Designing a Linear Power Supply

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The article explains how to design a mains powered linear power supply

If you have any suggestions for improving this application note, please drop us a line at: enquiries@electronworks.co.uk

It is worth reading the articles on Capacitors and Diodes before proceeding.

In our article on Capacitors, we learned that one of their applications is the storage of a dc voltage. We will now examine how they are used in power supply circuits.

The circuit of FIG 1 is used in most mains based equipment from industrial electronics to TVs.

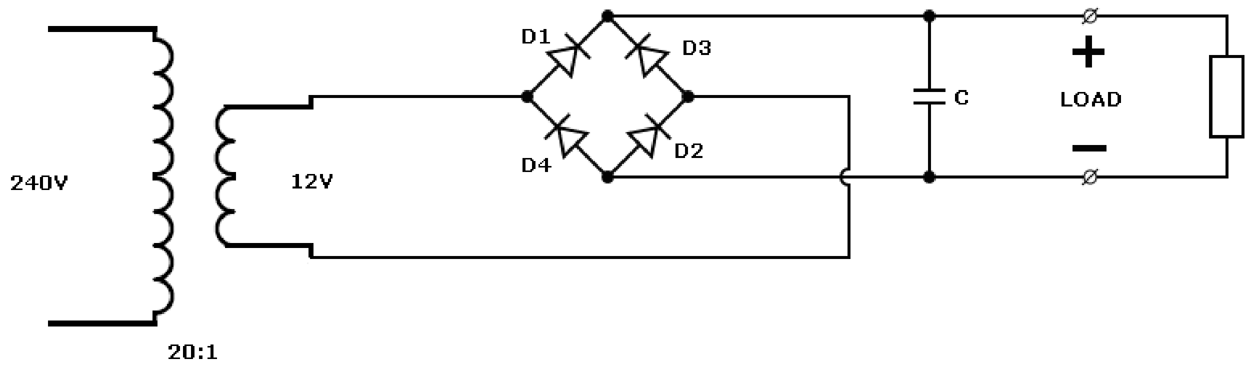

FIG 1

The 240V mains is applied to the input of a transformer with a turns ratio of 20:1. This means that for every 20 turns on the input side (the primary winding) there is 1 turn on the output side (the secondary winding).

Now, 240V is a measure of the main's 'rms' voltage. The rms voltage is equal to 0.707 of the peak voltage, so in truth the peak voltage of the mains is actually

$$Vpeak = \frac{240}{0.707} = 339V$$

This has important consequences as we shall see later.

The output voltage is $\frac{240}{20}$ V due to the turns ratio of the transformer. Similarly, this is an rms voltage, so its peak is

$$\frac{12}{0.707} = 16.9V$$

So we have an ac waveform with a peak voltage being applied to the diodes D1 – D4. (This configuration of diodes is known as a bridge rectifier). Referring to FIG 1, when the upper connection of the transformer output is positive, diode D1 conducts passing current to the output capacitor, C, and out to the load. The current flows through the capacitor and load and back through diode D2. Since the lower connection of the transformer is negative, diode D2 is biased into conduction and so the current returns to the transformer.

When the bottom connection of the transformer is more positive, the same happens, but with diode D3 conducting a positive voltage to the top of the capacitor. The current flows through the capacitor and out through diode D4. Since the top connection of the transformer is more negative, diode D4 is biased on and conducts the current back to the transformer

FIG 2 shows the waveforms that are present at each part of the circuit.

