Understanding AC/DC Power Supplies

By Tomas Hudson, Applications Engineer at MPS

What is a Power Supply?

A power supply is an electrical device that converts the electric current that comes in from a power source, such as the power mains, to the voltage and current values necessary for powering a load, such as a motor or electronic device.

The objective of a power supply is to power the load with the proper voltage and current. The current must be supplied in a controlled manner — and with an accurate voltage — to a wide range of loads, sometimes simultaneously, all without letting changes in the input voltage or in other connected devices affect the output.

A power supply can be external, often seen in devices such as laptops and phone chargers, or internal, such as in larger devices such as desktop computers.

A power supply can either be regulated or unregulated. In a regulated power supply, the changes in the input voltage do not affect the output. On the other hand, in an unregulated power supply, the output depends on any changes in the input.

The one thing all power supplies have in common is that they take electric power from the source at the input, transform it in some way, and deliver it to the load at the output.

The power at the input and output can be either alternating current (AC) or direct current (DC):

- Direct current (DC) occurs when the current flows in one constant direction. It usually comes from batteries, solar cells, or from AC/DC converters. DC is the preferred type of power for electronic devices.
- Alternating current (AC) occurs when the electric current periodically inverts its direction. AC is the method used to deliver electricity through power transmission lines to homes and businesses.

Therefore, if AC is the type of power delivered to your house and DC is the type of power you need to charge your phone, you are going to need an AC/DC power supply in order to convert the AC voltage coming in from the power grid to the DC voltage needed to charge your mobile phone's battery.

Understanding Alternating Current (AC)

The first step in any power supply design is to determine the input current. And in most cases, a power grid's input voltage source is AC.

The typical waveform for an alternating current is a sine wave (see Figure 1).

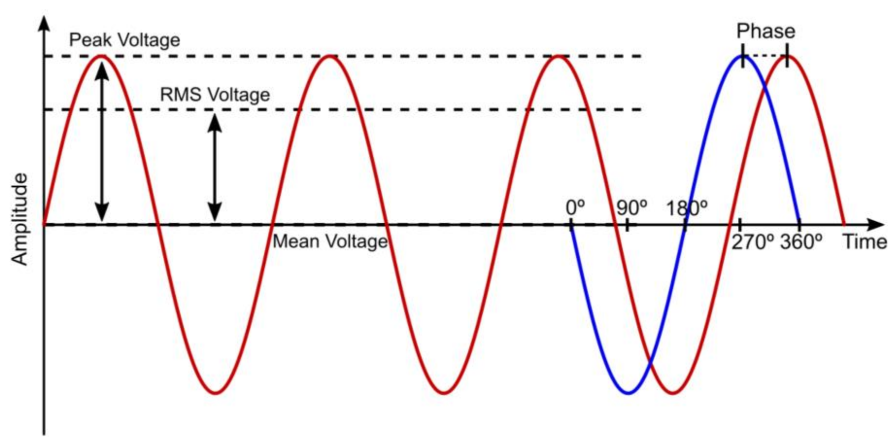

Figure 1: AC Waveform and Basic Parameter

There are several indicators that must be taken into account when working with an AC power supply:

- Peak voltage/current: The maximum value of amplitude the wave can reach
- Frequency: The number of cycles the wave completes per second. The time it takes to complete a single cycle is called the period.
- Mean voltage/current: The average value of all the points the voltage takes during one cycle. In a purely AC wave with no superimposed DC voltage, this value will be zero, because the positive and negative halves cancel each other out.
- Root-mean-square voltage/current: It is defined as the square root of the mean over one cycle of the square of the instantaneous voltage. In a pure AC sinusoidal wave, its value can be calculated with Equation (1):

  $$\frac{V_{PEAK}}{\sqrt{2}} \quad (1)$$

  It can also be defined as the equivalent DC power needed to produce the same heating effect. Despite its complicated definition, it is widely used in electrical engineering because it allows you to find the effective value of an AC voltage or current. Because of this, it is sometimes expressed as VAC.
- Phase: The angular difference between two waves. A complete cycle of a sine wave is divided into 360°, starting at 0°, having peaks at 90° (positive peak) and 270° (negative peak) and crossing the start point twice, at 180° and 360°. If two waves are plotted together, and one wave reaches its positive peak at the same time that the other reaches its negative peak, then, the first wave will be at 90°, while the second wave will be at 270°; this means the phase difference is 180°. These waves are considered to be in antiphase, as their values will always have opposite signs. If the phase difference is 0°, then we say the two waves are in phase.

