EEE118: Electronic Devices and Circuits

Lecture VI

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Review

1. Finished looking at the peak detector circuit.
2. Considered the use of the peak detector in AM radio demodulation
3. Introduced and described the operation of the diode voltage clamp circuit. The clamp can be broken down into,
    - 0° - $\sim 180^\circ$ - Diode not conducting, negligible charging of C through R.
    - 180° - $\sim 270^\circ$ - Diode conducts C charges through D.
    - 270° - $\sim 360^\circ$ - Diode not conducting, small discharge current flows from C through R.
    - All following cycles - Diode briefly conducts around $\sim 270^\circ$ to recharge C
4. Connected a peak detector to a voltage clamp to form a peak to peak detector

Review Continued

- Considered the equilibrium condition that defines how ideally the peak to peak detector acts as a voltage doubler
- Developed a three stage voltage doubler and looked at the voltage on the clamp and peak detector at each stage.
- Observed that the voltage doubler is often drawn as a ladder in which capacitors are the "edges" and diodes are the "rungs"
- Noted the existence of two useful - in terms of designing circuits and understanding them - programs for numerical and analytical simulation of electronic circuits.
  - LTSpice - Numerical simulation of linear and non-linear circuits
  - QsapecNG - Analytical (i.e. algebraic) simulation of linear circuits

Outline

1. Rectifiers: Linear Power Supplies
2. Single and Three Phase Supply
3. Half Wave Rectifier
4. Capacitive Smoothing
   - Choosing a Capacitor
5. Full Wave Rectifier
6. Full Wave Bridge Rectifier
7. Smoothing a Full Wave Rectifier
8. Review
9. Bear

Linear Power Supplies

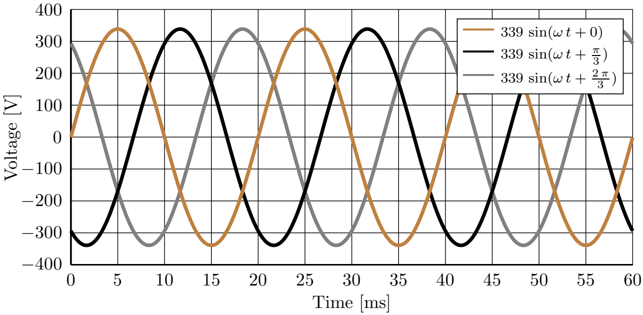
Rectification

Conversion of AC voltage into a unipolar voltage that is usually of the form of a DC component with a superimposed AC component.

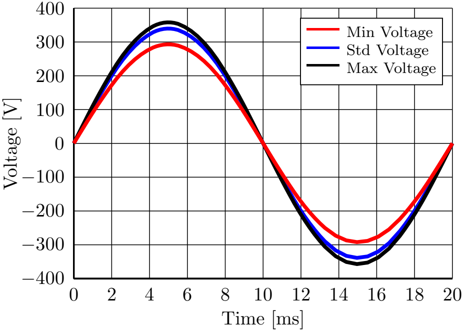
- The DC component is always the average value of the rectifier output voltage and the superimposed AC component, which is rarely sinusoidal, is called the ripple voltage.
- In this course the ripple voltage will always be the peak to peak value of the superimposed AC component.

Rectifier circuits are often divided into two categories half wave and full wave. In fact, full wave circuits can be looked at as two or more half wave circuits connected together.

Other descriptive terms applied to rectifier circuits are single phase and three phase. These terms relate to the nature of the AC power supply. Most medium/heavy industry (kilowatts and above) is supplied by a three phase AC power source while light industrial applications are more likely to be supplied by a single phase source. Domestic dwellings are supplied by a single phase source. Only single phase circuits are examinable.



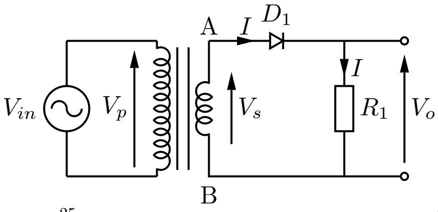
Single phase in the UK is 240 V RMS, 50 Hz. The standard gives 230 V ±10% at 50 Hz ±0.5 Hz (BS 7671)[1,2]. In practice 230 V is quoted so the UK conforms with western Europe, but since 240 V falls within the permissible limits the UK has not changed its generation voltage.

