CHAPTER 3:

RECTIFIERS AND FILTERS

(MARKS = 16)

3.1 Rectifiers

- *Need of rectifiers. Types of rectifiers:*
- *HWR,FWR (bridge and centre tap) circuit operation I/O waveforms for voltage & current*
- *Parameters of rectifier (without derivation) Average DC value of current &voltage, ripple factor, ripple frequency, PIV of diode, TUF, efficiency of rectifier.*
- *Comparison of three types of rectifiers*

3.2 Filters

- *Need of filters*
- *Circuit diagrams, operation and input-output waveforms of following types of filters.*

1. *Shunt capacitor*
2. *Series inductor*
3. *LC filter*
4. *π filter*

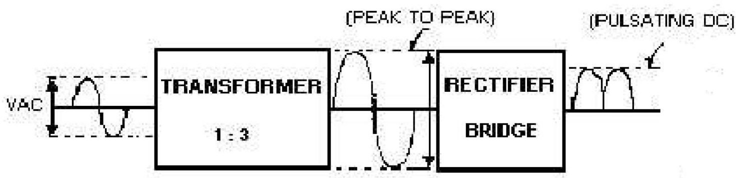
Numerical examples based on parameters of rectifier.

MR. NIKHIL S.

Rectifiers:

A Rectifier is a circuit which uses one or more diodes to convert A.C. voltage into pulsating D.C. voltage.

Block Diagram of Rectifier:



- A step down transformer is used to reduce the AC mains voltage to an small value.
- This voltage is converted into pulsating DC voltage by the rectifier.

Need of Rectifier:

- The DC power supply is essential for the operation of many electronic devices and circuits.
- This DC voltages has to be obtained from the AC supply.
- This DC supply is obtained from the rectifier.

Classification of Rectifier circuits:

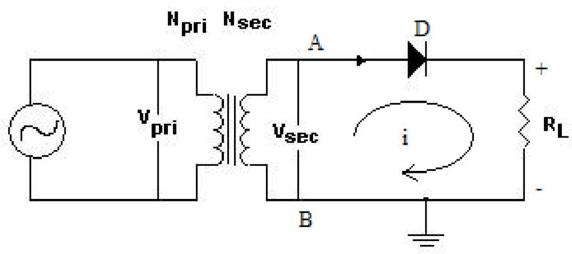
Rectifier circuits

- Half wave Rectifier (HWR)
- Full wave Rectifier (FWR)
  - FWR with center tapped transformer
  - Full wave bridge rectifier

Half Wave Rectifier (HWR):

- In half-wave rectification, the rectifier conducts current only during the positive half-cycle of input A.C. supply.
- The negative half-cycles of A.C. supply are suppressed i.e. during negative half-cycles no current is conducted and hence no voltage appears across the load.
- Therefore, current always flows in one direction (i.e. DC) through the load after one half-cycle.

Circuit Diagram:



- Fig. above shows the circuit where a single crystal diode acts as a half-wave rectifier.
- The AC supply to be rectified is applied in series with the diode and load resistance (R_L).
- A.C. supply is given through transformer which step up or step down the AC voltage as the situation demands.
- Transformer isolates the rectifier circuit from power line and thus reduces the risk of electric shock.

Operation:

1. In positive half cycle (0 - Π):

- During the positive half-cycle of input AC voltage, end A becomes positive w.r.t. end B.
- This makes diode forward biased and hence it conducts current. The current flows through the path

$\boxed{A - D - R_L - B}$

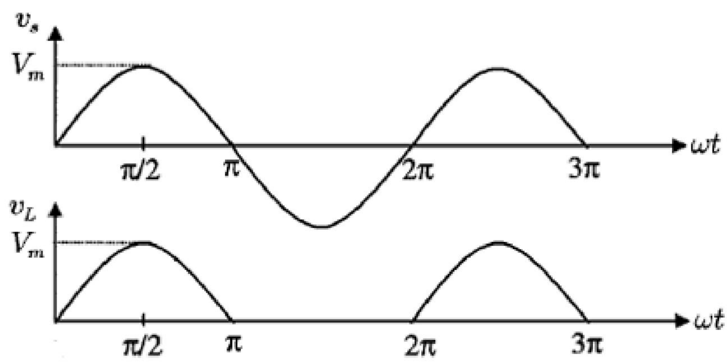
- This current makes voltage drop across the load current with polarities as shown in the fig above.
- This produces load voltage waveform and load current waveform same as input AC supply as shown in the waveforms.

2. <u>In negative half cycle (Π - 2Π):</u>

- During the negative half cycle, end A is negative w.r.t end B.
- Under this condition, the diode is reverse biased and it conducts no current and acts as a open circuit.
- Therefore there is no voltage and current through the load and it is zero.
- The waveform for negative half cycle is shown in waveforms

Therefore, current flows through the diode during positive half-cycle of input AC voltage only; it is blocked during negative half cycle.

<u>HWR waveforms:</u>



<u>Parameters of HWR:</u>

1. <u>DC or Average Load current (I_{LDC}):</u>

The average value of a periodic function is given by the area under one cycle of the function divided by the base(period).

$$Im = \frac{Vm}{R_S + R_F + R_L}$$

Im = Peak amplitude of load current.

R_F = Diode forward Resistance.

R_S = Transformer secondary resistance.

V_m = Maximum or peak secondary voltage.

