RECTIFICATION FILTERING STABILIZATION

Introduction :

Most devices used in electronics require a DC power supply. One solution would be to use batteries or cells, but their lifespan is limited, and they cannot provide high supply currents. It is possible to obtain a DC power source from the AC mains voltage (Effective voltage = 220V, frequency = 50Hz). This power supply mainly consists of three parts (see Figure 1):

Figure1

The first stage ensures the rectification of the AC voltage using components such as diodes, allowing for a variable voltage but with the same polarity or sign. The second stage performs filtering, resulting in a nearly constant voltage with low ripple. The third stage stabilizes the obtained voltage to compensate for load variations, mains disturbances, and other fluctuations, …

I- Static Characteristic of the Diode:

The diode is a non-linear component (see its characteristic in Figure 2). This very important property of the diode is widely used in electronics for applications such as rectification and detection, …

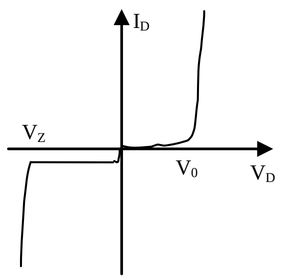


Figure2

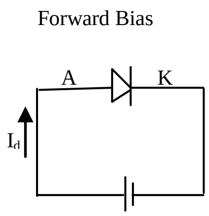


Figure3

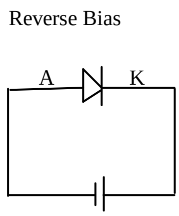


Figure4

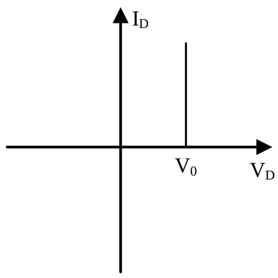


Figure5

In Figure 3, when the voltage across the diode (V_A - V_K) is greater than V_0, called the threshold voltage and defined as the voltage at which the diode begins to conduct, the diode allows a relatively significant forward current I_d to pass; it is said to be forward biased or "conducting".

On the other hand, in Figure 4, when the diode is reverse biased, only a very small (often negligible) current flows, as long as the reverse voltage does not exceed the Zener voltage V_Z; in this case, the diode is said to be blocked.

An ideal diode would have the characteristic shown in Figure 5:

When the voltage across it is greater than or equal to V_0, it behaves like a "short circuit".
In the opposite case, it behaves like an "open circuit".
V_0 strongly depends on temperature.

I.1 Dynamic Resistance :

It is possible to show that for small variations near the chosen operating point, the curve $I_D = f(V_D)$ can be approximated as a straight line with the equation: $\mathbf{v_D = V_0 + \rho I_D}$.

The parameter $\boldsymbol{\rho}$ is defined as: $\boldsymbol{\rho = \left(\frac{\Delta v_D}{\Delta I_D}\right)}$ **à** $\mathbf{I_D = I_0}$ and is called the dynamic resistance. It is clear that ρ varies with the operating point.

I.2 Diode Protection:

Let’s consider the half-wave rectifier circuit shown in Figure 6a. If the load R_L is accidentally short-circuited, this can lead to the destruction of the diode.

To prevent this, a protection resistor R_P is added before the diode, as shown in Figure 6b. This resistor limits the current through the diode to a value $I_D \leq I_{Dmax}$, as specified by the manufacturer.

$$e_{max} = v_D + R_P I_{Dmax}, \quad \text{where} \quad R_P \geq \frac{e_{max} - v_D}{I_{Dmax}}$$

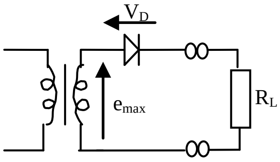


Figure6a

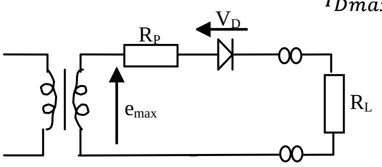


Figure6b

II- Half-Wave Rectification:

Consider the circuit in Figure 7, where e(t) is an AC voltage source, generally obtained from the mains (220V, 50Hz) using a transformer.

