Power Converter Design

Objective

1. To design different types of converters to meet the desired specifications.

2. To learn how to select between different filters and DC-DC converters.

Inroduction

A filter is a device that removes some unwanted components or features from a signal. As the output of rectifier contains harmonics so the achievement of good efficiency and pure dc output from rectifiers is our major concern. For this purpose, filters are used to smooth the output and remove or decrease the harmonics and make the output of rectifier pure dc. Filters which provide pure dc output are called dc filters. Commonly dc filters are L, C or LC filters as shown in the figures below

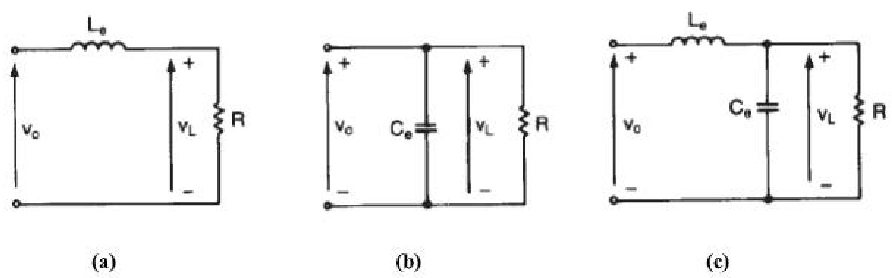
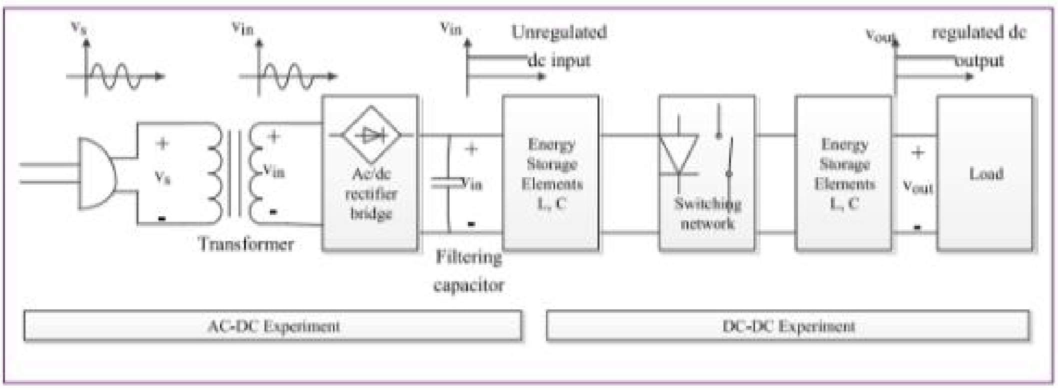


Fig.1. Dc Filters

Due to the rectification action, the input current of the rectifier also contains harmonics and an ac filter is also connected with the input of the rectifier for the removal of harmonics. Usually, an LC filter is connected in series with source of the system.

Design Task

Design a complete circuit that can control the 18 V DC from the AC-DC converter down to 5 V output of the DC-DC converter.



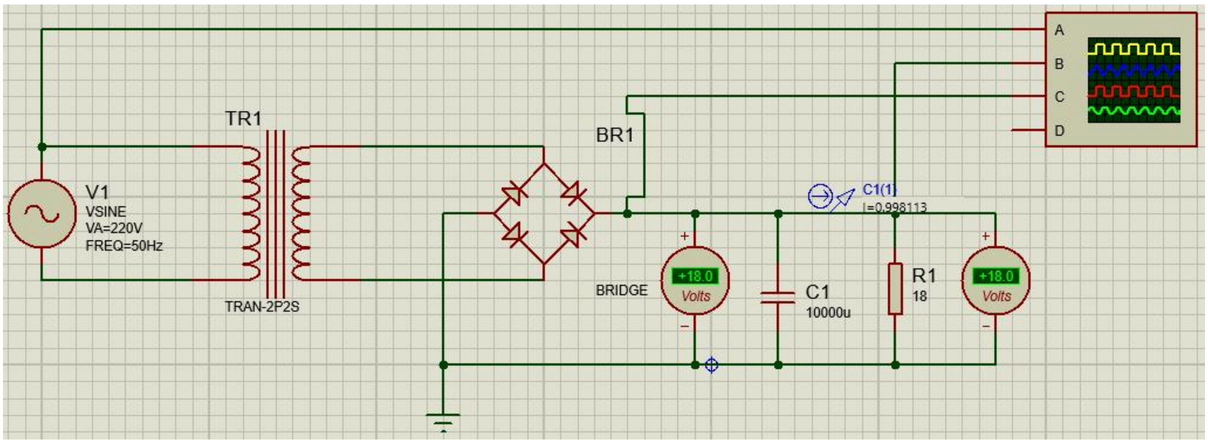
Design a single-phase rectifier:

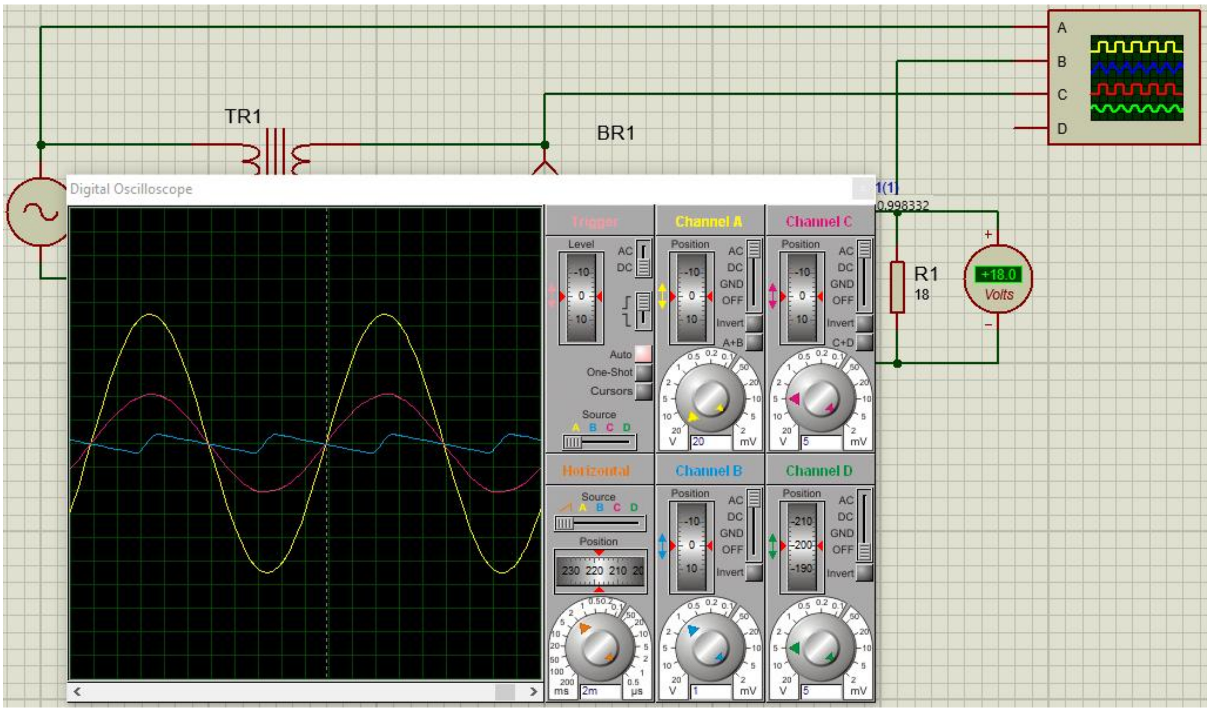
1. Construct a full wave rectifier circuit with resistance and inductor as load in such a way that final DC voltage at output is equal to 18V.