2. DC or Average Load Voltage (V_{LDC}):

$V_{LDC} = I_{LDC} \times R_L$

$V_{LDC} = \frac{Vm}{\Pi}$

3. A.C. or RMS load current (I_{Lrms}):

$I_{Lrms} = \frac{Im}{2}$

4. A.C. or RMS load Voltage (V_{Lrms}):

$V_{Lrms} = \frac{Vm}{2}$

5. Ripple Factor:

$$\text{Ripple Factor(r)} = \frac{\text{RMS value of the AC component of output}}{\text{DC or average value of the output}}$$

r = 1.21 or 121%

6. Rectification Efficiency or Power Conversion Efficiency:

Rectification efficiency is defined as,

$$\eta = \frac{\text{DC output power}}{\text{AC input power}} = P_{LDC} / P_{ac}$$

7. Transformer Utilization Factor (TUF):

It is defined as the ratio of DC output power to the AC power ratings of the transformer is being utilized.

$$TUF = \frac{\text{DC output power}}{\text{AC power rating of the transformer}}$$

TUF = 0.287 or 28.7 %

8. Peak Inverse Voltage (PIV):

This is the maximum negative voltage which appears across a non-conducting reverse biased diode.

PIV = Vm (Volts)

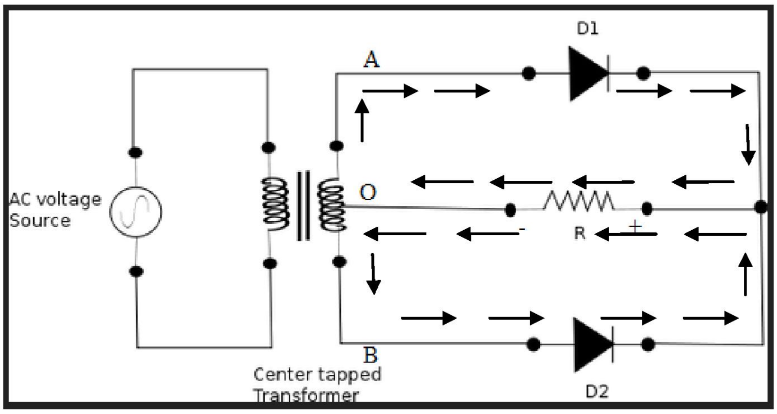
9. Ripple Frequency:

It is the frequency of the pulsating load voltage waveform. For the half wave rectifier, ripple frequency is 50Hz.

Full wave Rectifier with Center tapped transformer(FWR):

- In full wave rectification, the rectifier conducts in both the cycles as two diodes are connected.

Circuit diagram:



- The circuit employs two diodes D1 and D2 as shown. A center tapped secondary winding AB is used with two diodes connected. So that each uses one half –cycles of input AC voltage.
- Diode D1 utilized the AC voltage appearing across the upper half (OA), while diode D2 uses the lower half winding (OB).

Operation:

1. In positive half cycle (0-Π).

- The end A of the secondary winding becomes positive and end B negative.
- This makes diode D1 forward biased and diode D2 reverse biased. Therefore D1 conducts while D2 does not.
- The conventional current flow direction in the upper half winding as shown in the fig above.

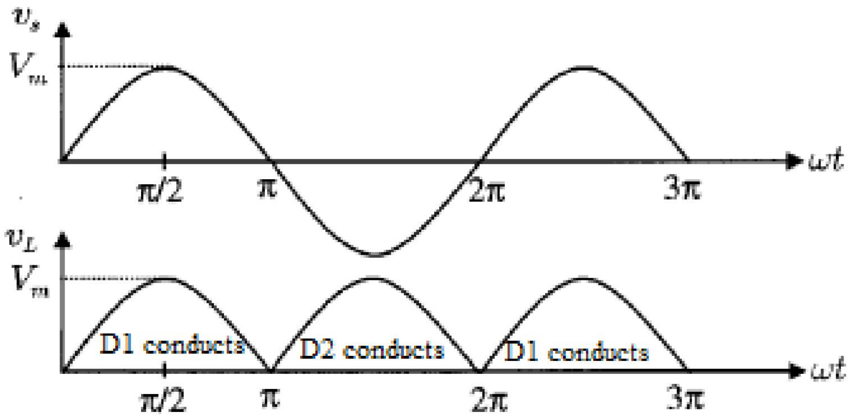
  A – D1 – R_L – O

2. In negative half cycle (Π-2Π):

- End A of secondary winding becomes negative and end B positive. Therefore diode D2 conducts while diode D1 does not.
- The conventional current flow is from as shown by the arrows in the above fig.

  B – D2 – R_L – O

- From fig. current in the load R_L is in the same direction for both half-cycles of input AC voltage. Therefore DC is obtained across the load R_L.



Parameters of FWR center tapped:

1. DC or Average Load current (I_{LDC}):

The average value of a periodic function is given by the area under one cycle of the function divided by the base (period).

$$Im = \frac{Vm}{R_S + R_F + R_L}$$

Im = Peak amplitude of load current.

R_F = Diode forward Resistance.

R_S = Transformer secondary resistance.

V_m = Maximum or peak secondary voltage.

2. <u>DC or Average Load Voltage (V_{LDC}):</u>

$V_{LDC} = I_{LDC} \times R_L$

$V_{LDC} = \frac{2Vm}{\Pi}$.