Since the diode conducts only when the anode potential V_A is higher than the cathode potential V_K, it can be shown that the voltage V_L across the load R_L will have the following waveform.:

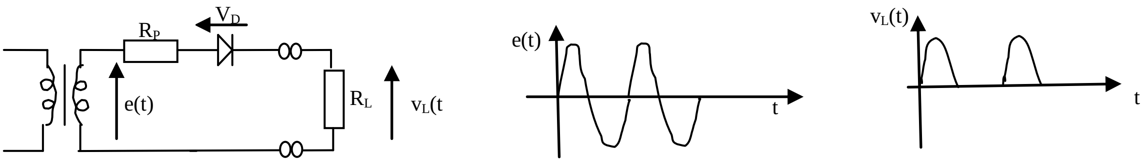


Figure7

Calculation of the Average Voltage Across (R_L):

When the diode is conducting, we can write: $e(t) = v_D + (R_P + R_L)i_D$

with $e(t) = E_m \sin wt$ and $v_D = V_0 + \rho i_D$ we conclude $i_D = \frac{e(t) - v_D}{R_P + R_L + \rho}$

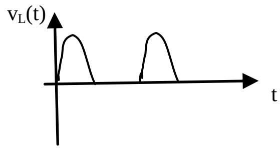
If we consider E_m ≫ V_0, we can assume that the diode conducts during one half-cycle of the alternating voltage.

The average voltage across R_L will be: $V_{Lmoy} = \frac{1}{T}\int_0^T v_L(t)dt = R_L \frac{1}{T}\int_0^T i_D(t)dt$

By neglecting R_P and ρ compared to R_L, we obtain:

$$v_L(t) = E_m \sin wt \quad \text{for} \quad 0 < t < \frac{T}{2} \quad \text{and} \quad v_L(t) = 0 \quad \text{for} \quad \frac{T}{2} < t < T$$

Finally, $V_{Lmoy} = \frac{1}{T}\int_0^{T/2} E_m \sin wt \, dt = \frac{E_m}{\pi}$ and $I_{Dmoy} = \frac{E_m}{\pi R_L}$



Remark: This result is valid only if $E_m \gg V_0$, $R_L \gg R_P$ and $R_L \gg \rho$.

III- Half-Wave Rectification with Capacitive Filtering:

To achieve a better approximation of a DC voltage, a capacitor is introduced in parallel with R_L (Figure 8).

As a result, the voltage $V_L(t)$ takes the following waveform:

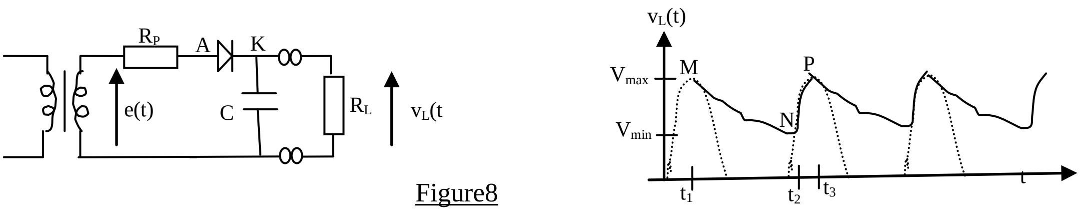


Figure8

Between the instants t=0 and $t=t_1=T/4$ (point M),

The **diode is conducting**, and the capacitor charges up to the voltage: $V_{max} \approx E_m$.

Between the instants **t_1 (point M) and t_2 (point N)**, the **diode remains blocked** because the potential of its anode $\mathbf{V_A}$ is lower than that of its cathode $\mathbf{V_K}$ (which is equal to the voltage of the charged capacitor).

At this stage, the capacitor **discharges** through the resistor $\mathbf{R_L}$ down to a value $\mathbf{V_{min}}$ with a time constant: $\tau = R_L C$.
From the instant $\mathbf{t_2}$ **(point N)**, the **diode starts conducting again**, allowing the capacitor to **recharge** until the instant $\mathbf{t_3 = 3T/4}$ **(point P)**.
This **cycle repeats continuously**.

Let $2\Delta v = V_{max} - V_{min}$.
It follows that the **charge received** by the capacitor **C** between $\mathbf{t_2}$ and $\mathbf{t_3}$ is:
$Q_{received} = C(2\Delta v)$
When the capacitor **discharges** through $\mathbf{R_L}$ from **M to N**, the **charge lost** is:
$Q_{lost} = i_{avg}(t_2 - t_1)$
With $i_{moy} = v_{moy}/R_L$
Since we can approximate $t_2 \approx T$ and $t_1 \ll T$ (which is valid when $\tau \gg T$), we get: $Q_{lost} = i_{avg}T$
By charge conservation, we equate $Q_{received} = Q_{lost}$, leading to:
Since for **mains rectification**, the frequency is **f=50Hz** and **T=1/f**, we can rewrite:
$\frac{\Delta v}{v_{avg}} = \frac{T}{2R_LC} = \frac{1}{2R_LCf}$

This result is only valid if $\tau = R_LC \gg T$.