Alternating current (AC) is the way electric power is transmitted from generating facilities to end users. It is used for power transportation because electricity needs to be transformed several times during the transportation process.

Electric generators produce voltages of about 40,000V, or 40kV. This voltage is then stepped up to anywhere between 150kV and 800kV, to reduce power losses when transporting electric current over long distances. Once it reaches its destination area, the voltage is stepped down to between 4kV and 35kV. Finally, before the current reaches individual users, it is reduced to 120V or 240V, depending on the location.

All these changes in voltage would be either complicated or very inefficient to do with direct current (DC), because linear transformers depend on voltage fluctuation to transfer and transform electrical energy, so they can only work with alternating current (AC).

Linear vs. Switching Power Supplies

Linear AC/DC Power Supply

A linear AC/DC power supply has a simple design.

By using a transformer, the alternating current (AC) input voltage is reduced to a value more suitable for the intended application. Then, the reduced AC voltage is rectified and turned into a direct current (DC) voltage, which is filtered in order to further improve the waveform quality (Figure 2).

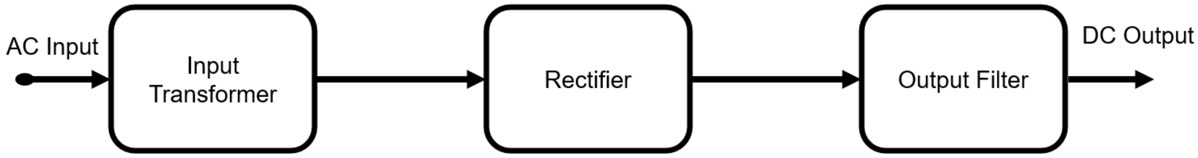

Figure 2: Linear AC/DC Power Supply Block Diagram

Traditional linear AC/DC power supply design has evolved over the years, improving in terms of efficiency, power range, and size — but this design has some significant flaws that limit its integration.

A huge limitation in a linear AC/DC power supply is the size of the transformer. Because the input voltage is transformed at the input, the necessary transformer would have to be very large and therefore very heavy.

At low frequencies (e.g. 50Hz), large inductance values are necessary to transfer high amounts of power from the primary to secondary coil. This demands large transformer cores, which makes miniaturization of these power supplies practically impossible.

Another limitation of linear AC/DC power supplies is the high-power voltage regulation.

A linear AC/DC power supply uses linear regulators to maintain a constant voltage at the output. These linear regulators dissipate any extra energy in the form of heat. For low power, does not pose much of a problem. However, for high power, the heat that a regulator would have to dissipate to maintain a constant output voltage is very high, and would require adding extremely large heatsinks.

Switching AC/DC Power Supply

New design methodology has been developed to solve many of the problems associated with linear or traditional AC/DC power supply design, including transformer size and voltage regulation.

Switching power supplies are now possible thanks to the evolution of semiconductor technology, especially thanks to the creation of high-power MOSFET transistors, which can switch on and off very quickly and efficiently, even if large voltages and currents are present.

A switching AC/DC power supply enables the creation of more efficient power converters, which no longer dissipate the excess power.

AC/DC power supplies that are designed using switching power converters are called switched-mode power supplies. AC/DC switched-mode power supplies have a slightly more complex method for converting AC power to DC.

In switching AC power supplies, the input voltage is no longer reduced; rather, it is rectified and filtered at the input. Then the DC voltage goes through a chopper, which converts the voltage into a high-frequency pulse train. Finally, the wave goes through another rectifier and filter, which converts it back to direct current (DC) and eliminates any remaining alternating current (AC) component that may be present before reaching the output (see Figure 3).