3. <u>A.C. or RMS load current (I_{Lrms}):</u>

   $I_{Lrms} = \frac{Im}{\sqrt{2}}$

4. <u>A.C. or RMS load Voltage (V_{Lrms}):</u>

   $V_{Lrms} = \frac{Vm}{\sqrt{2}}$

5. Ripple Factor (r)
   r = 0.48 or 48%
6. <u>Ripple Efficiency :</u>

   $\eta = 8 R_L / (\Pi^2(R_S + R_F + R_L))$

7. <u>Peak Inverse Voltage:</u>

   PIV = 2 Vm Volts

8. <u>Ripple frequency:</u>

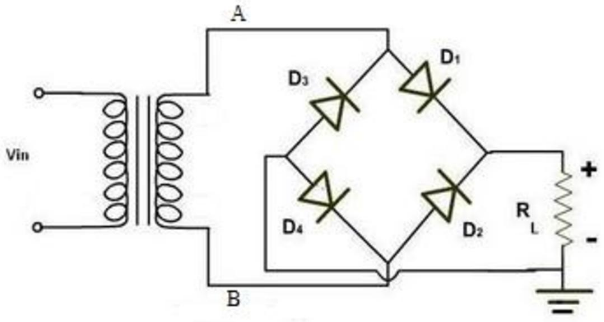
The ripple frequency if FWR is twice that of the HWR i.e. 100Hz.

MR. NIKHIL S.

3. **Full wave Bridge Rectifier:**

- The need of center tapped power transformer is eliminated in the bridge rectifier.
- It contains four diodes D1, D2, D3and D4 connected to form bridge as shown in the fig. below.
- The A.C. supply to be rectified is applied to the diagonally opposite ends of the bridge through the transformer.
- Between other two ends of bridge the load resistance, R_L is connected.

Circuit Diagram:



Operation:

1. In positive half cycle (0 to Π):

- The end A of the secondary winding becomes positive and end B negative.
- This makes diode D1 and D4 forward biased while diode D2 and D3 are reverse biased.
- These two diodes will be in series through the load R_L. The conventional current direction is as follows.

A – D1 – R_L – D4 – B

- This makes load voltage polarities as shown in the fig above.

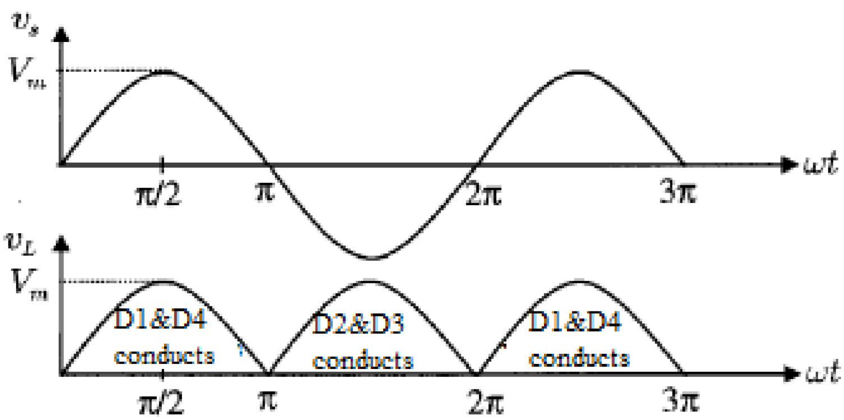
2. In negative half cycle (Π to 2Π).

- The end B is positive and A is negative. This makes diode D2 and D3 forward biased and diode D1 and D4 is reverse biased.

- The conventional current through diode D2 and D3 when it is conducting is as follows.

B – D2 – R_L – D3 - A

Waveforms:



Parameters of Bridge Rectifier:

1. DC or Average Load current (I_{LDC}):

The average value of a periodic function is given by the area under one cycle of the function divided by the base(period).

$$Im = \frac{Vm}{R_S + R_F + R_L}$$

Im = Peak amplitude of load current.

R_F = Diode forward Resistance.

R_S = Transformer secondary resistance.

V_m = Maximum or peak secondary voltage.

MR. NIKHIL S.

2. DC or Average Load Voltage (V_{LDC}):

$V_{LDC} = I_{LDC} \times R_L$

$V_{LDC} = \frac{2Vm}{\Pi}$.

3. DC output current

   $I_{LDC} = \frac{2\,Im}{\Pi}$

4. RMS output voltage:

   $V_{Lrms} = \frac{Vm}{\sqrt{2}}$

5. RMS output current:

   $I_{Lrms} = Vm / (\sqrt{2}\, R_L)$

6. Ripple Factor:

   r = 0.482 or 48.2%

7. Rectification Efficiency:

   η = 0.812 or 81.2%

8. Peak Inverse Voltage (PIV):

   PIV = Vm (Volts)

9. Ripple Frequency:

   The ripple frequency is twice the input frequency i.e. 100Hz.

