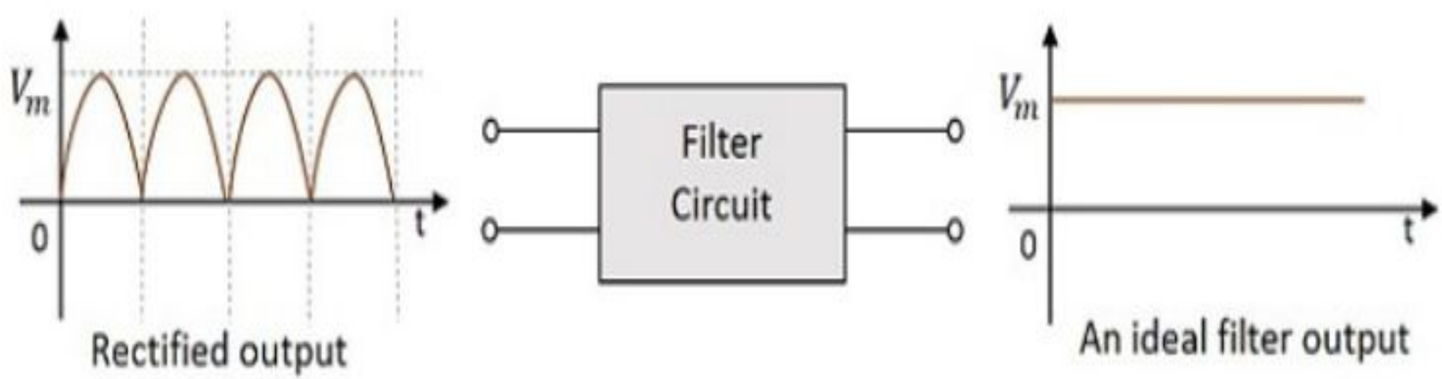
UNIT II

FILTERS

Filters

- The output of a rectifier contains dc component as well as ac component. (Ripple)
- This ac component has to be completely removed in order to get pure dc output.
- So, we need a circuit that **smoothens** the rectified output into a pure dc signal.
- A **filter circuit** is one which removes the ac component present in the rectified output and allows the dc component to reach the load.

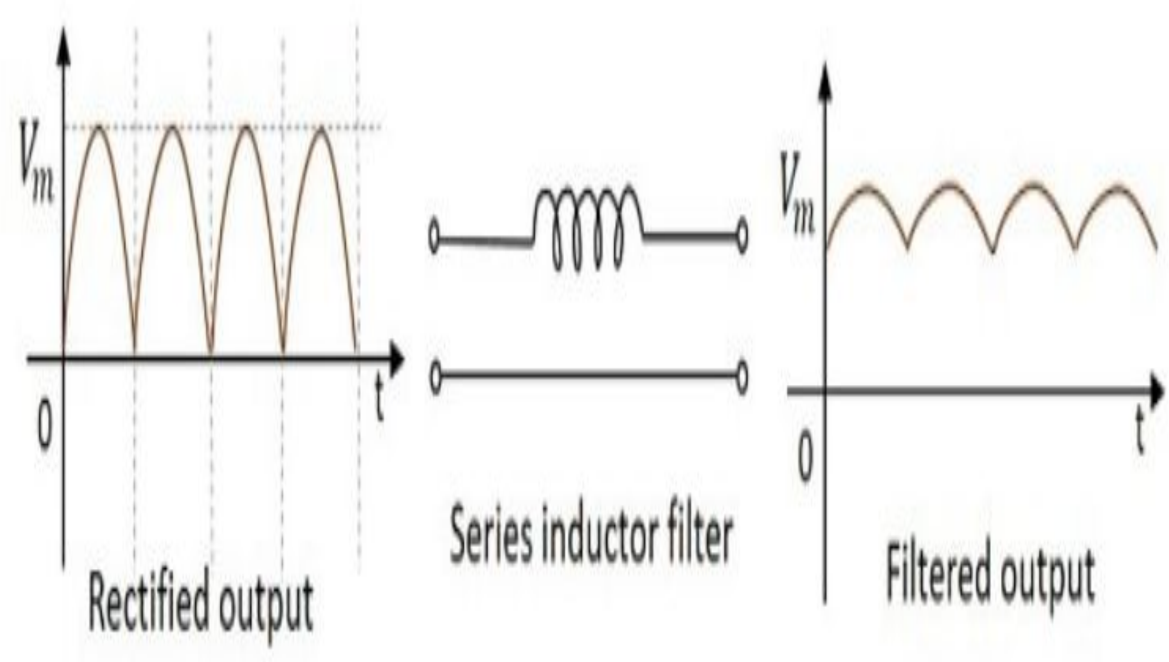


- A filter circuit is constructed using two main components, inductor and capacitor.
  - An inductor allows **dc** and blocks **ac**.
  - A capacitor allows **ac** and blocks **dc**.