2. Provide specific frequency to the circuit

3. Determine the required ripple factor for the designing of filter components

4. Choose a value for filter either capacitive or inductive to reduce the ripple factor and increase the efficiency.





Horizontal Time Base: 2 milliseconds per division (2 ms/div)

Vertical Sensitivity: 1 volt per division (1 V/div)

The waveform appears to be a sawtooth wave.

The peak-to-peak voltage spans approximately 2 divisions vertically, indicating a peak-to-peak voltage of 2V.

Vpp = 2V

Vp = Vpp/2 = 2V/2 = 1V

Vrms(AC) = Vp/3 = 1V/3 ≈ 0.577V

The ripple factor is given by the formula:

RF = Vrms(AC)/VDC

Since we assume the DC component (Vdc) is approximately the same as the peak voltage:

VDC ≈ Vp = 1V

RF = 0.577V/1V = 0.577RF

Thus, the ripple factor is approximately **0.577**.

Now, in order to remove these ripples, we'll use LC filter.

Let's choose a cutoff frequency that is below the ripple frequency (as our switching frequency is 10kHz, choose fc=1kHz):

Inductor (L) Calculation

L = R/(2πfc)

L = 18Ω/(2π×1000Hz) ≈ 2.87mH

Capacitor (C) Calculation:

C = 1/(2πfcR)

C = 1/(2π×1000Hz×18Ω) ≈ 8.84µF

Output Current

$$I_{out} = \frac{V_{out}}{R} = \frac{5}{5} = 1\,\mathrm{A}$$

Input Power:

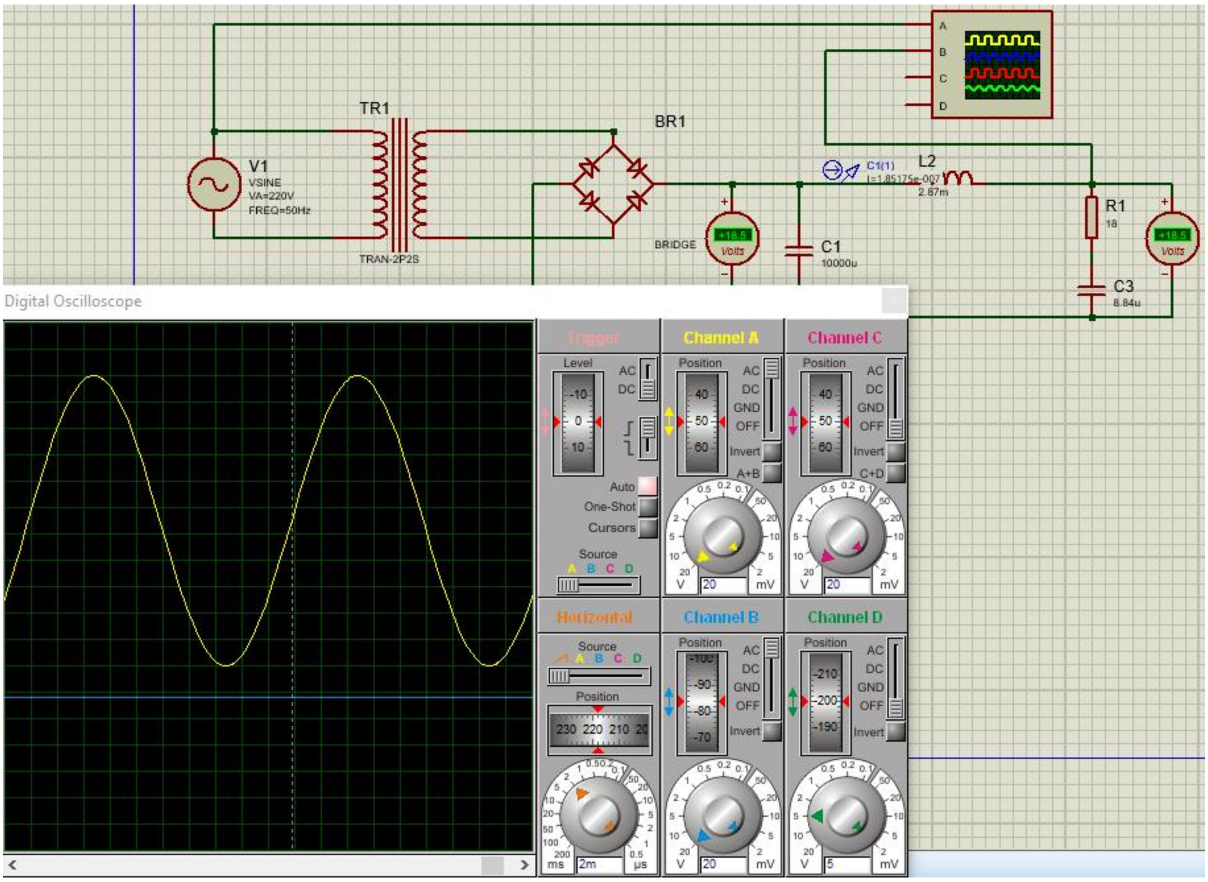
$$P_{in} = 220\,V \times 1.1\,A = 242\,W.$$

