Rectifiers

Authors: Slovenian MegaVet team

Internal study material with exam questions, used only for the preparation of corresponding MegaVet application.

1. Rectifier

A rectifier is an electronic circuit, which converts a single-phase or a multi-phase alternating current (AC) to direct current (DC). It is composed of one or more power diodes.

2. Power diode

The forward voltage drop Vf of power silicon diode is approximately 0,7V.The power diode has a much larger PN junction area compared to the signal diode, resulting in a high forward current and reverse blocking voltage capability. Due to high capacitance of Large PN junction, usual silicon power diodes are not suitable for high frequency applications (switching power supplies) and for small output voltages. In this case Schottky diodes must be used, because of their short recovery time and lower voltage drop. Power diodes have very low ON resistance and very high reverse blocking resistance. Larger power diodes are designed to be mounted on heatsinks, to reduce their thermal resistance.

1. Half-wave rectifier

A diode conducts electric current only in one direction. If an alternating voltage is applied across, the diode will conduct only during the positive half cycle and this will not be the case during the negative half.

This type of rectifier is known as the half-wave rectifier:

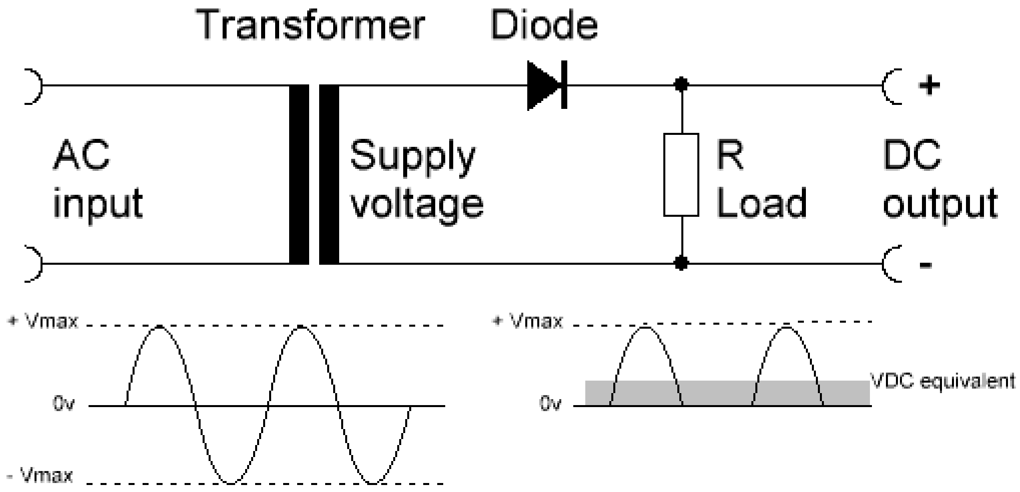

Figure 1. Half-wave rectifier

The current, flowing in the load is proportional to the voltage. The voltage across the load is the same as the supply voltage for the first half (positive) cycle, subtracted by the voltage drop on PN junction V_f (for silicon about 0,7V). During the negative half cycle, the diode is reverse biased. Therefore no voltage appears across the load. The value of load voltage is equal to an equivalent DC voltage of 0,318x V_{max}, or 0,45x V_{RMS} of the input sinusoidal waveform.

The equivalent DC voltage across the resistive load is calculated (with ideal diode):

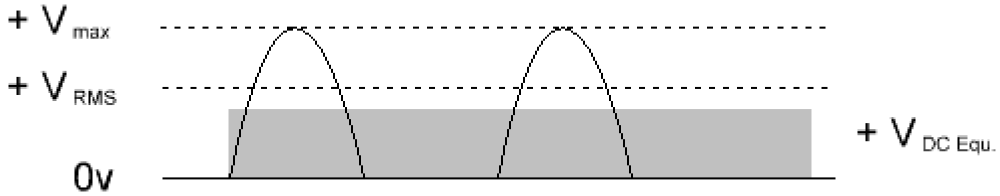

Figure 2. Output DC voltage of the half-wave rectifier

$$V_{DC} = V_{max}/\pi = 0{,}318x\ V_{max} = 0{,}45x\ V_{rms}$$

Where V_{max} is the maximum (peak) value of the AC sinusoidal input, and V_{RMS} is its RMS value.