- Some important filters are:
  - Inductor filter
  - Capacitor filter
  - LC or L section filter
  - CLC or Π-type filter

Series Inductor Filter

- **Series Inductor Filter** can be constructed by connecting the inductor in series, between the rectifier and the load.
- The rectified output when passed through inductor filter, blocks the ac components that are present in the signal, in order to provide a pure dc.



- The inductor carries the property of opposing the change in current that flows through it.
- The inductor offers high impedance to the ripples and no impedance to the desired dc components.
- When the rectifier output current increases above a certain value, energy is stored in it in the form of a magnetic field and this energy is given up when the output current falls below the average value.
- The choke offers high impedance to the ac components but offers almost zero resistance to the desired dc components. Thus ripples are removed to a large extent.

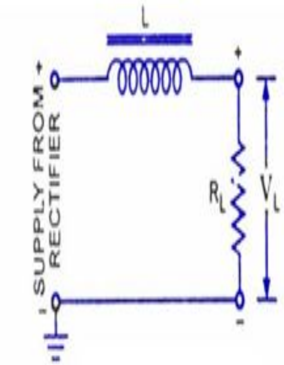
• Full-Wave Rectifier with Series Inductor filter

- By placing a choke coil in series with the rectifier output and load, any sudden change in current that might have occurred in the circuit without an inductor is smoothed out by the presence of the inductor L.
- From the circuit, for zero frequency dc voltage, the choke resistance R_i in series with the load resistance R_L forms a voltage divider circuit, and thus the dc voltage across the load is

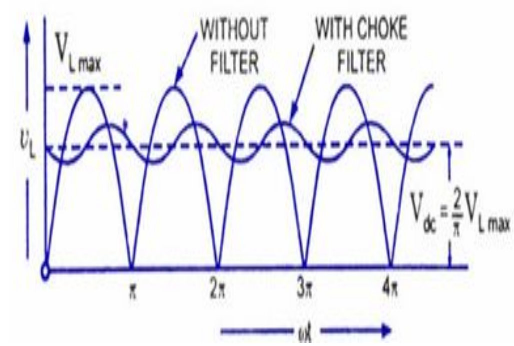
$$\mathbf{V_{dc} = R_L/(R_i + R_L)}$$

  – V_{dc} is the output from a full wave rectifier.
  – In this case, the value of R_i is negligibly small when compared to R_L.

Full Wave Rectifier with Series Inductor Filter

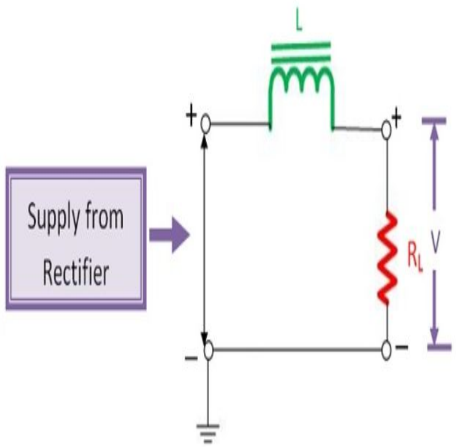


Circuit Diagram



- The effect of higher harmonic voltages can be easily neglected as better filtering for the higher harmonic components take place.
- This is because of the fact that with the increase in frequency, the reactance of the inductor also increases.
- It should be noted that a decrease in the value of load resistance or an increase in the value of load current will decrease the amount of ripples in the circuit.
- So, the series inductor filter is mostly used in cases of high load current or small load resistance.