Comparison of rectifier circuits:

Sr. No.	Parameter	HWR	FWR	Bridge rectifier
1.	DC or average load current ($I_{L\,dc}$)	$\frac{I_m}{\pi}$	$\frac{2\,I_m}{\pi}$	$\frac{2\,I_m}{\pi}$
2.	Maximum average load voltage $V_{L\,dc}$	$\frac{V_m}{\pi}$	$\frac{2\,V_m}{\pi}$	$\frac{2\,V_m}{\pi}$
3.	RMS load current $I_{L\,rms}$	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
4.	RMS load voltage $V_{L\,rms}$	$\frac{V_m}{2}$	$\frac{V_m}{\sqrt{2}}$	$\frac{V_m}{\sqrt{2}}$
5.	DC load power P_{dc}	$\frac{I_m^2}{\pi^2} R_L$	$\frac{4I_m^2 R_L}{\pi^2}$	$\frac{4I_m^2 R_L}{\pi^2}$
6.	Maximum rectification efficiency (η)	40 %	81.2 %	81.2 %
7.	TUF	28.7 %	69.3 %	81.2 %
8.	Ripple factor	121 %	48 %	48 %
9.	Ripple frequency	50 Hz	100 Hz	100 Hz
10.	Number of diodes used	One	Two	Four

FILTERS:

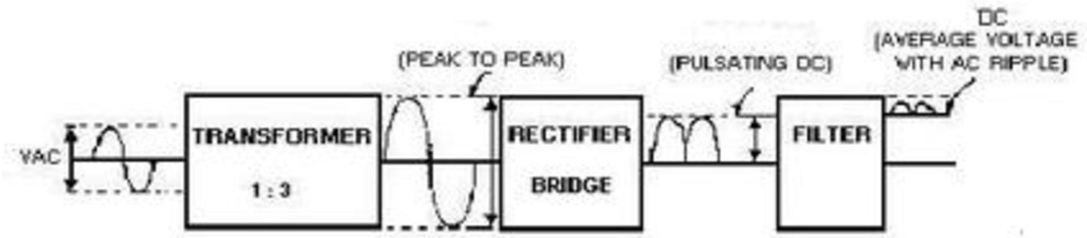
- A filter circuit is a device which removes the AC component of rectifier output but allows the DC component to reach the load.
- A filter circuit should be installed between the rectifier and the load.
- A capacitor passes AC component to the ground but does not pass DC component at all.
- On the other hand, an inductor opposes AC but allows DC component to pass through it.

Need of filters:

- Filters are the electronic circuits used along with rectifiers in order to get a pure ripple free DC voltage.
- Till now we have seen that from all the rectifiers we get a "pulsating" DC voltage.
- But this is not what we want; we want a pure DC waveform.
- In order to obtain it we use filters.
- A filter is connected at the output of the rectifier as shown below.

Inductor (L) is connected in series

Capacitor (C) is connected in parallel.



Types of filters:

Filters are classified depending upon the type of component used.

1. Capacitor input filter (shunt capacitor filter)
2. Choke input filter (series inductor filter)
3. LC filter

MR. NIKHIL S.

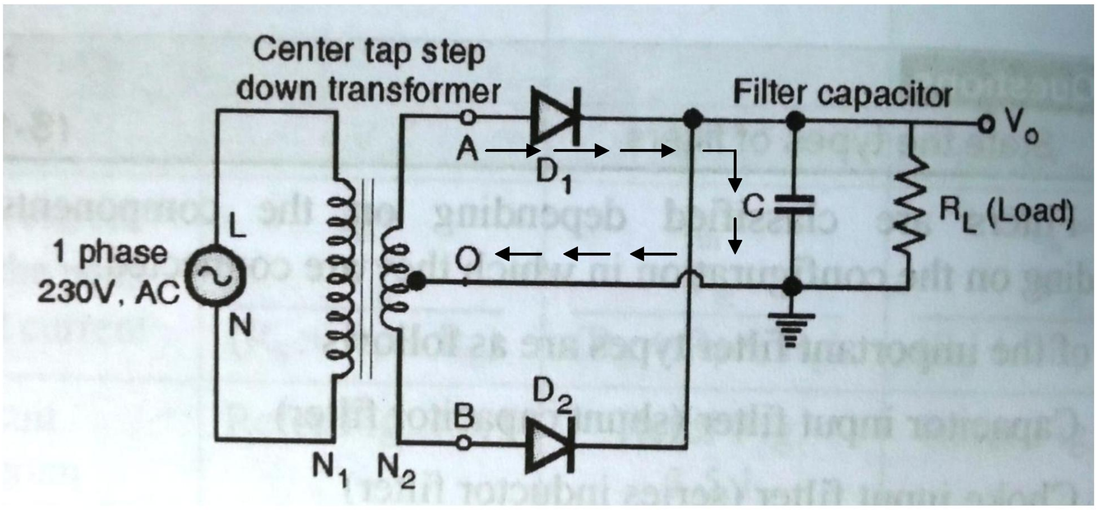
4. Π type filter
5. RC filter

Capacitor input filter (shunt capacitor filter).