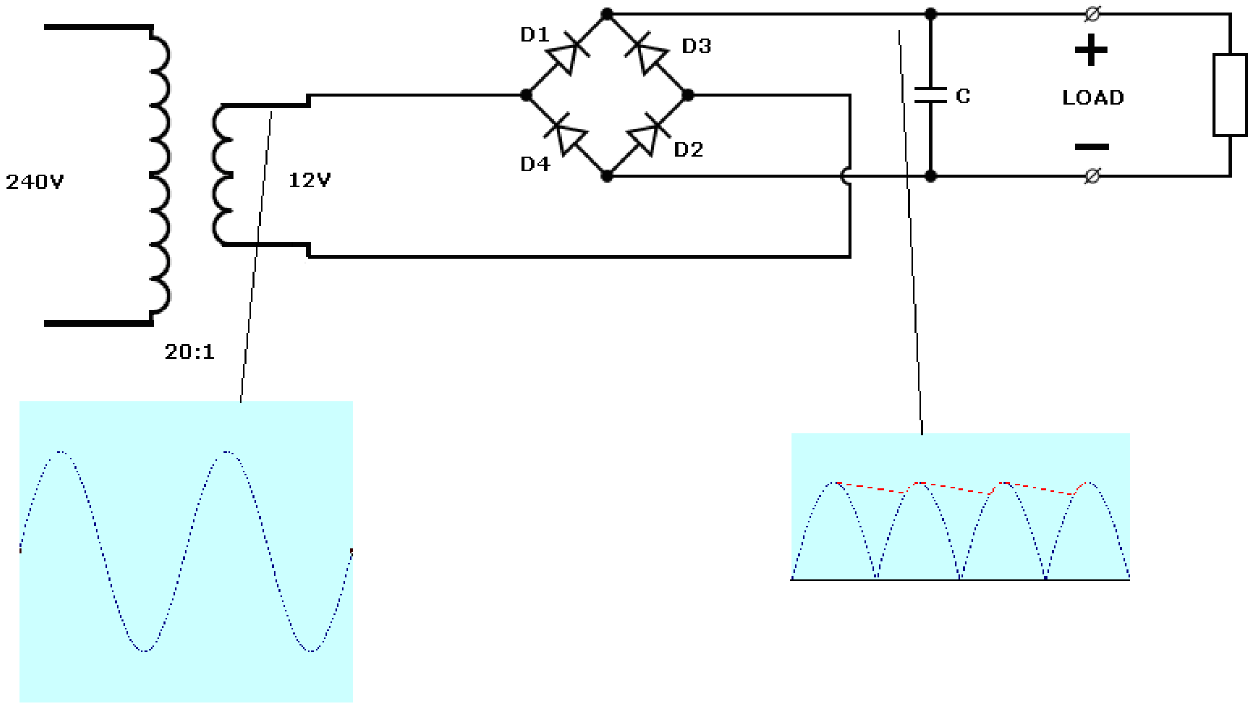

FIG 2

The voltage across the capacitor is shown as the red dotted line in FIG 2. If the capacitor is removed, we will get the output voltage of the bridge rectifier (shown in blue), so we can see that we have transformed the waveform from a sinewave at the input to the circuit to a pulsed waveform (shown in blue - coming out of the diode bridge), then to a smoothed voltage using a capacitor on the output (to produce the red waveform).

So what output voltage do we get? The transformer outputs a peak voltage of 16.9V, but its voltage is then dropped by 0.6V as it passes through a diode (D1). It is then dropped by another 0.6V as it passes through another diode (D2), so the highest voltage we will get across the capacitor is 16.9 – 1.2 = 15.7V. Referring back to our article on capacitors, we now have to choose our capacitor to have a working voltage of at least 15.7V. Good engineering practice states you should not take a component to within 80% of its maximum rating, so a capacitor with a voltage of 20V should allow enough 'headroom'.

So why isn't the voltage across the capacitor flat dc? Well, let's examine the red waveform. When the rectified output is at its maximum, the capacitor is fully charged. As the rectified voltage drops the capacitor holds charge, keeping the voltage high at the output. However, during this time, the load takes current from the capacitor, discharging it. When the rectified voltage comes back up again, it recharges the capacitor voltage and the cycle starts again. This change in dc voltage across the capacitor is called the ripple voltage.

The amount of droop on the capacitor is determined by the current drawn from the capacitor (the load current) and the capacitor value. (as a reminder, in our article on capacitors we mentioned that the discharge of a capacitor is dependent on the current being drawn from it).

There is an equation that describes this discharge:

$$I = C\frac{dv}{dt}$$

I is the current (in Amps) being taken from the capacitor, C is the capacitor value (in Farads), dv is the *change* in voltage and dt is the *change* in time.

Now for some numbers…

Our load current is normally known. Let's assume it is 100mA (=0.1A). If our output voltage is a maximum of 15.7V, we should normally design for a ripple voltage of no more than 10%, although 5% is better. I am going to design for a ripple voltage of 5%, so this gives me a 'dv' of 0.785V. This is illustrated in FIG 3.

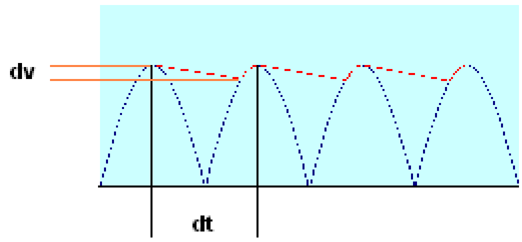

FIG 3

The only other unknown is the value of 'dt'. Looking at FIG 2, we see that the input voltage is at mains frequency (50Hz). The rectified voltage is at twice that frequency (100Hz). This has a period of 10ms (0.01s). We can see that our red waveform droops for nearly 10ms (but not quite), but it is good enough to approximate the droop time to be 10ms.

We now have all the information needed to work out what capacitor value will give us no more than 0.785V with a load current of 100mA. Plugging these numbers into the above equation gives:

$$0.1 = C\frac{0.785}{0.01}$$

Implying that C is 1273uF. Looking at my components catalogue, the next value above 1273uF is 2200uF. There are two versions – one with a working voltage of 16V and one with a working voltage of 35V. I will play safe and use the 35V version.

Putting this capacitance value back into the above equation implies my ripple (dv) should be about 454mV.

And so my power supply is designed!