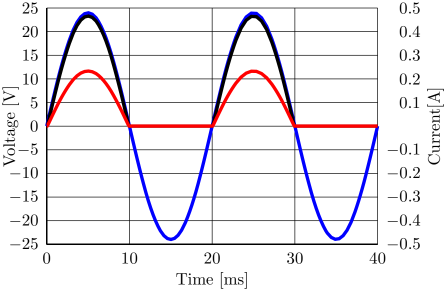


[1] Kitcher, C., *Practical guide to inspection, testing and certification of electrical installations : conforms to 17th edition IEE Wiring Regulations (BS 7671:2008) and Part P of Building Regulations*, Oxford: Newnes, 2009, 621.31924 (K)

[2] `http://www.tlc-direct.co.uk/Book/1.1.htm`

Half Wave Rectifier





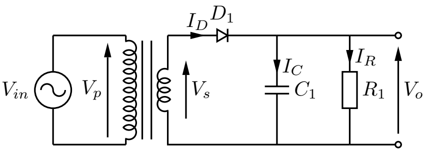
Red: I, Black: V_o, Blue: V_{in}

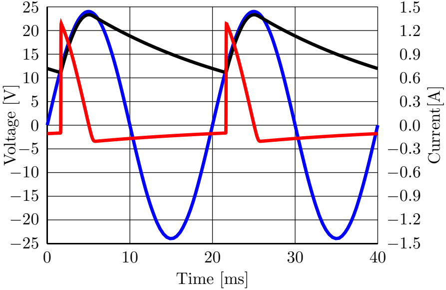
- The diode conducts when the voltage at A is more than 0.7 V positive with respect to B.
- Positive half-cycles of the secondary winding current pass through the diode. Negative half-cycles are blocked.
- If the orientation of the diode was reversed the negative half cycles would pass and the positive ones would be blocked.

- There is a limited range of power supply applications in which this wave shape is acceptable.
- Most electronic equipment requires a relatively smooth supply voltage that approximates continuous DC (e.g. a battery)
- V_o for the half-wave rectifer is unipolar (no negative part, only positive in this case).
- The average value (the DC component) is positive, but the ripple (AC component) is large.
- For the circuit to be useful as a DC power source for most electronic circuits, the output may be *smoothed* to reduce the amplitude of the AC component or “ripple voltage”
- There are various ways in which smoothing can be achieved. Each requires the storage of energy so that it can be redistributed more evenly across the cycle - essentially filling in the gaps.

Capacitive Smoothing

The simplest method is to use a capacitor in parallel with the load resistance to store charge when the diode is conducting, and deliver charge to the resistor when the diode is not conducting.



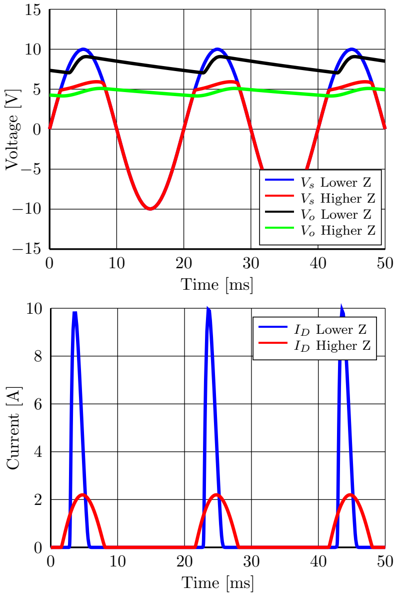


This is a peak detector circuit. C is charged in the vicinity of the peak of every positive half cycles and provides current for the load in between the positive peaks. Note the remaining ripple (somewhat exaggerated in the diagram) is a good approximation to a triangle - this will simplify calculations later.

The current waveform has large amplitude charging pulses of relatively short duration. The peak pulse amplitude can be many times greater than the load current. These may be troublesome for several reasons,

1. The rapid $\mathrm{d}I/\mathrm{d}t$ can cause radiative interference problems (EMI) - more in EEE6010.
2. The external supply is delivering most of the energy used at one point in the cycle. This can set up impulsive mechanical loads in the utility machinery.
3. These pulses develop proportionately high $I^2 R$ losses, unnecessarily heating the circuit, and lowering efficiency.

Fortunately in most situations the series impedance associated with transformers and the utility supply mean that the impulsive currents are not as troublesome as they would be under ideal conditions.