RMS (Root Mean Squared) is an amount of AC power, which gives the same heating effect, as an equivalent DC power. So, RMS voltage (or effective voltage) supplies the same electrical power to a given load, as an equivalent DC voltage.

The calculation is accurate only in case, when an ideal diode is being used. In reality, diodes are not ideal. During positive half cycle, the current flows through one diode, so the output voltage is for one voltage drop, or approximate 0,7V less than the input voltage V_{max}. The ripple frequency is equal to the supply frequency (50Hz).

2. Half-wave rectifier with smoothing elements

The amount of ripple voltage* can be reduced by using smoothing elements (capacitor, inductor, or both). In order to satisfy the reduction of ripple voltage, we need large (and expensive) smoothing elements; hence, the half-wave rectifier is most commonly used in low power applications, which do not need steady and smooth DC supply voltage.

*Where ripple voltage is the unwanted residual periodic variation of the DC output voltage.

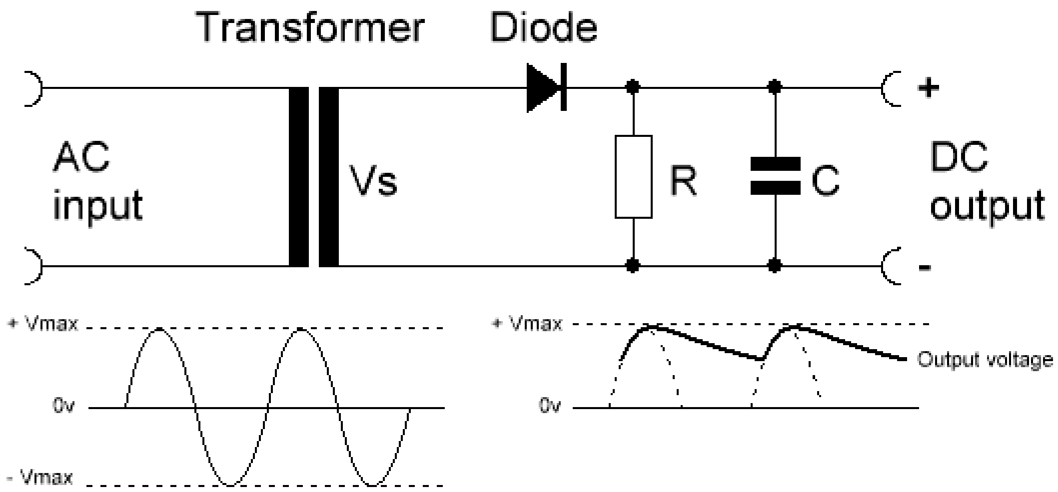

Figure 3. Half-wave rectifier with smoothing capacitor

$V_{Peak\ DC}$= 1,41x V_{rms}

$V_{Average\ DC}$ = 0,9x V_{rms}

3. Full-wave rectifier

In full-wave rectifier we use two diodes instead of only one, namely one diode for each of the cycle. A transformer, whose secondary winding is split into two equal halves with a common central tap, is used for proper functioning of the rectifier. Each diode conducts, when its anode is positive with respect to the transformer central tap, producing an output during both half cycles.