When operating at high frequencies, the transformer's inductor is able to transfer more power without reaching saturation, which means the core can become smaller and smaller. Therefore, the transformer used in switching AC/DC power supplies to reduce the voltage amplitude to the intended value can be a fraction of the size of the transformer needed for a linear AC/DC power supply.

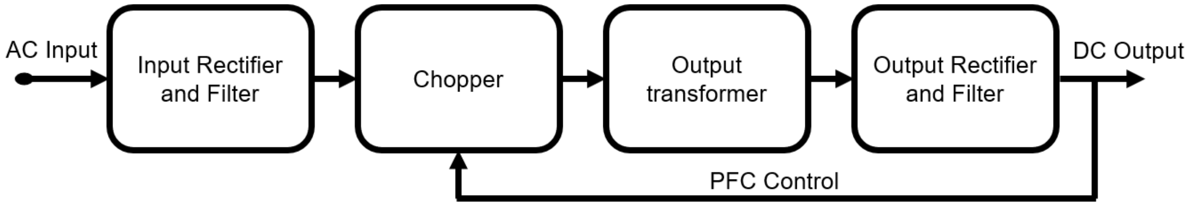

Figure 3: Switched-Mode AC/DC Power Supply Block Diagram

As could be expected, this new design method does have some drawbacks.

Switching AC/DC power converters can generate a significant amount of noise in the system, which must be treated to ensure it is not present at the output. This creates a need for more complex control circuitry, which in turn adds complexity to the design. Nevertheless, these filters are made up of components that can be easily integrated, so it does not affect the size of the power supply significantly.

Smaller transformers and increased voltage regulator efficiency in switching AC/DC power supplies are the reason why we can now convert a 220V¬RMS AC voltage to a 5V DC voltage with a power converter that can fit in the palm of your hand.

Table 1 summarizes the differences between linear and switching AC/DC power supplies.

Table 1: Linear vs. Switching Power Supplies

	Linear AC/DC Power Supplies	**Switching AC/DC Power Supplies**
Size and Weight	Large transformers are necessary, adding substantial size and weight.	Higher frequencies allow for much smaller transformers, if needed.
Efficiency	If unregulated, transformer losses are the only significant causes for efficiency loss. If regulated, high power applications will have a critical effect on efficiency.	Transistors offer small switching losses, because they behave as small resistances. This enables **efficient high-power applications**.
Noise	Unregulated power supplies may have significant noise caused by the voltage ripple, but **regulated linear AC DC power supplies can have extremely low noise**. **That is why they are used in medical sensing applications.**	When transistors switch very quickly, they generate noise in the circuit. However, this can be either filtered out, or the switching frequency can be made extremely high, above the limit of human hearing, for audio applications.
Complexity	A linear AC/DC power supply tends to have fewer components and simpler circuits, than switching AC/DC power supply.	The added noise generated by the transformers forces the addition of large, complex filters, as well as control and regulation circuitry for the converters.

Single-Phase vs. Three-Phase Power Supplies

An alternating current (AC) power supply can either be single-phase or three-phase:

- A three-phase power supply is composed of three conductors, called lines, which each carry an alternating current (AC) of the same frequency and voltage amplitude, but with a relative phase difference of 120°, or one-third of a cycle (see Figure 4). These systems are the most efficient at delivering large amounts of power, and are therefore used for delivering electricity from generating facilities to homes and businesses all around the world.

- A single-phase power supply is the preferred method to supply current to individual homes or offices, so as to distribute the load evenly between lines. In this case, the current flows from the power line through the load, then back through the neutral wire. This is the type of supply found in most installations, except large industrial or commercial buildings. Single-phase systems cannot transfer as much power to loads and are more prone to power failures, but single-phase power also allows use of much simpler networks and devices.