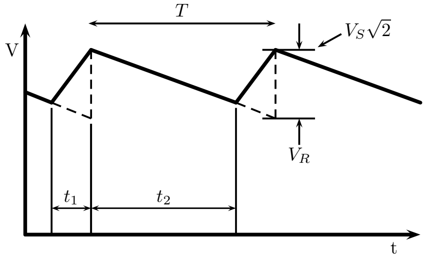
These graphs show voltage and current for the secondary V_s and the output V_o for a small transformer. The series impedance has been exaggerated somewhat in the graphs to make the effect clear. Note that the ideal secondary voltage is $V_s\sqrt{2}\sin\left(2\pi f_s t\right)$ neither of the shown V_s lines agree perfectly with the ideal, but the data representing the lower impedance situation comes quite close.

- The series impedance means that a large impulsive charging current is no longer possible.
- The resulting green output voltage waveform is somewhat lower in voltage than the nearly ideal black case. Because C_1 can not charge quickly enough the charging pulses are broader and smaller in amplitude - and area - to the ideal case.
- Note that the ripple voltage is still triangular in shape.
- Manufacturers do not give figures for the impedance of a transformer. If this information was available it would be of little value as the calculations involved are taxing. Regulation information is available, but it relates to the transformer only. Generally bigger VA leads to better regulation.
- The output voltage from a simple linear power supply with capacitor smoothing is poorly defined, will often be lower than ideal estimates and will be a function of the load resistance.

Choosing a Capacitor to Meet a Ripple Specification

Assumptions:

1. The ripple is triangular
2. The capacitor discharges throughout the charging cycle and charges instantaneously at the peak of each charging cycle
3. The transformer and power source are ideal (i.e. zero series impedance)
4. The load current is constant
5. Discharge occurs for the whole interval between charging peaks



Using the instantaneous charging model the voltage across C_1 reduces at a constant rate over the interval T as the load current I_R is drawn from C_1.

$$Q = C\,V\,, I = \frac{dQ}{dt} = C\,\frac{dV}{dt} = C\,\frac{V_R}{T}$$

Since this is a half-wave rectifier $T = \frac{1}{f_s}$ where f_s is the supply frequency (UK: 50 Hz, USA: 60 Hz JPN: both!). If the load is purely resistive (as shown several slides ago) then,

$$I_L = \frac{\sqrt{2}\,V_s}{R_L}$$

For example

A half wave rectifier power supply is loaded by a power amplifier which is driving an AC machine. The load can modelled by a 5 Ω resistance. Find the ripple voltage if the smoothing capacitor bank has a total capacitance of of 68,000 μF and the transformer secondary voltage (V_s) is 80 V RMS.

Solution

Find the peak load current,

$$I_L = \frac{\sqrt{2}\,V_s}{R_L} = \frac{\sqrt{2}\cdot 80}{5} = 22.6274\ \mathrm{A} \tag{1}$$

Find the time over which the smoothing capacitor is discharged (the period of the waveform)

$$T = \frac{1}{f_s} = \frac{1}{50} = 20\ \mathrm{ms} \tag{2}$$

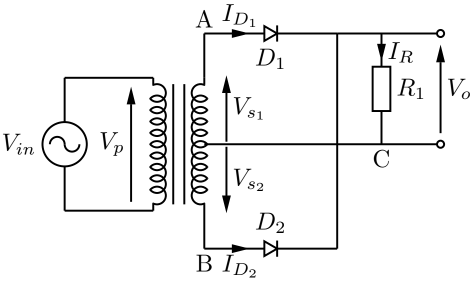
Transpose the capacitor equation $I = C\left(\mathrm{d}V/\mathrm{d}t\right)$ to obtain the solution.

$$I_L = C\,\frac{V_R}{T}\,,\, V_R = \frac{I_L\,T}{C} = \frac{22.6274\cdot 0.02}{68\times 10^{-3}} = 6.66\ \mathrm{V} \tag{3}$$

In many cases this is an overestimate. But an overestimate is more desirable than an underestimate!

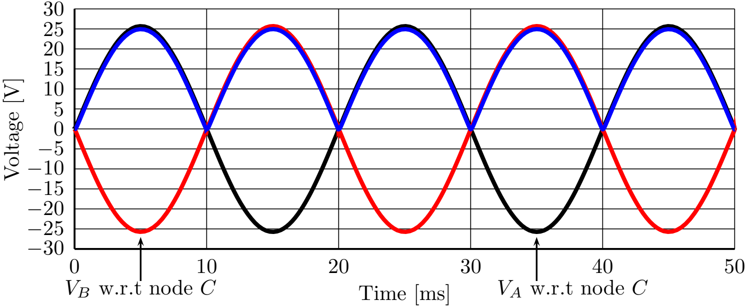
Full Wave Rectifier

The full wave rectifier is essentially the combination of two half wave circuits.