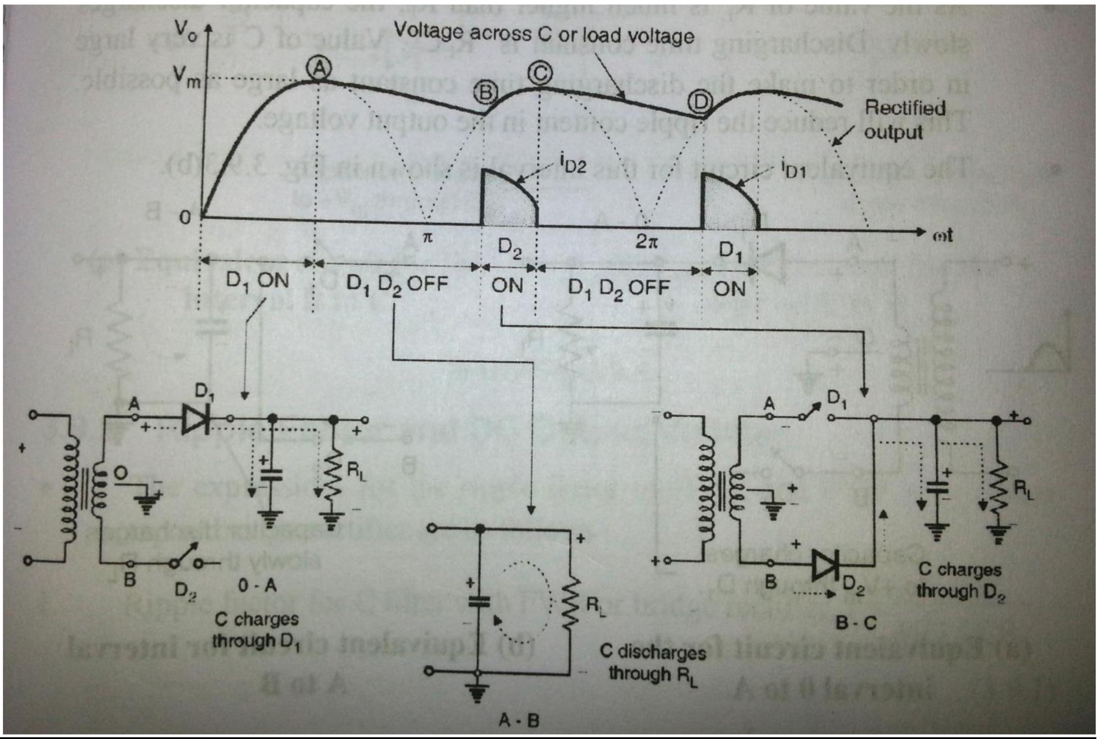
- The shunt capacitor filter is used to reduce the ripple contents in the output of a rectifier to obtain a pure DC voltage.
- The filter capacitor is connected across (in shunt with) the load, the filter is called as shunt capacitor filter.

Full wave Center tapped Rectifier with shunt capacitor filter:

Circuit diagram, Operation and waveform:



- The fig below shows the waveform of the load voltage with the capacitor filter. Along with the waveforms the equivalent circuits for various intervals have been shown.
- Operation of full wave rectifier with capacitor filter can be explained in four different intervals.



<u>Operation in the interval 0 to A:</u>

- The initial voltage in capacitor "C" is assumed to be zero. In the first positive half cycle of the supply. D1 is forward biased and starts conducting. D2 is reverse biased and acts as an open switch. Diode D1 supplies for the charging current of the capacitor and the load current.
- Capacitor starts charging through D1 and at the end of this interval i.e. at "A" it charges to the peak value if secondary voltage i.e. "Vm"
- After point "A" the instantaneous secondary voltage starts reducing as shown by the dotted waveform of rectifier output. This will reverse bias the diode D1, hence at "A" diode D1 is turned off. The equivalent circuit is shown above.

<u>Operation in the interval A to B:</u>

- During the interval, voltage on the capacitor is higher than rectifier output (shown by the dotted lines). Hence D1 and D2 both remain off. The capacitor discharges exponentially through the load resistance RL.

- The capacitor discharges slowly.

Operation in the interval B to C:

- At “B” the instantaneous rectified voltage is equal to the voltage on capacitor and after “B” it is greater than V_C.
- Therefore the diode D2 starts conducting at instant B. The capacitor charges through D2 and at the end of this interval i.e. at point “C”, the voltage on the capacitor is again equal to +Vm.
- Due to this D2 is reverse biased and stops conducting at point “C” as shown above.

Operation in the interval C to D:

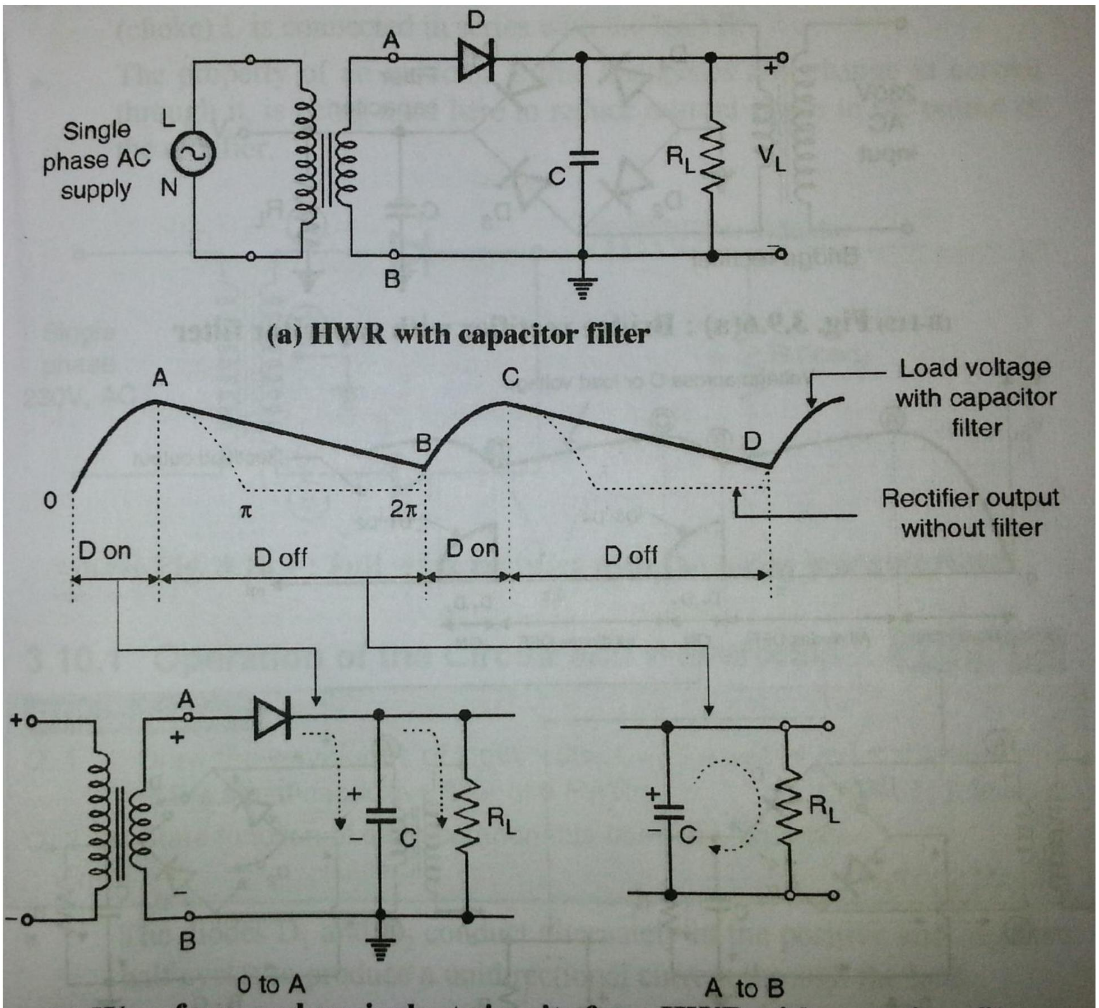
The operation in this interval is identical to that in the interval A to B.

HWR with shunt capacitor filter:

The circuit diagram of a HWR with capacitor filter is as shown in the fig below.

Operation and Waveforms:

- For the intervals 0 to A, B to C the diode is forward biased and the capacitor charges through the diode almost instantly.
- For the intervals A to B, C and D etc. the capacitor voltage is higher than the instantaneous secondary voltage. Hence the diode is off and the capacitor discharges through R_L slowly.
- Note that the discharging time with HWR is longer than that with the FWR. Hence the capacitor discharges to a lower voltage (point B and D). Hence the ripple increased.
- So the ripple factor of this circuit is higher than that of the capacitor filter with FWR.