Output DC voltage and Ripple factor



- Let the voltage across load resistor R_L be V_L.
- Thus, the value of V_L is

$$V_L = V_{dc} \times \frac{R_L}{R_L + R_C} = \frac{V_{dc}}{1 + \frac{R_C}{R_L}}$$

  – Where V_{dc} is the DC output voltage output of full wave rectifier, and R_c is the resistance of inductor coil.
- Expanding the term of V_L with the help of Fourier series we get

$$v_L = V_{Lmax}\left(\frac{2}{\pi} - \frac{4}{3\pi}cos2\omega t - \frac{4}{15\pi}cos4\omega t - \ldots\ldots\ldots\ldots\right)$$

- The value of resistance of inductor coil is much less than the value of resistance of load resistor.
- Thus, the entire DC voltage will appear across the load resistor and the value of DC voltage across R_L will be equal

- The reactance of inductor coil or choke coil increases with the increase of frequency thus at higher frequencies the voltage will be negligible.
- Thus, the AC … ed s … second harmonics only i…

$$V_{ac\,max} = \frac{4}{3\pi} V_{Lmax} \frac{R_L}{\sqrt{R_L^2 + X_L^2}} \qquad V_{ac\,rms} = \frac{4}{3\pi\sqrt{2}} V_{Lmax} \frac{R_L}{\sqrt{X_L^2 + R_L^2}}$$

$$\text{Ripple Factor, } \gamma = \frac{V_{ac\,rms}}{V_{dc}} = \frac{\frac{4}{3\pi\sqrt{2}} V_{L\,max} \frac{R_L}{\sqrt{X_L^2 + R_L^2}}}{\frac{2}{\pi} V_{L\,max}} = \frac{R_L\sqrt{2}}{3\sqrt{X_L^2 + R_L^2}} = \frac{\sqrt{2}}{3\sqrt{1 + \frac{X_L^2}{R_L^2}}}$$

Since $X_L = 2\omega L$, beacaue frequency is double in Full wave rectifier as compared to half wave rectifier.

$$\boxed{\gamma = \frac{\sqrt{2}}{3\sqrt{1 + \frac{4\omega^2 L^2}{R_L^2}}}} \qquad \boxed{\text{If } 2\omega L >> R_L, \quad \gamma = \frac{\sqrt{2}\, R_L}{3 \times 2\omega L}}$$

- When the value of load resistance is infinite, … tput circuit will behave as an open circuit, in this ca… ctor can be given by

$$\boxed{\gamma = \frac{\sqrt{2}}{3} = 0.471}$$

Problems

1. A dc voltage of 380V with a peak ripple voltage not exceeding 7V is required to supply a 500Ω load. Find out the inductance required.

Given the ripple voltage is 7V. So,

$7=1.414V_{RMS}$

$\Upsilon=V_{RMS}/V_{DC}=4.95/380=0.0130.$

$\Upsilon=1/3\sqrt{2}(R_L/L_\omega)$

So, L=28.8henry.

2. A full wave rectifier with a load resistance of 5KΩ uses an inductor filter of 15henry. The peak value of applied voltage is 250V and the frequency is 50 cycles per second. Calculate the ripple factor .

$\Upsilon=I_{AC}/I_{DC}$,

$I_{AC}=2\sqrt{2}V_m/3\pi(R_L{}^2+4\omega^2{}_L{}^2)^{1/2}$

By putting the values, I_{AC}=4.24Ma.