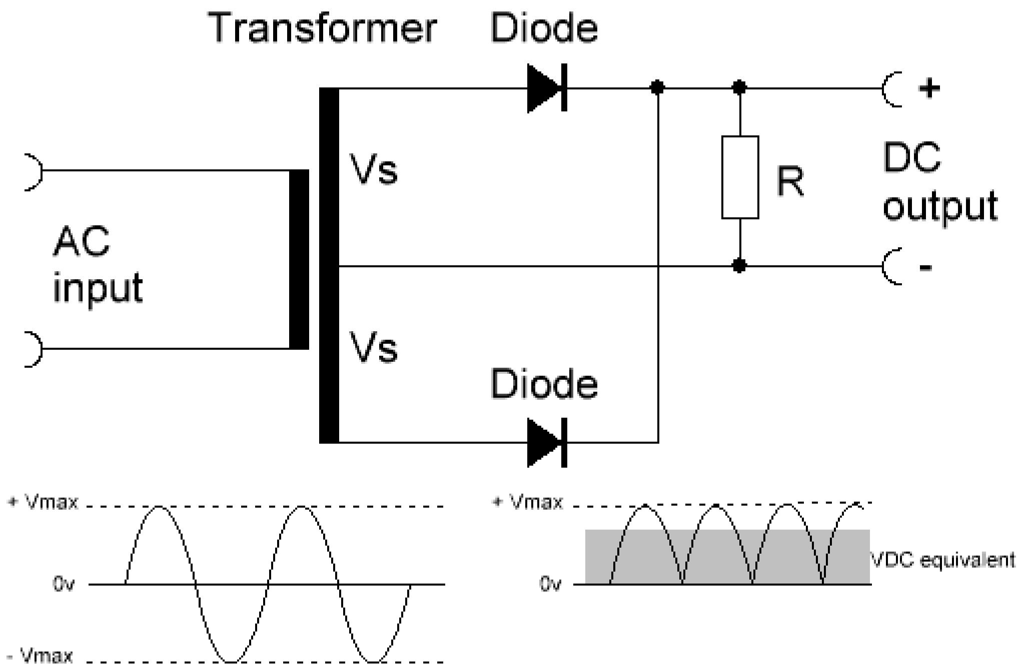

Figure 4. Full wave rectifier

The average DC output voltage across the load is now double that of half-wave rectifier. The value of load voltage is equal to an equivalent DC voltage of 0,637x V_{max} or 0,9x V_{RMS} of the input sinusoidal waveform.

The equivalent DC voltage across the resistive load is calculated:

$$V_{DC} = 2x\ V_{max}/\pi = 0{,}637x\ \ V_{max} = 0{,}9x\ V_{rms}$$

Where V_{max} is the maximum (peak) value of the AC sinusoidal input, and V_{RMS} is its RMS value.

During each half cycle the current flows through one diode, so the output voltage is for one voltage drop, or approximate 0,7V less than the input voltage Vmax. The ripple frequency is twice the supply frequency (100Hz).

This type of rectifier main disadvantage is larger transformer, because of two identical secondary windings with relatively high peak currents through them.

4. Full-wave bridge rectifier

This type of rectifier produces the same output waveform as the full wave rectifier above. Instead of the transformer with two secondary windings, four power diodes are used for full-wave diodes. This type of the circuit is often referred to as Graetz bridge.

