P O W E R   S U P P L Y   D E T A I L S

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Many times, in power supplies, the designers put aside some important details.

This article tries to show some of them under the conceptual point of view.

With Figure 1 help, let's analyze the problem on a simple power supply, with half-wave rectifier, with no regulation. As the aim is a conceptual one, for such an analysis we would consider:

1 – the resistance of the input circuit zero.

2 – the diodes are ideal.

3 – the electrolytic capacitor has no losses.

4 – the output ripple is much smaller than the DC voltage itself. This makes the charge of the capacitor under constant current, or linear voltage with time.

5 – the time constant RC is much greater than the period T. This makes the capacitor discharge under constant current, or linear voltage with time.

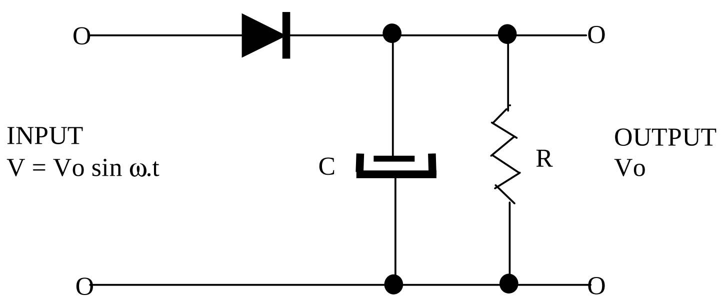

Figure 1

In Figure 2 we see that the capacitor charges during the first semi-cycle and, approximately at the voltage peak, the diode cuts off because the input voltage becomes smaller than the capacitor one, letting the latter to discharge through the resistance R. The discharge goes on until the next semi-cycle reaches the diode conduction and the capacitor starts to acquire charge till the next peak. The discharge time is T - Δt and the charge time that repeats is Δt.

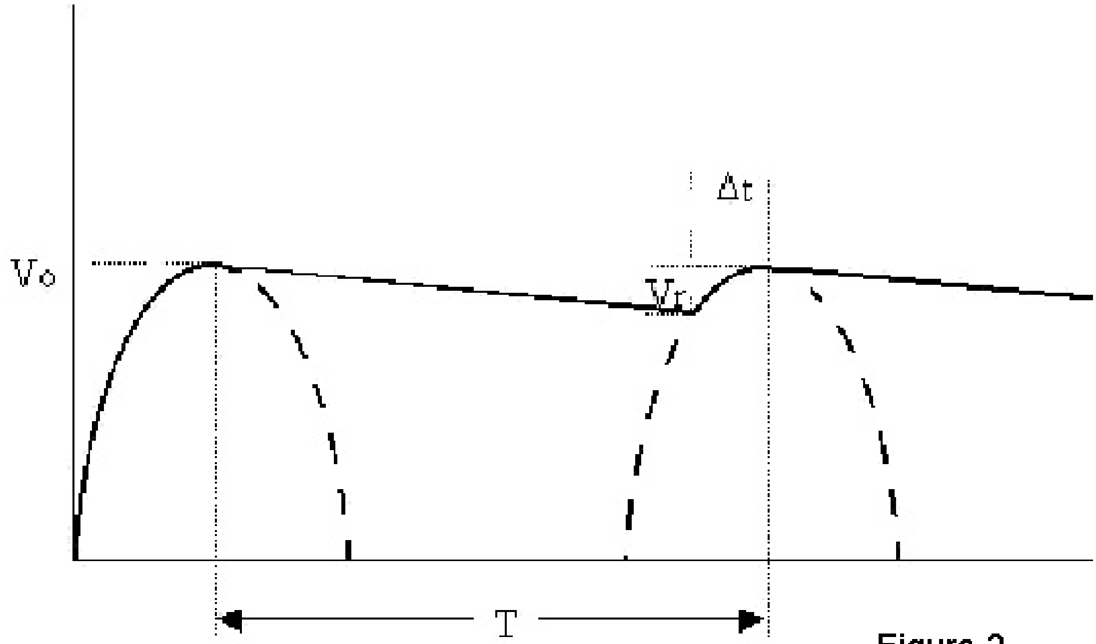

Figure 2

We see clearly that the smaller the ripple voltage Vr, the smaller the charge time Δt.