$V_{DC}=2V_m/\pi$,

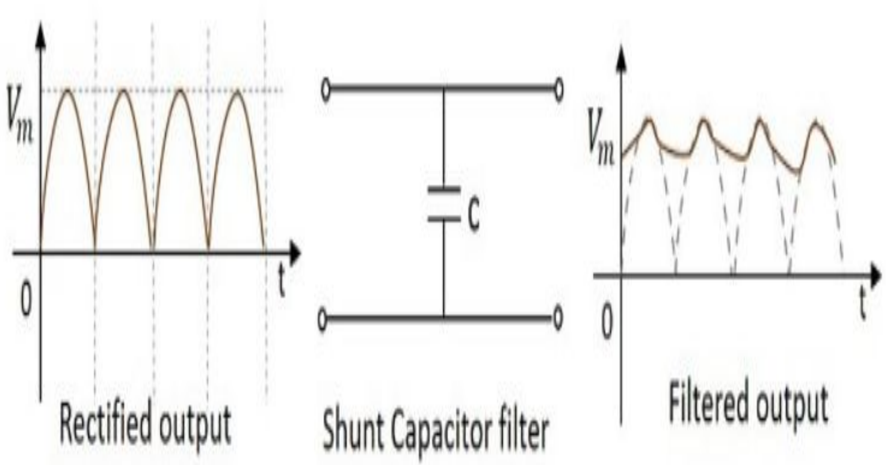
$I_{DC}=V_{DC}/R_L=2V_m/R_L\ \pi$

$I_{DC}=2*250/(3.14*15*10^3)=10.6mA.$

$\Upsilon=4.24/10.6=0.4.$

Shunt Capacitor Filter

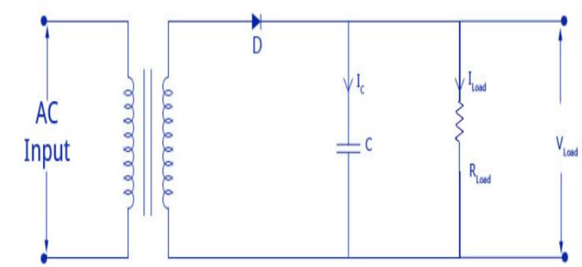
- **Shunt Capacitor Filter** can be constructed using a capacitor, connected in shunt.
- The rectified output when passed through this filter, the ac components present in the signal are grounded through the capacitor which allows ac components.
- The remaining dc components present in the signal are collected at the output.

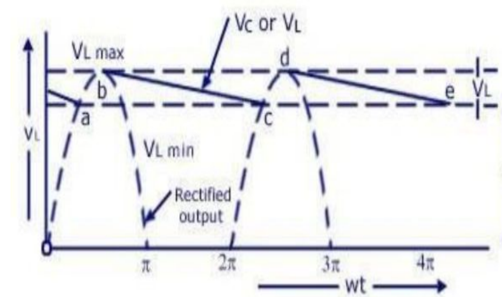


Half-wave Rectifier with Capacitor Filter

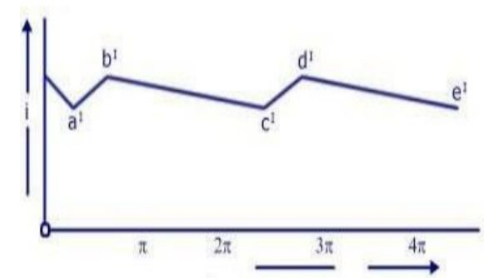
- The filter is applied across the load R_{load}.
- The output of the R_{Load} is V_{Load},
- The current through it is I_{Load}.
- The current through the capacitor is I_c.
- During the positive half cycle of the input ac voltage, the diode D will be forward biased and thus starts conducting. During this period, the capacitor ‘C’ starts charging to the maximum value of the supply voltage V_s.
- When the capacitor is fully charged, it holds the charge until the input ac supply to the rectifier reaches the negative half cycle. As soon as the negative half supply is reached, the diode gets reverse biased and thus stops conducting.