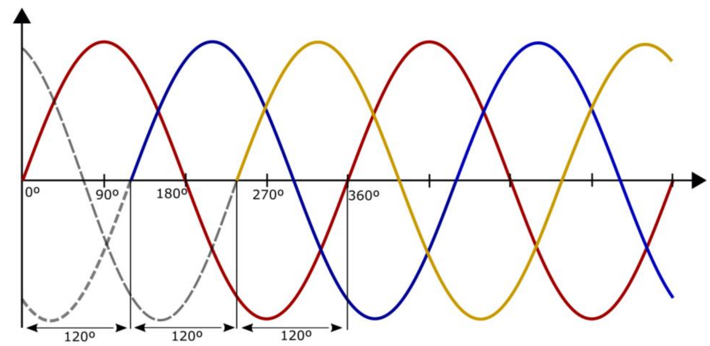

Figure 4: Three-Phase Power Supply AC Waveform

There are two configurations for the transmission of power through a three-phase power supply: delta (Δ) and wye (Y) configurations, also referred to as triangle and star configurations, respectively.

The main difference between these two configurations is the ability to add a neutral wire (see Figure 5).

Delta connections offer greater reliability, but Y connections can supply two different voltages: phase voltage, which is the single-phase voltage supplied to homes, and line voltage, for powering larger loads. The relationship between phase voltage (or phase current) and line voltage (or line current) in a Y configuration is that the line voltage (or current) amplitude is $\sqrt{3}$ times larger than the phase magnitude.

Because a standard power distribution system must supply power to both three-phase and single-phase systems, most power distribution networks have three lines and a neutral. This way, both homes and industrial machinery can be supplied with the same transmission line. Therefore, the Y configuration is the most commonly used for power distribution, whereas the delta configuration is typically used to power three-phase loads, such as large electric motors.

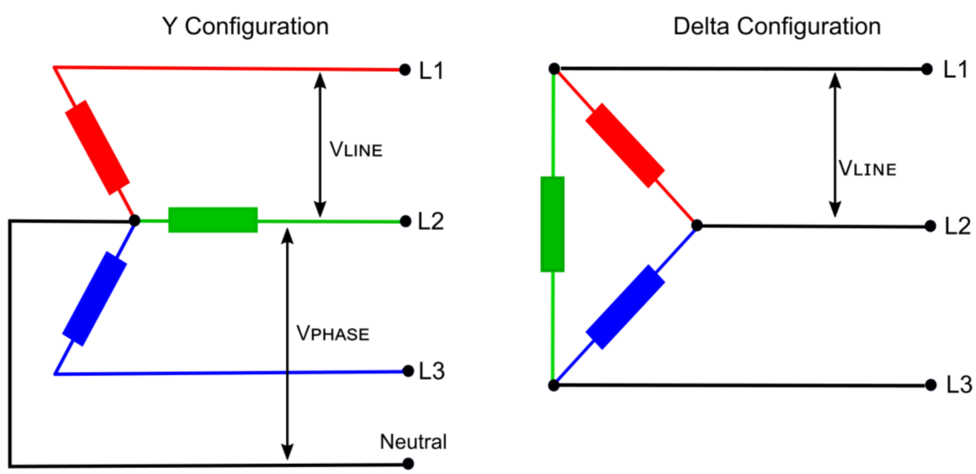

Figure 5: Y and Delta Three-Phase Configurations

The voltage at which the power grid delivers single-phase electric power to its users has various values, depending on the geographical location. That is why it is very important to check a power supply's input voltage range before buying or using it, to ensure that it is designed to work in your country's power grid. Otherwise, you could damage the power supply or the device connected to it.

Table 2 compares the grid voltages in different areas around the world.

Table 2: Grid Voltages by Region

RMS (AC) Voltage	Peak Voltage	Frequency	Region
230V	310V	50Hz	Europe, Africa, Asia, Australia, New Zealand, and South America
120V	170V	60Hz	North America
100V	141V	50Hz/60Hz	Japan*

*Japan has two frequencies in its national grid because of the origins of its electrification in the late 19th century. In the western city of Osaka, electricity suppliers bought 60Hz generators from the United States, while in Tokyo, which is in the east of Japan, they bought 50Hz German generators. Both sides refused to change their frequency, and to this day Japan still has two frequencies: 50Hz in the east, 60Hz in the west.