Output Power:

$$P_{out} = 18\,V \times 1\,A = 18\,W.$$

Efficiency:

$$\eta = \frac{P_{out}}{P_{in}} \times 100 = \frac{18}{242} \times 100 \approx 74.4\%.$$



	Ci	Li	Vac	Vdc	Iac	Idc	Efficiency
Calculated	8.84uF	2.87mH	220V	18V	1.1A	1A	74.4%
Measured	8.84uF	2.87mH	220V	18.0V	1.05A	0.98A	73%

Design a DC-DC converter:

1. Design a DC-DC converter to get an output voltage of 5V when input is 18V. Explain the reason of selection in proper words.

2. Use switching frequency of 10kHz for PWM signal.

3. For simplicity, start with the following assumptions, the power switching devices and the converter components are lossless such as Pin = Pout.

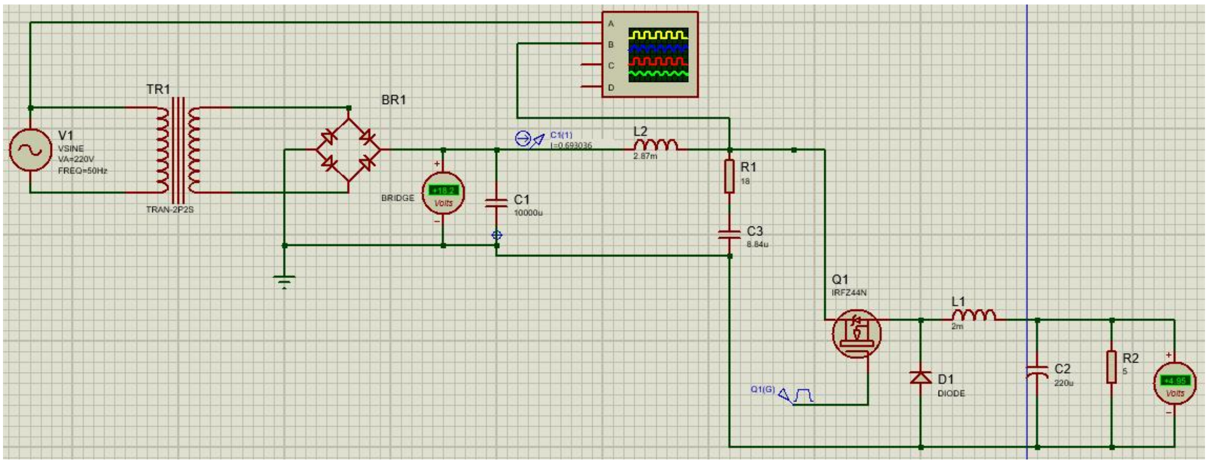
4. Calculate the ripple current in the inductor L