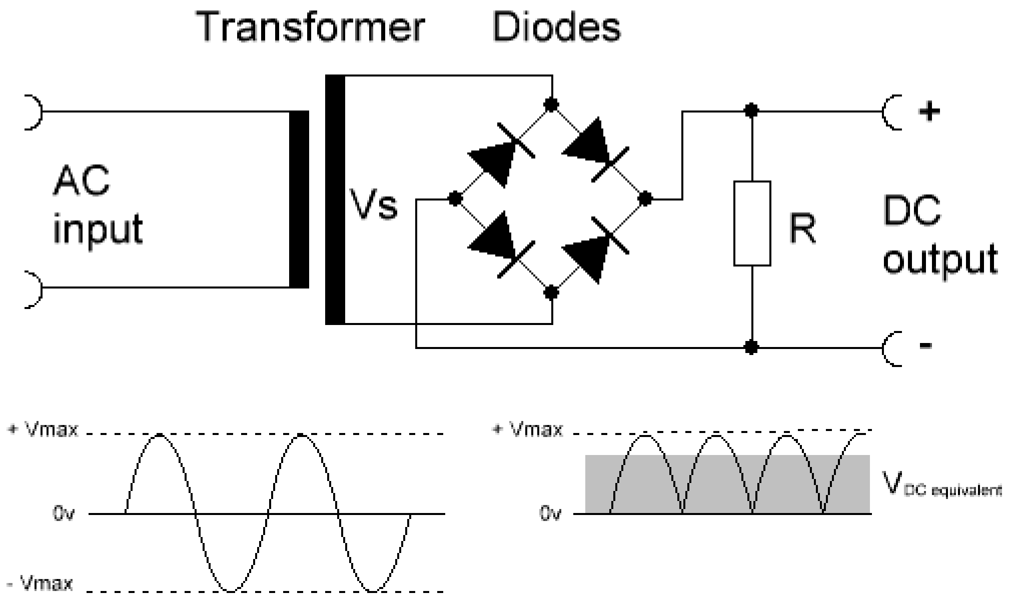

Figure 5. The full-wave bridge rectifier

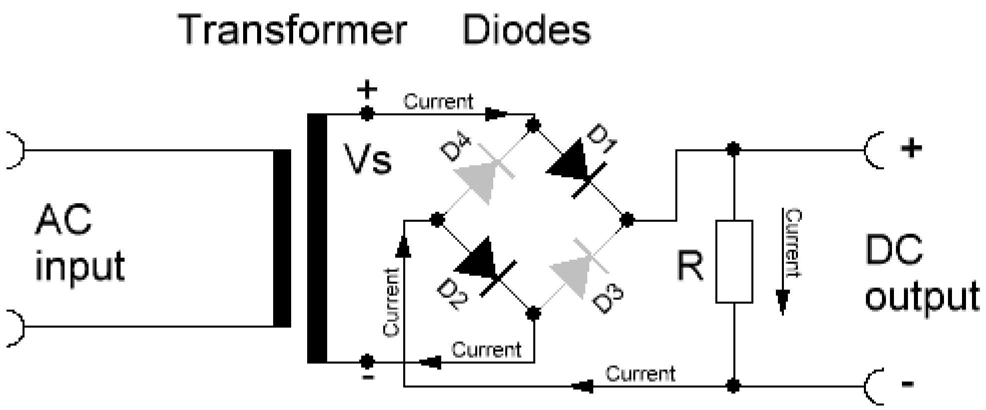

Figure 6. During positive half-cycle, only diodes D1 and D2 conduct. Diodes D3 and D4 are reverse biased, so they don't conduct.

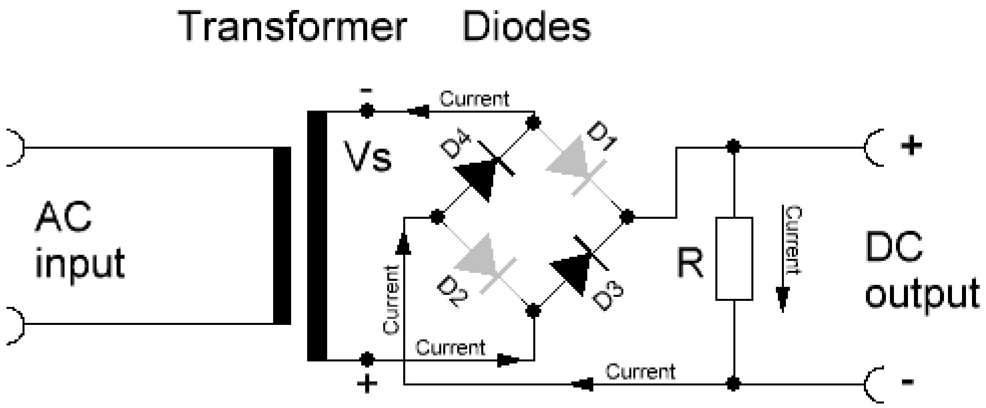

Figure 7. During negative half-cycle, only diodes D3 and D4 conduct. Diodes D1 and D2 are reverse biased, so they don't conduct.