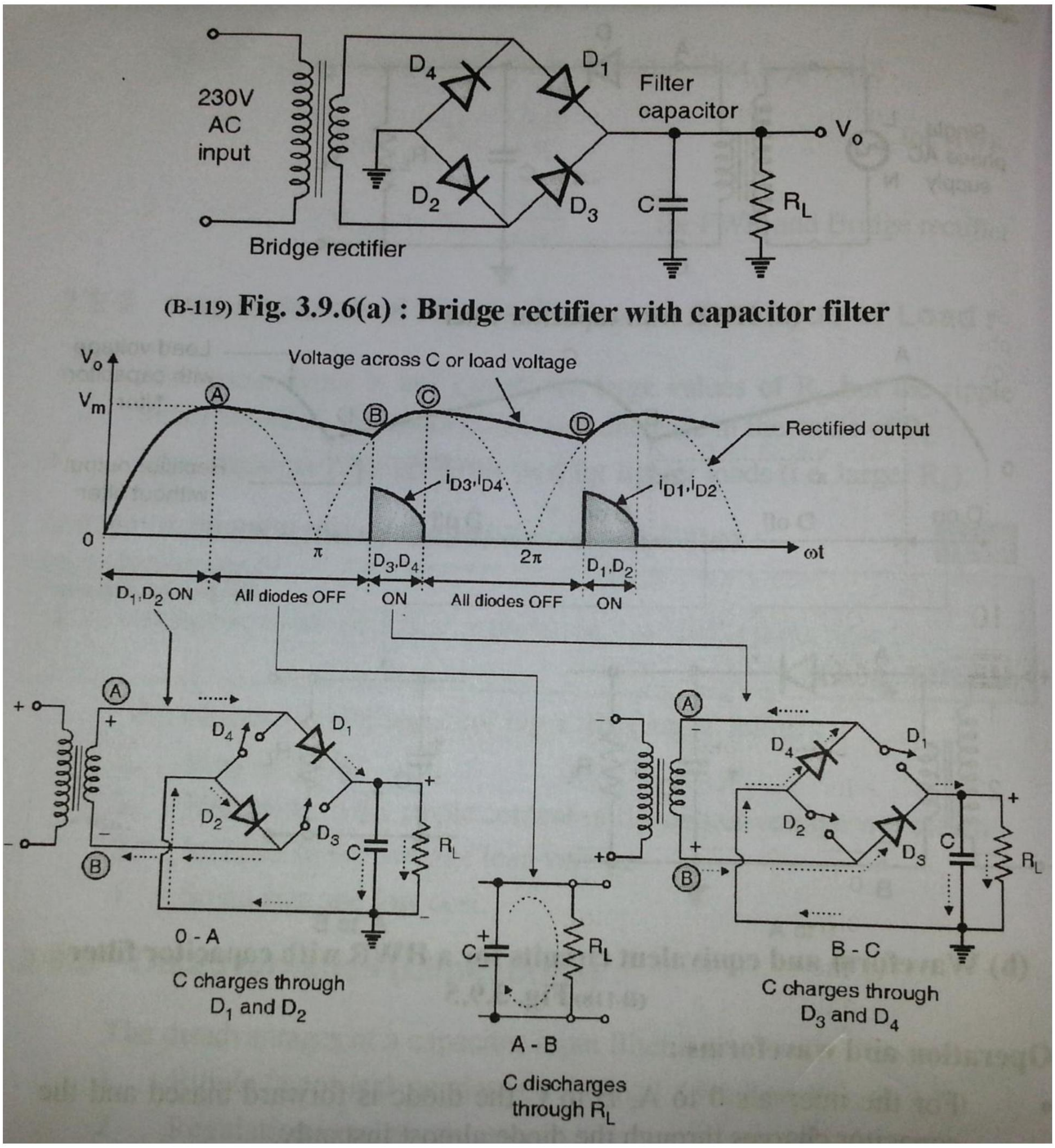


(a) HWR with capacitor filter

(b) Waveform and equivalent circuits for a HWR with capacitor filter

Bridge Rectifier with Shunt capacitor filter:

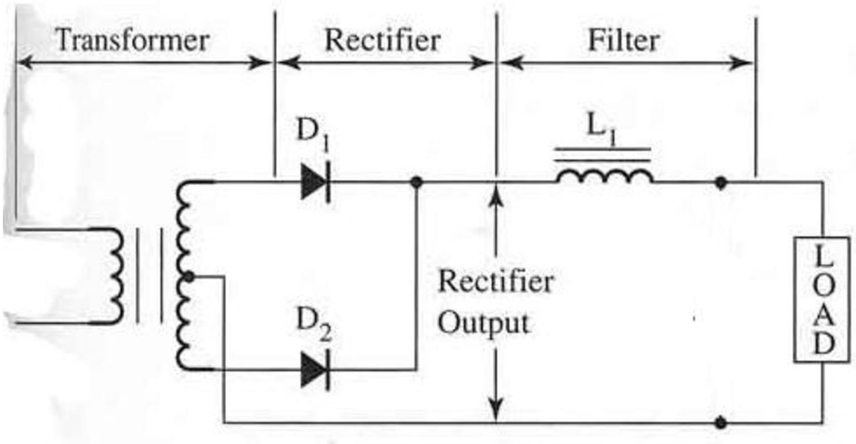
- The bridge rectifier with capacitor filter is shown below



- Note that the voltage waveform is exactly same as that for a FWR with capacitor filter. The only change is that here two diodes conduct simultaneously instead of one in FWR.

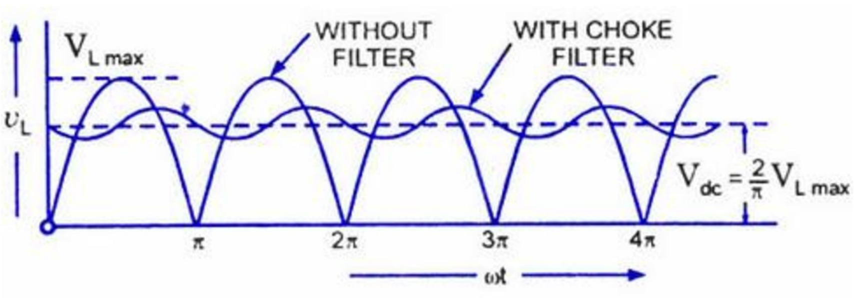
Series Inductor Filter (Choke Input filter):

- The series inductor filter is as shown below. An inductor (choke) L is connected in series with the load R.
- The property of an inductor is that it opposes any change in current through it, is being used here to reduce current ripple in the output of the rectifier.



Operation of the circuit and waveforms:

- The diodes D1 and D2 conduct alternately in the positive and negative half cycles to produce a unidirectional current through the load.
- Due to the inclusion of inductor L in series with the load, the current ripple reduces to a great extent and the load current is smooth as shown.
- Higher the value of inductor is, lower will be the peak to peak ripple in the load current waveform.
- The load voltage waveform is same as the load current waveform.



MR. NIKHIL S.