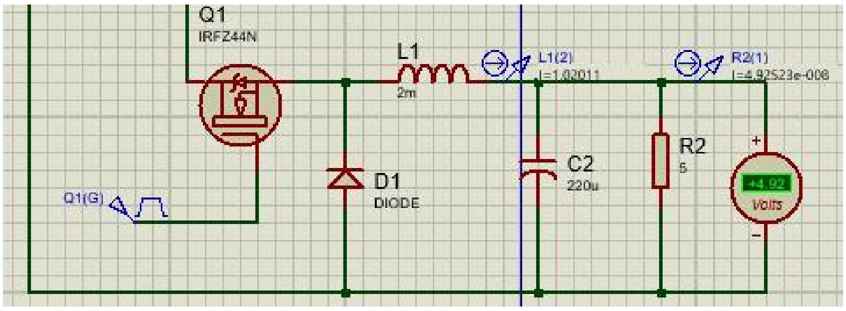
5. Calculate the transfer functions Vo/Vin and Io/Iin.

6. Calculate an approximate expression for the efficiency of the DC-DC converter.

7. Test and verify the output of DC-DC converter without assembling the rectifier at this stage (Use variable DC source as input).

Note: Use duty cycle as per your design.





A buck converter was chosen for the DC-DC conversion in this lab because it efficiently steps down the input voltage (18V) to a lower output voltage (5V) while maintaining high efficiency. The buck converter operates by using a switch (typically a transistor) to control the energy flow and store it in an inductor, thus providing a stable output with minimal power loss. It is particularly well-suited for applications where the input voltage is higher than the desired output voltage, making it ideal for this task of reducing 18V DC to 5V DC with minimal ripple and high efficiency, which is critical for ensuring the system's stability and performance.

- **Input Voltage**: Vin=18V
- **Output Voltage**: Vout=5V
- **Duty Cycle** (D):

$$D = \frac{V_{out}}{V_{in}} = \frac{5}{18} \approx 0.28$$

Switching Frequency: fs=10 kHz

Calculate the inductor value (L) to limit ripple current (ΔIL) to 20% of output current (Iout).

$$\Delta I_L = 0.2 \times I_{out} = 0.2 \times 1A = 0.2A$$

$$L = \frac{(V_{in} - V_{out}) \cdot D}{\Delta I_L \cdot f_s}$$

$$L = \frac{(18 - 5) \cdot 0.28}{0.2 \cdot 10,000} = \frac{13 \cdot 0.28}{2000} \approx 1.82\,\text{mH}$$

$L = 2\,\text{mH}.$

Calculate cappacitor value.

$$C = \frac{I_{out}}{8 \cdot f_s \cdot \Delta V}$$

Assume $\Delta V = 1\% \cdot V_{out} = 0.05V$:

$$C = \frac{1}{8 \cdot 10,000 \cdot 0.05} = \frac{1}{4000} = 250\,\mu F$$

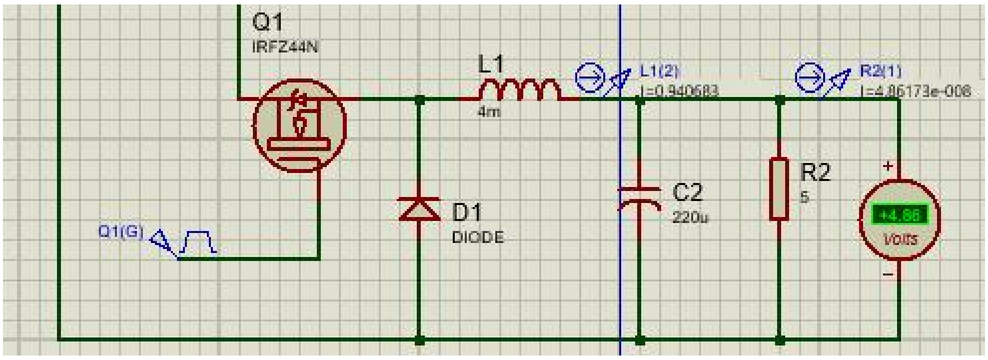
C = 220uF

And Resistive load R = 5ohm to draw 1A at 5V.

$$I_{\text{out}} = \frac{V_{\text{out}}}{R_{\text{load}}} = \frac{5}{5} = 1\,A$$

Duty Cycle	Output Voltage		Output Current		Inductor Current	
	Measured	Calculated	Measured	Calculated	Measured	Calculated
28%	4.92V	5V	0.98A	1A	0.14A	0.2A

If the inductor value is doubled, how would this affect the behavior of converter?