The value of load voltage is equal to an equivalent DC voltage of 0,637x V_{max} or 0,9x V_{RMS} of the input sinusoidal waveform.

During each half cycle the current flows through two diodes, so the output voltage is for two voltage drops, or approximate 1,4Vless than the input voltage Vmax. The ripple frequency is twice the supply frequency (100Hz).

5. Full-wave rectifier with smoothing elements

The amount of ripple voltage can be reduced by using smoothing elements (capacitor, inductor, or both). Due to double ripple frequency, to satisfy the reduction of ripple voltage, we need much smaller (and inexpensive) smoothing elements than in half-wave rectifier. This type of rectifier meets most of the needs for a wide range of power applications.

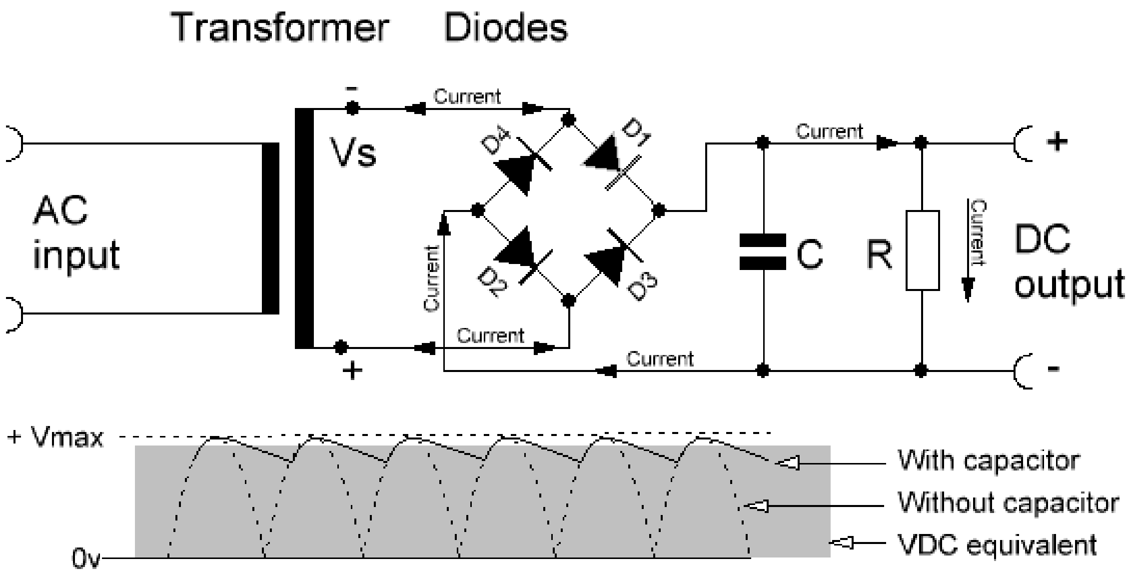

Figure 8. Typical full-wave rectifier with smoothing capacitor

Because of charging the capacitor to maximal voltage in absence of load current, the peak DC voltage is:

$V_{Peak\ DC} = 1{,}41x\ V_{rms}$

And DC output voltage under normal load current is:

$V_{Average\ DC} = 0{,}9x\ V_{rms}$

The ripple voltage in this circuit is determined by the capacitance of the smoothing capacitor and the load current.

$V_{ripple} = I_{load}/f \times C$, (Volts)

Where ILoad is DC load current in Amperes, f is twice the frequency of the input voltage in Herz and C is capacitance in Farads.

Ripple voltage is superimposed on top of the output DC voltage. With a complex filter (the combination of smoothing capacitor and inductor) it can be virtually eliminated. If we need stabilized DC voltage, we must use additional serial or switching regulators.