Half wave Rectifier with Capacitor Filter





Rectified and filtered Output Voltage Waveform

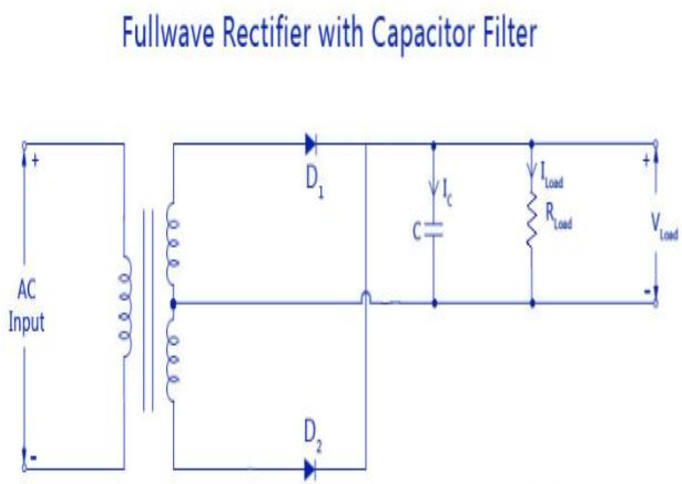


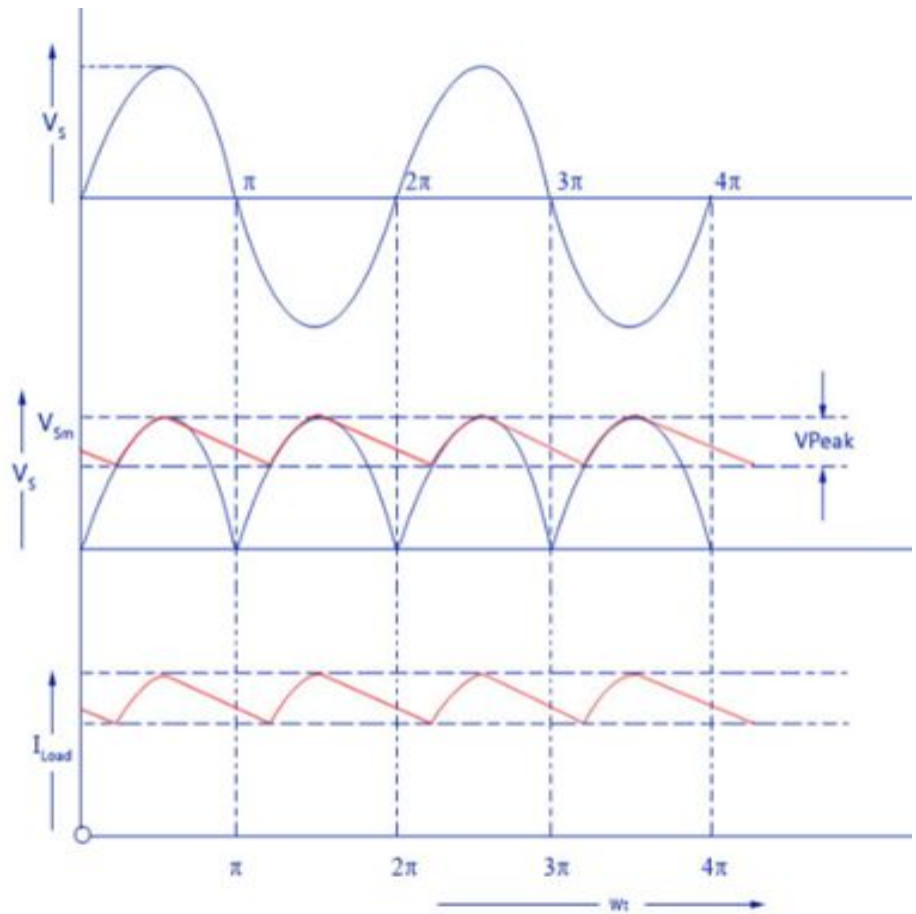
Load Current Waveform
Half-wave Rectifier With Shunt Capacitor Filter

- During the non-conducting period, the capacitor ‘C’ discharges all the stored charges through the output load resistance R_{Load}.
- As the voltage across R_{Load} and the voltage across the capacitor ‘C’ are the same ($V_{Load} = V_c$), they decrease exponentially with a time constant ($C*R_{Load}$) along the curve of the non-conducting period.

Full-wave Rectifier with Shunt Capacitor Filter

- Two pulses of current will charge the capacitor during alternate positive (D1) and negative (D2) half cycles.
- Similarly capacitor C discharges twice through R_{Load} during one full cycle.





- # Ripple factor

Let V_r be the ripple component of voltage, and V_{dc} is the DC value of Voltage and voltage across the load resistor R_L be $V_{L\,max.}$

$$V_{dc} = V_{Lmax} - \frac{V_r}{2}$$

Let the charging duration be T1, and discharging duration be T2. Then, total charge lost during non-conduction or discharge will be given as:-

The value of charge **Q = CV$_r$.**

In steady state, $Q_{Charge} = Q_{discharge}$

$$CV_r = I_{dc}T_2$$

$$V_r = \frac{I_{dc}T_2}{C}$$

Considering T1 <<< T2,

$$T_2 = T = \frac{1}{f}$$

In case of Full wave rectifier,

$$T_2 = \frac{T}{2} = \frac{1}{2f}$$

$$V_r = \frac{I_{dc}}{2fC}$$

$$V_{dc} = V_{L\,max} - \frac{V_r}{2} = V_{L\,max} - \frac{I_{dc}}{4fC}$$

$$V_{ac\,rms} = \frac{V_r}{2\sqrt{3}}$$

Thus, ripple factor in this case will be $\gamma = \dfrac{V_{ac\,rms}}{V_{dc}} = \dfrac{V_r}{I_{dc}R_L 2\sqrt{3}} = \dfrac{1}{CfR_L 4\sqrt{3}}$

1. A half wave rectifier, operated from a 50Hz supply uses a 1000µF capacitance connected in parallel to the load of rectifier. What will be the minimum value of load resistance that can be connected across the capacitor if the ripple% not exceeds 5?