IV- Full-Wave Rectification:
Let's consider the circuit diagram in Figure 9:

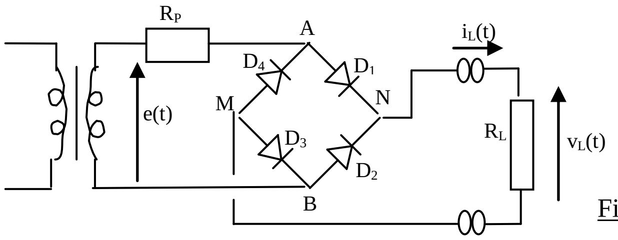
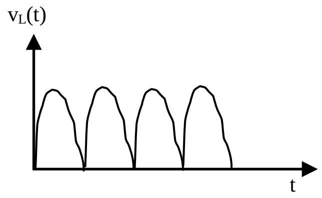


Figure 9



For 0<t<T/2, during the **positive half-cycle** of **e(t)**:
- The potential at **point A** is higher, and the potential at **point B** is lower.
- **Diodes** $\mathbf{D_1}$ **and** $\mathbf{D_3}$ **conduct**, while $\mathbf{D_2}$ **and** $\mathbf{D_4}$ **are blocked**.

For T/2<t<T, during the **negative half-cycle** of **e(t)**:
- The potential at **point A** is lower, and the potential at **point B** is higher.
- **Diodes** $\mathbf{D_1}$ **and** $\mathbf{D_3}$ **are blocked**, while $\mathbf{D_2}$ **and** $\mathbf{D_4}$ **conduct**.

As a result, the current $\mathbf{i_L(t)}$ always flows in the same direction. The output voltage T/2<t<T $\mathbf{V_L(t)}$ remains **always positive**, but with a period reduced by half, meaning the frequency is **doubled**: f'=100Hz.
By applying the same assumptions as for **half-wave rectification**, it is easy to show that the **average voltage** will be: $V_{Lavg} = 2\frac{E_m}{\pi}$.

V- Full-Wave Rectification with Capacitive Filtering:
As with half-wave rectification, it is sufficient to add a capacitor C in parallel with the load resistor R_L.
The same reasoning applies, but with f'=100Hz and T'=T/2.
We find, $$\frac{\Delta v}{v_{avg}} = \frac{T'}{2R_LC} = \frac{1}{2R_LCf'}$$

VI-Stabilization:

VI.1 <u>The Zener Diode</u>:

The reverse current-voltage characteristic of a Zener diode is shown in the figure 10:

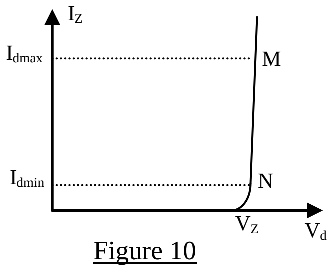


Figure 10

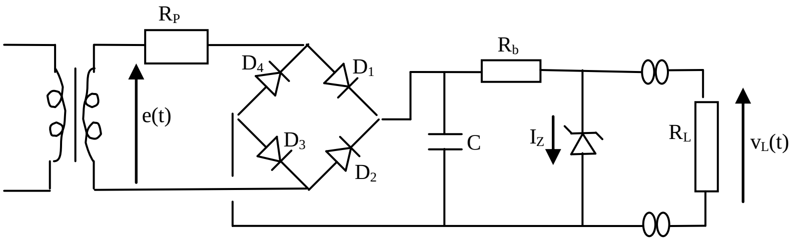


Figure 11

When the voltage across the **Zener diode** reaches $\mathbf{V_Z}$, the current increases sharply, whereas it was almost zero for $V_d<V_Z$.
As a result, the **dynamic resistance** of the diode is **very low** for $V_d>V_Z$. This property is used for **voltage stabilization**.
The **operating point** of the diode is always chosen in the **linear region MN**.

VI.2 <u>Voltage Regulator Circuit</u>:

The goal is to obtain a stable output voltage regardless of variations in the input voltage and load variations.

One solution is to use the voltage regulator circuit shown in Figure 11.

The output voltage $v_L(t)$ will be regulated only if the Zener current I_Z remains within the linear region MN of its characteristic curve.

This condition imposes limits on the variations of R_L and e(t).

The circuit elements are calculated such that a sufficient current I_Z flows through the Zener diode, ensuring a voltage close to V_Z across the load.