In this circuit V_{s_1} and V_{s_2} are 180° out of phase i.e. when node A is at $\sqrt{2}\,V_s$, node B is at $-\sqrt{2}\,V_s$. V_{s_1} and D_1 form one half wave rectifier and V_{s_2} and D_2 form another. The outputs of these two half wave rectifiers are combined before being applied to the load.

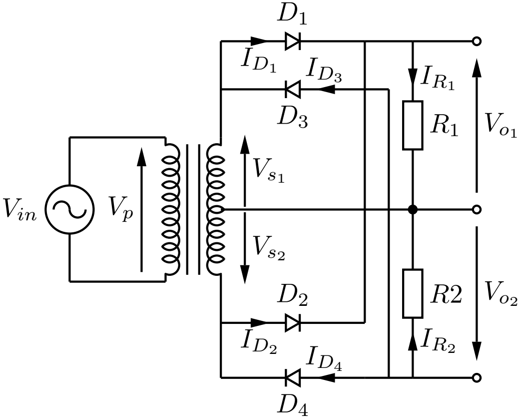
Because of the 180° phase shift between V_{s_1} and V_{s_2}, V_{s_2} and D_2 are active when V_{s_1} and D_1 are not active. Therefore there is a current flowing in R_1 for every half cycle



Blue: V_o, Black: V_{s_1} Red: V_{s_2}

If the diodes in the full wave circuit were reversed, V_o would be negative, (i.e. upside down). Is it possible to add reversed versions of D_1 and D_2 to nodes A and B in the full wave circuit? Could this then provide a simultaneous positive and negative output with respect to node C?

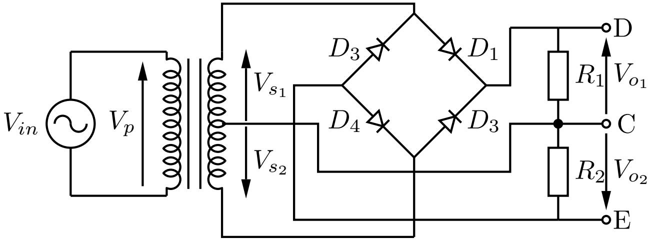
This circuit consists of four half wave rectifiers connected to rectify the full wave.



V_{s_1} and V_{s_2} face opposite directions because the transformer centre tap is the reference. Re-arranging this circuit the standard version of this circuit is obtained, where the diodes are drawn to form a *bridge*. This circuit is known as a full wave bridge rectifier.

Full Wave Bridge

In these figures the diodes D_1 and D_2, R_1 and V_{o_1} are exactly the same as the simple full wave (two diode) case. The outputs from the bridge rectifier can be used in various ways. If node C is the reference point, node D is a positive output voltage and node E is a negative output.



Or if node E is the reference point, both nodes C and D are positive with D having twice the magnitude of node C.

Applications

Yet another possibility is that node D is the reference and both C and E are negative with E having twice the magnitude of C.

Applications

- A positive and negative output with respect to node C. This is used extensively in analogue systems where bipolar signals centred on zero are used, e.g. audio amplifiers. It is often called a "centre zero" power supply.
- A single output of node D with respect to node E This is the low cost version e.g. for a car battery charger. In this case the connection between the centre tap of the transformer and node C is often omitted.

Smoothing a Full Wave Rectifier

- Smoothing a full wave rectifier output is very similar to smoothing a half wave circuit. The main difference is that the half wave rectifier charges the smoothing capacitor *once per input cycle*, whilst a full wave rectifier charges the smoothing capacitor *twice per input cycle*.
- In all other respect the behaviour is the same.
- Because of this the prior equations can be used to choose a capacitor to meet the ripple voltage requirements or to estimate the ripple given the circuit values and operating conditions.
- When calculating capacitances for full wave power supplies remember that the capacitance is replenished at 100 Hz. Not 50 Hz as is the case with the half wave circuit.

Review

1. Introduced the idea of linear power supplies
2. Briefly discussed some differences between single phase and three phase supplies
3. Considered the half wave rectifier in detail
4. Used a peak detector circuit to smooth the output voltage of the peak detector
5. Developed a simple model to find a suitable capacitor value for a power supply filter
6. Considered full wave and bridge rectifiers as an extension to the half wave principle
7. Noted that in the full wave circuit the smoothing capacitor is replenished at double the line frequency
8. Observed that the output voltage polarity available is only a function of where the reference is placed