HWR with Series Inductor Filter:

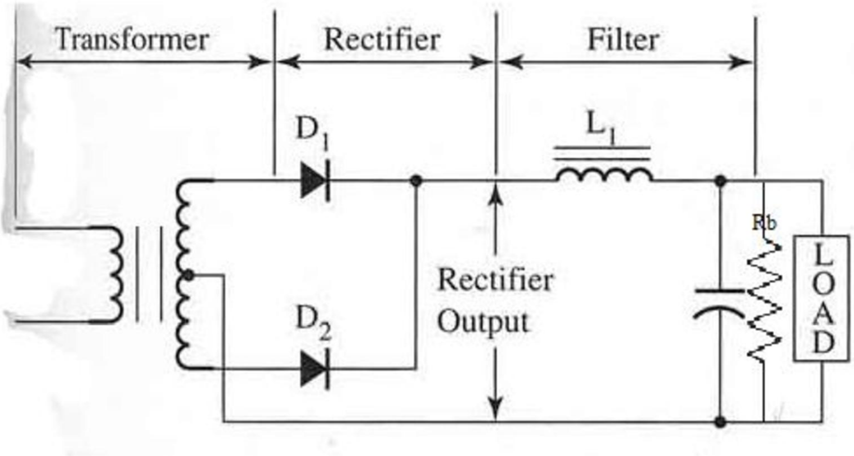
Done in lecture

Bridge Rectifier with series inductor filter:

Done in lecture

LC Filter:

- The circuit diagram for an LC filter used with a full wave rectifier is shown below.
- This is the combination of inductor filter and a capacitor input filter.
- The LC filter can give low ripple factor irrespective if the load as it is a combination of the two filters.
- The series connected inductor offers a high reactance to the harmonic components (ripple) in the output and attenuates them and the parallel capacitor provides a low reactance by pass path for them. This will reduce the ripple further.



Role of bleeder Resistor:

- The resistance Rb connected across the capacitor is called as bleeder resistance. It is used to maintain a continuous current through the filter inductance L.
- If the current through L is not continuous i.e. if it is interrupted then a large back emf will be developed across the inductor.
- This voltage may exceed the PIV rating of the rectifier diodes and damage them. This voltage may exceed the maximum rated voltage of the capacitor as well.
- Hence the induced back emf is dangerous for diodes as well as the capacitor.
- This back emf will not appear if the current through L is continuous Rb will maintain a continuous current through L.

LC filter with HWR:

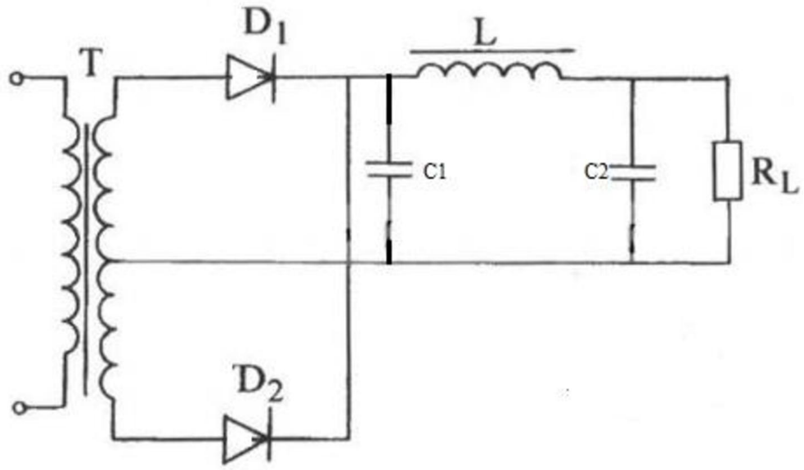
(done in lecture)

LC filter with Bridge rectifier:

(done in lecture)

Π type filter (CLC filter):

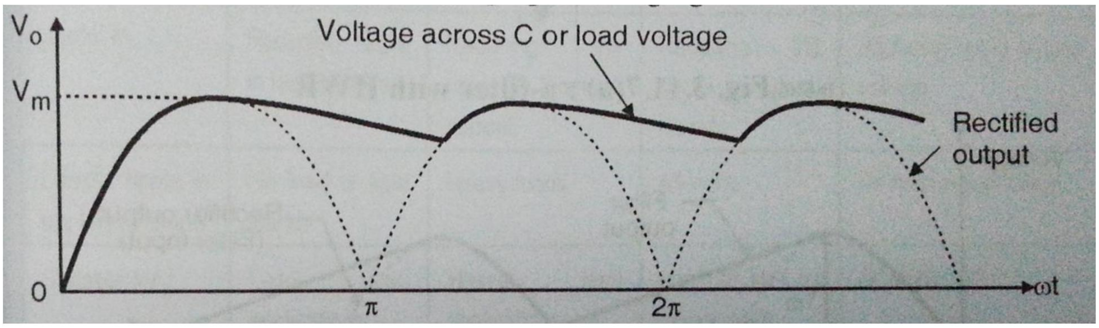
The Π type filter is the combination of capacitor input filter and LC filter as shown below. It consists of two capacitors C1 and C2 along with the inductance L. Generally both the capacitors are of same value.



- A full wave rectifier drives the Π type filter as shown above.
- As C1 comes first, looking from the rectifier side, the Π type filter behaves in a very similar way as the capacitor input filter. All the advantages and disadvantages of capacitor input filter are all applicable to the Π type filter as well.
- A Π type filter can be considered as a combination of shunt capacitor filter and LC filter as shown.
- This improves the effectiveness of the Π type filter as far as filtering of ripple is concerned.
- Due to the use of three filtering elements (C1, L and C2), the ripple factor of the Π-type filter is very low as compared to the other filter.
- The capacitors C1 and C2 provide a low reactance path for the ripple whereas the series inductor L provides a high reactance to the AC ripple. The combination effect of this is the reduction in ripple, and improvement in the output waveform.

MR. NIKHIL S.

Waveform:



Mr. Nikhil S.