For a half wave filter,

$\Upsilon=1/2\sqrt{3}\ fCR_L=1/2\sqrt{3}*50*10^{-3}*R_L$

$R_L=10^3/5\sqrt{3}=115.47\Omega$.

2. A 100µF capacitor when used as a filter has 15V ac across it with a load resistor of 2.5KΩ. If the filter is the full wave and supply frequency is 50Hz, what is the percentage of ripple frequency in the output?

For a full wave rectifier, $\Upsilon=1/4\sqrt{3}\ fCR_L$

$=1/4\sqrt{3}*50*10^{-3}*2.5$

$=0.01154$. So, ripple is 1.154%.

3. A full wave rectifier uses a capacitor filter with 500µF capacitor and provides a load current of 200mA at 8% ripple. Calculate the dc voltage.

The ripple factor $\Upsilon=I_L/\ 4\sqrt{3}\ fCV_{DC}$

$V_{DC}=200*10^{-3}/\ 4\sqrt{3}\ *50*500*8$

$=14.43$.

4. A shunt capacitor of value 500μF fed rectifier circuit. The dc voltage is 14.43V. The dc current flowing is 200mA. It is operating at a frequency of 50Hz. What will be the value of peak rectified voltage?

We know, $V_m = V_{dc} + I_{dc}/4fC$

$= 14.43 + \{200/(200*500)\}\ 10^3$

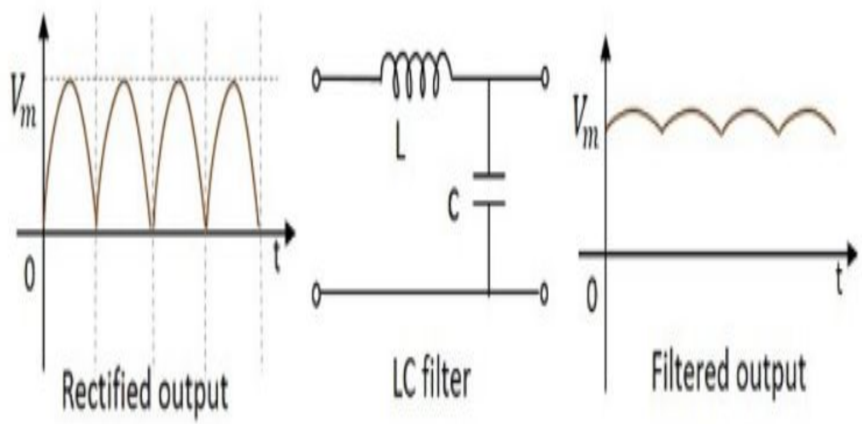
$= 14.43 + 2 = 16.43V.$

Combinational filters

- A simple series inductor filter
  - reduces both the peak and effective values of the output current and output voltage
  - ripple factor increases with the increase in load resistance R_L
- A simple shunt capacitor filter
  - reduces the ripple voltage but increases the diode current
  - Ripple factor varies inversely with load resistance R_L
- The diode may get damaged due to large current and at the same time it causes greater heating of supply transformer resulting in reduced efficiency
- By using combination of inductor and capacitor
  - ripple factor can be lowered
  - diode current can be restricted
  - ripple factor can be made almost independent of load resistance (or load current).
- Two types of most commonly used combinations are

L-C Filter

- A filter circuit can be constructed using both inductor and capacitor in order to obtain a better output where the efficiencies of both inductor and capacitor can be used.
- This filter is also called as a **Choke Input Filter** as the input signal first enters the inductor.
- Choke-input filter consists of a choke L connected in series with the rectifier and a capacitor C connected across the load .
- This is also sometimes called the L-section filter because in this arrangement inductor and capacitor are connected, as an inverted L.



- The choke L on the input side of the filter readily allows dc to pass but opposes the flow of ac components because its dc resistance is negligibly small but ac impedance is large.
- Any fluctuation that remains in the current even after passing through the choke are largely by-passed around the load by the shunt capacitor because X_c is much smaller than R_L.
- Ripples can be reduced effectively by making X_L greater than X_c at ripple frequency.
- However, a small ripple still remains in the filtered output and this is considered negligible if it than 1%.

