Introduction

What is power electronics?

In contrast with other branches of electronics, which deal with processing or transmitting information using electric energy, power electronics deals with processing the flow of electric energy *per se*. The task of power electronics is to control the current or voltage waveforms to a desired form, which is required by the load or by the supply.

A power converter is the building block of power electronic systems. Most modern power converters are a variable structure systems (that change their structure via switching components to achieve a new, average behavior), whose state is controlled to obtain the desired waveforms. They can generally be divided into four categories, based on the forms of both sides:

From \ To:	DC	AC
DC	DC/DC converters: Nonisolated: buck, boost, buck-boost, Ćuk Isolated: full-bridge, flyback Applications: portable devices, PFC, internal power distribution.	Inverters: single/multi-phase, full/half-bridge Applications: renewable energy, UPS, electric vehicles, HVDC.
AC	Rectifiers: single/multi-phase, full/half-bridge Applications: all grid powered electronic devices, HVDC.	AC/AC converters: indirect conversion, Cycloconverters, matrix converters Applications: variable frequency drive, renewable energy.

Good texts on power electronics in general are Mohan, Undeland and Robbins [2] and Rashid [4]. Switching power supplies, and isolated converters in particular, are extensively explained in Pressman, Billings and Morey [3].

Our design example – a switch mode power supply

We look at the basic structure of a switching single phase AC/DC power supply, shown in Figure 1. A rectified AC voltage is passed through a capacitive low-pass filter, which holds the voltage at a fairly constant DC level with a ripple determined by its capacitance. Often, regulation also requires power factor compensation (PFC), which warrants an additional circuit before the filtering. A highly regulated low voltage, typically in the order of 3-24V, is usually required on the DC side, hence a DC/DC converter is used to step down the voltage. For safety reasons and the high voltage ratio, an insulated DC/DC converter topology is generally used (such as flyback, forward, push-pull, half and full bridge topologies [6]), which incorporates a high frequency transformer. To allow a proper functioning of the DC/DC converter, the ripple on its input voltage V_c must be constrained. The filter capacitor, with capacitance C, must supply the load between line peaks (at twice the grid frequency, if a full bridge rectifier is used) and allow the voltage to drop to a minimum $V_{\min}$. If we do not use a PFC, then the capacitance needed is

$$C = \frac{P}{f\left(V_{\text{pk}}^2 - V_{\min}^2\right)}, \tag{1}$$

where P is the converter input power, f the grid frequency and V_{pk} is the minimal peak voltage of the grid [5].

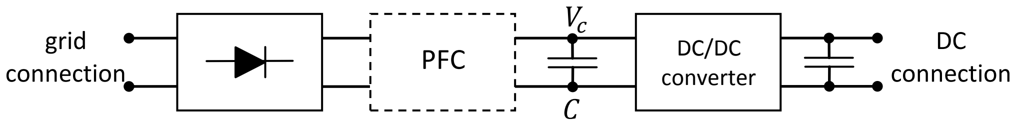

Figure 1: Simplified structure of a switching AC/DC power supply. The alternating grid voltage is first rectified, then filtered by a capacitor, converted to the required voltage and filtered again at the output side. The PFC stage is optional.

A practical rule of thumb is to choose the ripple on V_c to be 25-30% of the minimum peak grid voltage. Using (1), we find that a typical 500W power supply would require a 300μF capacitor (the capacitance is proportional to the power of the converter).

Basic circuit theory

There are four basic types of two-terminal circuit elements, each corresponding to a relation between two independent variables:

1. Relationship between the voltage V and the current I: a *resistor* ;
2. Relationship between V and the charge Q: a *capacitor* ;
3. Relationship between I and the magnetic flux Φ: an *inductor* ;
4. Relationship between Q and Φ: a *memristor* [1].

A relationship does not necessarily mean a function. For example, in a hysteresis type relation between I and Φ, as common in an inductor, Φ cannot be expressed as a function of I (and vice verse). Often, a circuit element can be expressed by a continuous and piecewise smooth curve in the correct plane, one of the following I-V, Q-V, I-Φ or the Q-Φ plane. Then the element is characterized by that curve, and will belong to the corresponding type.

When the relationship describing a component is a linear function, the component is said to be linear. Therefore, a linear resistor is characterized by a straight line through the origin of the $V-I$ curve, and is described by $V = IR$ where R is the *resistance*. Similarly, a linear capacitor is described by $Q = CV$ where C is the *capacitance*, a linear inductor is described by $\Phi = LI$ where L is the *inductance*, and a memristor is described by $\Phi = MQ$ where M is the *memristance* (a memristor will not be discussed further in this course).

Since only voltage and current are measurable in a conventional electrical circuit (that way, we can relate to them as *signals*), we are interested in the effect of capacitors and inductors on those variables. We recall that the charge Q is the time integral of the current I, and that the magnetic flux is the time integral of the voltage V (Faraday's law), hence

$$C\dot{V} = I,\ \ L\dot{I} = V\ . \tag{2}$$

The conservation of energy and charge are expressed in Kirchhoff laws, namely:

1. The sum of currents in the conductors meeting at a point is zero. (KCL)
2. The sum of the voltages around any closed network is zero. (KVL)

The relations (2) and Kirchhoff's laws enable us to describe the behavior of a linear circuit (a circuit that includes only linear components) via a set of ordinary differential equations. Consequentially, using the Laplace transform we can write a transfer function between the various signals (voltage or current) in the circuit.

An example:

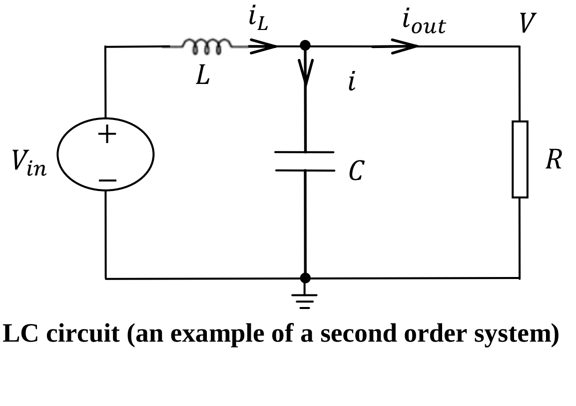

Figure 2: A LC circuit (an example of a second order system)

We write down the ODE corresponding to each capacitor and inductor:

$$L\dot{i}_L = V_{in} - V ,$$
$$C\dot{V} = i = i_L - V/R .$$

Hence,

$$\ddot{V} + \frac{1}{RC}\dot{V} + \frac{1}{LC}V = \frac{V_{in}}{LC} .$$

Using Laplace transform we get the transfer function from V_{in} to V:

$$H(s) = \frac{V}{V_{in}} = \frac{1}{LCs^2 + \frac{L}{R}s + 1} .$$

In this course we also deal with switching components (for example, FETs and IGBTs, discussed in the lecture by Prof. Weiss), diodes (components that conduct current only in one direction) and transformers. The latter are fundamental components in all isolated power converters, and will be discussed later on.

References

[1] M. Di Ventra, Y. V. Pershin and L. O. Chua, "Circuit elements with memory: memristors, memcapacitors and meminductors," in *Proc. of IEEE*, vol. 97, no. 10, Oct. 2009.

[2] N. Mohan, T. M. Undeland and W. P. Robbins, *Power electronics: converters, applications and design*, 3rd ed., Hoboken, NY: John Wiley and Sons, Inc., 2003.

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[4] M. H. Rashid, *Power Electronics: Circuits, Devices, and Applications*, 3rd ed., Englewood Cliffs, NJ: Prentice-Hall Inc., 2003.

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