	500	100	100
(c)	Almost certain ventricular fibrillation (if shock duration is over one heart beat interval)	1375	1375	275	275

'Let go' current

Threshold for 50% of males and females tested

Consider that the source is grounded and the equipment is not grounded



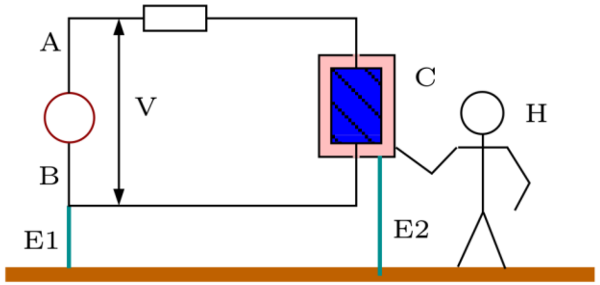


R_c = equipment load resistance = 58 Ω

R_I = equipment insulation resistance

The current through the person during insulation failure ($R_I = 0\ \Omega$)

$$I_H = \frac{V}{R_H + R_{E1}} = \frac{240}{2000 + 1} \approx 120 \text{ mA}$$



Instead, if the equipment is grounded, the current will prefer the ground path since it offers low resistance

Some pictures of 'Earthing' in our department