Characteristics of Choke filter or L-section filter

Regulation: The variation of DC output voltage from rectifier with respect to the DC flowing through load resistor of the rectifier circuit is termed as regulation.

Output Voltage of Rectifier $v_L = \frac{2}{\pi} V_{L\,max} - \frac{4}{3\pi} V_{L\,max} \cos 2\omega t$

Considering that the inductor's reactance is negligible in comparison to load resistance

$$V_{dc} = \frac{2}{\pi} V_{L\,max}$$

If R_C is the choke resistance, then

$$V_{dc} = \frac{2}{\pi} V_{L\,max} - I_{dc} R_C$$

Ripple factor

- The most effective way to minimize the ripple factor is to increase the value of inductive reactance.
- The combined reactance of load resistor and capacitor can be minimized up to a large extent by using the capacitor of low reactance so that the complete AC signal get bypassed through the capacitor and regulated DC voltage can be obtained across the load resistor.
- In these conditions, the net impedance will be due to inductor

$$I_{ac\,rms} = \frac{4V_{L\,max}}{3\pi\sqrt{2}\,X_L} = \frac{\sqrt{2}}{3}\frac{V_{dc}}{X_L}$$

AC Voltage across the load (the ripple voltage) is equal to voltage across the capacitor. Thus,

$$V_{ac\,rms} = I_{ac\,rms}X_c = \frac{\sqrt{2}}{3}V_{dc}\frac{X_C}{X_L}$$

Where, $X_c = \frac{1}{2\omega C}$ *is the reactance of the capacitor at the second harmonic frequency.*

$$\text{Ripple factor, } \gamma = \frac{V_{ac\,rms}}{V_{dc}} = \frac{\sqrt{2}}{3}\frac{X_C}{X_L} = \frac{\sqrt{2}}{3}\frac{1}{2\omega C}\frac{1}{2\omega L} = \frac{1}{6\omega^2 LC\sqrt{2}}$$

Advantages of Choke Filter or L-section Filter

1. It provides better voltage regulation.
2. The ripple factor can be varied according to the need.

Disadvantages of Choke Filter or L-Section filter

1. Bulky Size: These kinds of filters were popular in ancient time but it has become obsolete now due to bulky size of inductors and capacitors.
2. Not suitable for low voltage power Supplies: These are not suitable for low voltage power supplies. IC regulators or active filters are used in such devices.

Problems

1. An L section filter with L=2henry and C= 49µF is used in the output of a full wave single phase rectifier that is fed from a 40-0-40 V peak transformer. The load current is 0.2A. Calculate the output dc voltage. Given, V_L= 40V.

$V_{DC}=2/\pi*V_L=2/\pi*40=25.46V$.

2. Calculate LC for a full wave rectifier which provides 10V dc at 100mA with a maximum ripple of 2%. Input ac frequency is 50Hz.

$LC=1/6\sqrt{2}\omega^2\Upsilon$

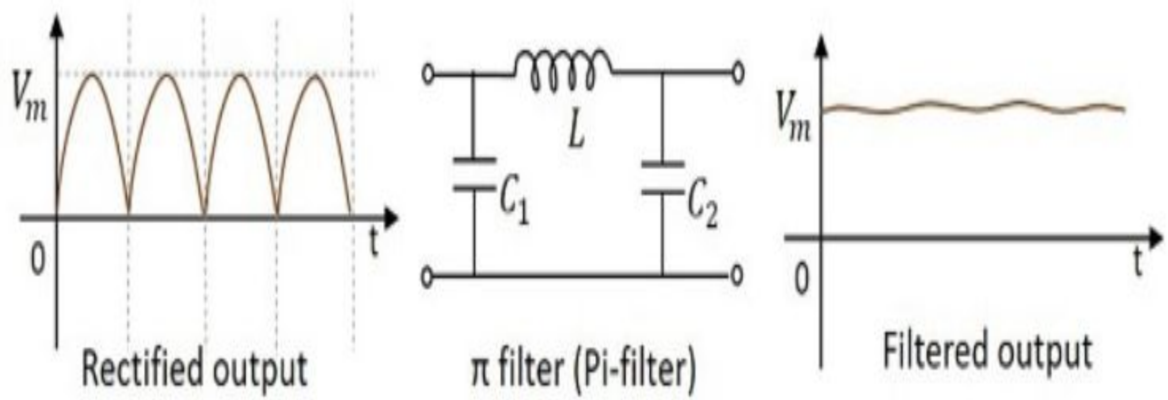
$\omega=2\pi f=314$

By putting the values,

$LC=1/6\sqrt{2}(314)^2\ 0.02=40*10^{-6}$.