Let's analyze:

In each repetitive cycle, the capacitor loses charge through the resistance R during the time T - Δt. To recuperate its initial voltage Vo, it has to acquire charge during the time Δt. As the discharge occurs under constant current Io = Vo/R and the charge under constant current I, both are proportional to their duration time:

Lost charge Qp = Io . (T - Δt) and the restored charge Qr = I . Δt

As both those charges are equal, as the capacitor returns to its initial state, we have:

I . Δt = Io . (T - Δt) from where we get I:

I = Vo . (T – Δt) / (R . Δt)

In the small ripple hypothesis, T >> Δt and we have:

I = Vo . T / (R . Δt)   [1], valid for **Δt << T**

In [1], we see that, for constant Vo, R and T, the smaller Δt (smaller 'ripple'), the greater the charge current, which may be many times greater than the DC current Io.

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This means that, even for relatively low DC currents, the diode must support a repetitive current peak very high, if the desired ripple is small{1}.

If Δt is, for instance, 10% of T, I will 10 times greater than Io. If Δt is 1% T, I will be 100 times greater than Io!

So, it is not enough, therefore, to chose the diode relying only in the DC current. It may burn out if we demand a very small ripple. Let's see this rewriting [1]:

Considering $V = Vo \cdot \cos \omega.t$, at the charge semi-cycle, we have:

$Vo - Vr = Vo \cdot \cos \omega.\Delta t$, with $\omega = 2 \cdot \pi / T$:

or $2 \cdot \pi / T \cdot \Delta t = \text{Arc cos } (Vo - Vr) / Vo$

In the linear ramp charge approximation (small ripple), the function Arc cos (Vo – Vr) / Vo may be written as $1 - (Vo - Vr) / Vo$, or:

$2 \cdot \pi / T \cdot \Delta t = 1 - (Vo - Vr) / Vo$, from which we get Δt:

$\Delta t = Vr \cdot T / (2 \cdot \pi \cdot Vo)$ [2]

Carrying [2] to [1], one gets:

$I = 2 \cdot \pi \cdot Vo^2 / (R \cdot Vr)$ [3]

That shows now explicitly the dependence of the repetitive peak current I with the ripple Vr.

The energy Ec lost by the capacitor C during the discharge on R is:

$Ec = ½ \cdot C \cdot Vo^2 - ½ \cdot C \cdot (Vo - Vr)^2$

But this energy is dissipated in R (considering still $T >> \Delta t$):

$Ec = Vo^2 \cdot T / R$

Therefore:

$½ \cdot C \cdot Vo^2 - ½ \cdot C \cdot (Vo - Vr)^2 = Vo^2 \cdot T / R$

or $½ \cdot C \cdot Vo^2 - ½ \cdot C \cdot Vo^2 \cdot (1 - Vr / Vo)^2 = Vo^2 \cdot T / R$

If we consider $Vo >> Vr$, the expression $(1 - Vr / Vo)^2$ may be written as $(1 - 2 \cdot Vr / Vo)$ and we have:

$½ \cdot C - ½ \cdot C \cdot (1 - 2 \cdot Vr / Vo) = T / R$

{1}**This repetitive current peak must not be confused with the non-repetitive one that occurs during the capacitor charge at the first semi-cycle, but that is also a factor to be taken into account by the designer.**

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or C . Vr / Vo = T / R and we have for Vr:

Vr = Vo . T / (R . C)   [4]

Carrying [4] to[3]:

I = 2 . π . Vo . C / T   [5]

The expression [5] shows now the dependence of I with C, that is, I increases with C.

So, we ca see that the decrease of a power supply ripple by simply increasing the filter capacitor C may be disastrous, leading to the rectifier diode(s) burn-out.

Fortunately in the practical world fortunately the initial conditions of this article are not strictly valid. The input/diode/capacitor resistances are not zero and this limits, indeed, the maximum peak current, protecting the rectifier.

May be, however, that the output voltage is lower than the expected for the ideal case. When the input is done through a transformer, we have to take into account this smaller voltage in the choice of the former.

The operation in full-wave rectification leads to the same conclusions, only T falls to its half and, therefore, also the ripple. The repetitive peak currents on the diodes are divided by two: the charge time can be even kept, but the charge quantity is halved, as more charge remains in the capacitor after the discharge; besides, the charge current is shared by two diodes and, therefore, the average current per diode is halved too.

In the input, the voltage is sinusoidal, but the current is not. But being periodic, it may be decomposed in the fundamental and its harmonics.

Through the energy dissipated in R per period and the energy delivered by the input, we see that the output DC current related to the fundamental of the current, with no contribution from any harmonic to that energy.

This article doesn't want teach how to design power supplies. Many designs exist in the literature on the subject. It only tries to clear certain conceptual ideas commonly, are unknown or put aside by the designer.

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