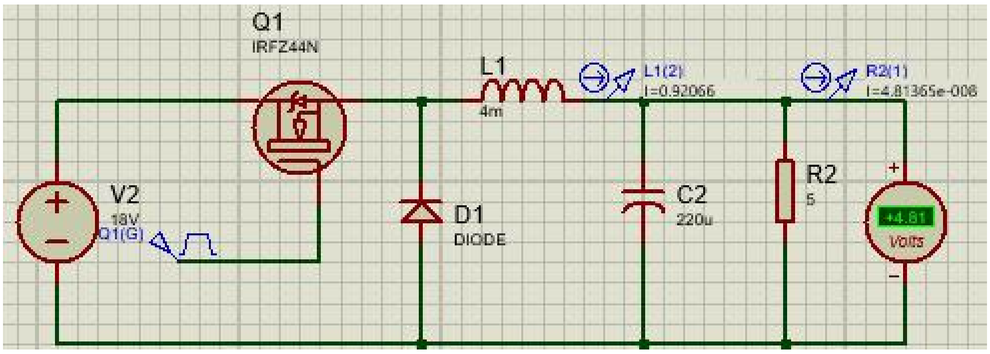
If the **inductor value is doubled**:

1. **Ripple Current** (ΔIL) decreases because:

$$\Delta I_L \propto \frac{1}{L}.$$

2. Smoother inductor current but **slower transient response**.

Test and verify the output of DC-DC converter without assembling the rectifier at this stage (Use variable DC source as input)



Voltage Transfer Function (Vo/Vin):

The output voltage V_o is related to the input voltage V_{in} and the duty cycle D as:

$$\frac{V_o}{V_{in}} = D$$

Using $V_o = 5\,V$ and $V_{in} = 18\,V$:

Now, calculating current transfer function

Substituting $V_{in} = 18\,V$ and $V_o = 5\,V$:

$$\frac{I_o}{I_{in}} = \frac{18}{5} = 3.6$$

Now, calculating efficiency

Efficiency η is given by:

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

Output power $P_{out} = V_o I_o = 5\,V \times 0.98\,A = 4.9\,W$.

Input power $P_{in} = V_{in} I_{in} = 18\,V \times 1.05\,A = 18.9\,W$.

$$\eta = \frac{4.9}{18.9} \times 100 \approx 73\%$$

<u>Questions:</u>

How single phase and half wave rectification are different from each other?

In half-wave rectification, only one half-cycle of the AC input (positive or negative) is used, while the other half is blocked, resulting in higher ripple content and lower efficiency. A single diode is used, and the output voltage is lower. In contrast, full-wave rectification uses both half-cycles of the AC input, providing smoother output, higher efficiency, and better utilization of the AC input.

What will be the difference in efficiency if only capacitance is connected as filter to rectifier instead of LC?

A capacitor-only filter reduces ripples by charging and discharging but cannot fully suppress harmonics, resulting in higher ripple voltage and lower efficiency under load. An LC filter (inductor and capacitor) smooths the current and voltage more effectively, providing a cleaner and more stable DC output, reducing ripples, and significantly improving efficiency.

Conclusion:

In this, a full-wave rectifier was designed with an LC filter to reduce ripple and provide a stable 18V DC output, achieving a measured efficiency of 73%. The DC-DC buck converter, stepping down the voltage from 18V to 5V with a duty cycle of 28%, demonstrated an efficiency of 73%. The use of an LC filter was more effective than a capacitor-only filter in minimizing ripples and improving efficiency. The design also showed that increasing the inductor value decreased ripple current but slowed transient response. The transfer functions for voltage and current were calculated, confirming the relationship between input and output, with the LC filter ensuring a cleaner DC output and higher efficiency.