Π- Filter(Pi filter)

- It has capacitor at its input and hence it is also called as a **Capacitor Input Filter**.
- Here, two capacitors and one inductor are connected in the form of π shaped network.
- A capacitor in parallel, then an inductor in series, followed by another capacitor in parallel makes this circuit



- **Capacitor C_1** − This filter capacitor offers high reactance to dc and low reactance to ac signal. After grounding the ac components present in the signal, the signal passes to the inductor for further filtration.
- **Inductor L** − This inductor offers low reactance to dc components, while blocking the ac components if any got managed to pass, through the capacitor C_1.
- **Capacitor C_2** − Now the signal is further smoothened using this capacitor so that it allows any ac component present in the signal, which the inductor has failed to block.
- Thus we, get the desired pure dc output at the load.

$$V_r = \frac{I_{dc}}{2fC}$$

In the case of Pi filter $C = C_1$

$$V_{ac\,rms} = \frac{V_r}{\pi\sqrt{2}} = \frac{1}{\pi\sqrt{2}}\frac{I_{dc}}{2fC_1} = I_{dc}X_{C1}\sqrt{2}$$

$$X_{C1} = \frac{1}{2\omega C_1} = \frac{1}{4\pi f C_1}$$ *reactance of input capacitor* C_1 *at second harmonic frequency.*

Now $V_{ac\,rms}$ *is applied to L – section so the ripple voltage can be obtained by multiplying* X_{C2}/X_L *i.e.*

$$V'_{ac\,rms} = V_{ac\,rms} \times \frac{X_{C2}}{X_L} = \sqrt{2}I_{dc}X_{C1} \times \frac{X_{C2}}{X_L}$$

Now the ripple factor,

$$\gamma = \frac{V'_{ac\,rms}}{V_{dc}} = \frac{I_{dc}X_{C1}X_{C2}\sqrt{2}}{V_{dc}X_L} = \frac{I_{dc}X_{C1}X_{C2}\sqrt{2}}{I_{dc}R_LX_L} = \frac{X_{C1}X_{C2}\sqrt{2}}{R_LX_L}$$

$$\gamma = \frac{\sqrt{2}}{R_L}\frac{1}{2\omega C_1}\frac{1}{2\omega C_2}\frac{1}{2\omega L} = \frac{\sqrt{2}}{8\omega^3 C_1C_2LR_L}$$

Advantages

1. **High Output Voltage:** Pi filter's offers low voltage drop across choke coil and capacitor C_2 in order to main high output voltage across its output terminals.
2. **Low Ripple factor:** Due to two capacitors in addition with one inductor it provides improved filtering action. This leads to decrement in ripple factor.
3. **High PIV:** The peak inverse voltage in the case of Pi filters is more in comparison to L-section filter.

Disadvantage

Poor Voltage Regulation: Capacitor is not suitable for varying loads. In an application where load current varies, pi filters are not suitable. Thus, in such application, we can use L-section filters as its output voltage do not vary largely with load current.

Application of Pi filter (π- filter)

These are used in communication devices for retrieving the particular signal after modulation.

In transmission, the signal is modulated into multiples of high frequency. While on the receiver side, filters are used to

1. A single phase full wave rectifier makes use of pi section filter with 10μF capacitors and a choke of 10henry. The secondary voltage is 280V and the load current is 100mA. Determine the dc output voltage when f=50Hz.

Given, V_{RMS}=280V

So, V¬m = 1.414*280=396V.

From theory of capacitor filter, V_{DC} =

$V_m - I_{DC}/4fC = 396 - 0.1/(4*50*10*10^{-6}) = 346V$.

2. For a given CLC filter, the operating frequency is 50Hz and 10μF capacitors used. The load resistance is 3460Ω with an inductance of 10henry. Calculate the ripple factor.

We have, $\Upsilon = 5700 / (LC_1C_2R_L)$

$= 5700 / (10*100*10^{-12}*3460)$

=0.165%.