As mentioned before, three-phase power is not only used for transportation, but is also used to power large loads, such as electric motors or charging large batteries. This is because the parallel application of power in three-phase systems can transfer much more energy to a load, and can do so more evenly, due to the overlapping of the three phases (see Figure 6).

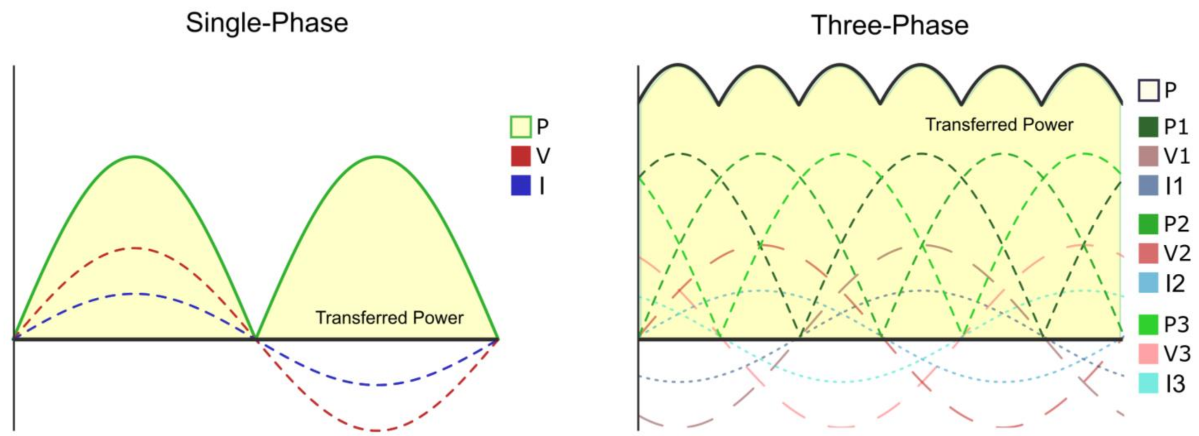

Figure 6: Power Transmission in Single-Phase (Left) and Three-Phase (Right) Systems

For example, when charging an electric vehicle (EV), the amount of power you can transfer to the battery determines how fast it charges.

Single-phase chargers are plugged into the alternating current (AC) mains and converted to direct current (DC) by the car's internal AC/DC power converter (also called an on-board charger). These chargers, are limited in power by the grid and the AC socket.

The limitation varies from country to country, but is typically less than 7kW for a 32A socket (in EU, 220 x 32A = 7kW). On the other hand, three-phase power supplies convert the power from AC to DC externally, and can transfer over 120kW to the battery, enabling super-fast charging.

Summary

AC/DC power supplies are everywhere. The main job of an AC/DC power supply is to transform the alternating current (AC) into a stable direct current (DC) voltage, which can then be used to power different electrical devices.

Alternating current is used to transport electric power all across the electric grid, from generators to end users. An alternating current (AC) circuit can be configured as a single-phase or a three-phase system. Single-phase systems are simpler, and can deliver enough power to supply an entire house, but three-phase systems can deliver much more power in a more stable way, which is why they are frequently used to supply power for industrial applications.

Designing an efficient AC/DC power supply is no easy task, as current markets demand high-power, extremely efficient, minuscule power supplies that are capable of maintaining efficiency over a wide range of loads.

Methods for designing an AC/DC power supply have changed over time. Linear AC/DC power supplies are limited in size and efficiency, because they work at low frequencies and regulate the output temperature by dissipating the excess energy in the form of heat. By contrast, switching power supplies have become extremely popular, because they use switching regulators to convert AC to DC power. Switching power supplies work at higher frequencies and convert electrical power far more efficiently than previous designs, which has enabled the creation of palm-sized, high-power AC/DC power supplies.