DC Power Supplies - Fundamental Concepts

An Online Continuing Education Course for Engineers

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DC POWER SUPPLIES: FUNDAMENTAL CONCEPTS

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Scope of Course

This course describes the functions, basic components, circuit configurations, and performance characteristics of typical DC power supplies (DCPS) found in all modern electronic devices which receive power from the common AC (alternating current) wall socket. The discussion relates to "power supplies", which process the power from a source into one or more DC (direct current) voltages, as distinguished from "power sources", which may be batteries, solar cells, or AC power systems. That distinction also defines the primary purpose of a DCPS.

Modern appliances typically have electronic components for sensing, control, timing, and, sometimes, power switching. Older kitchen appliances did not need a DCPS, since they used the AC directly for motors, relays, small timing devices, and all their other necessary functions. Today's ovens, refrigerators, and dishwashers usually have circuits requiring a DCPS, along with TV, radios, and computers.

Three configurations of DCPS are discussed in the sequence they were developed and entered the mainstream of electronic products. Each is identified for purposes of this course by an acronym, as follows:

LRPS: Linear Regulator Power Supply
SRPS: Switching Regulator Power Supply
SMPS: Switched Mode Power Supply

The term DCPS is used when the discussion applies to all three types.

Electrical Quantities

The names of common electrical quantities are capitalized because they usually are named in honor of scientists and inventors who contributed to fundamental advances in science. Units, their related name sources, and definitions are:

Volt (V): Alessandro Volta, 1745-1827, Italian physicist
The unit of "electromotive force" (emf, V)) which causes electricity to "flow". One volt is equal to the emf produced across a resistance of one Ohm in which is flowing a current of one Ampere.

$V = I \times R$ V (Voltage = current x resistance, Volts)

Ampere (A): Andre Marie Ampere, 1775-1836, French physicist
The unit of electrical current (I) equal to a flow of one Coulomb per second and equal to the current produced by one Volt applied across a resistance of one Ohm.

$I = V/R$ A (Current = voltage / resistance, Amperes)

Watt (W): James Watt, 1736-1819, Scottish inventor
The unit of power (P) equal to the work done at the rate of one Joule per second or the rate of work represented by a current of one Ampere under an emf pressure of one Volt.

$P = I \times V$ W (Power = current x voltage, Watts)

Ohm (Ω): Georg Simon Ohm, 1787-1854, German physicist
The unit of electrical resistance (R) equal to the resistance of a circuit in which a potential difference of one Volt produces a current of one Ampere.

$R = V / I$ Ω (Resistance = voltage / current, Ohms)

Hertz (Hz): Heinrich Rudolf Hertz, 1857-1894, German physicist
A unit of frequency equal to one cycle per second.

Coulomb (C): Charles Augustine de Coulomb, 1736-1806, French physicist
The unit of electrical charge (Q) equal to the quantity of electricity transferred by a current of one Ampere in one second.

$Q = I \times T$ C (Charge = current x time (sec), Coulombs)

Joule (J): James Prescott Joule, 1818-1889, English physicist
The unit of work or energy (E) equal to that resulting from a power of one Watt applied for one second.

$E = P \times T$ J (Energy = power x time(sec), Joules)

Some of the definitions given may seem esoteric. What is significant for this course are the names and symbols of the most common units of measurement and their relationships to the other units.

AC Power Source

Our wall socket standard is 120 Vrms, 60 Hz power, a fundamental factor in DCPS design. Other voltages and/or 50 Hz frequency are used in some other countries. The origin of this type of power source is so little known, and its impact on the world so pervasive, that a brief history is in order.

In the 1880s, renowned inventor Thomas Edison was busily capitalizing on one of his many inventions, the incandescent light bulb. That industry depended on power for the light bulbs, so Edison was designing and installing electric generator stations while routing electric wires to buildings and homes. In addition to light bulbs, DC motors were a major interest for mechanizing many tasks formerly done by hand labor. The power was DC because designs for DC generators and motors were well known while AC motor designs were believed to be technically unfeasible.

DC has some drawbacks. In the transmission of electricity, the transmission wires carrying the power have resistance which causes part of the power to be lost as heat. The lost power and resulting voltage "drop" are calculated by:

$P_L = I^2 R$

$V_L = I R$

Where

P_L is power lost, W

I is current, A.

R is resistance, Ohms.

V_L is voltage loss, V

In order to deliver a certain voltage to the load, the generator had to supply a higher voltage, allowing for the voltage drop. Even then, the practical distance from a generating station to the point of use was limited to a mile or so. Larger conductors would reduce resistance (and voltage drop and loss) but were not economical or practical. Higher transmission voltage would reduce the current (and voltage drop and loss) for the same amount of power, since $P = I V$, i.e., the higher the voltage, the lower the current. Unfortunately, DC voltages above a few hundred volts were difficult to generate and converting DC from one voltage to another was not a simple process. As a result, a great number of relatively small generating stations had to be built, each serving only a limited surrounding area.

It was at that time that a brilliant young Serbian engineer named Nikola Tesla immigrated to the U.S. He had worked on electrical systems for years in Europe and, on his own, had conceived the design for AC motors and entire AC systems, having already built such a motor and successfully tested it. He had not been able to interest anyone in even looking at his concept and designs. He worked for a time for Edison, who was not receptive to a system which he believed could not work (and, if it did, would render his own power stations obsolete). After leaving Edison and enduring some difficult times, Tesla patented an array of AC devices - motors, generators, systems. Another successful inventor, George Westinghouse, hired Tesla, bought his patents and expertise, and established AC power as the preferred technique. (The entire story is much longer, much more technically complex, and very interesting.)

The advantages of AC over DC are fundamental. With electrical transformers, moderate voltages generated could be easily increased ("stepped up") to very high voltages, many thousands of volts, for long-distance power transmission. The correspondingly lower current caused less voltage drop and loss, and smaller conductors could be used. At the point of use, the voltage was converted ("stepped down") to a lower one suitable for home and office use or other voltages for industrial use.

Tesla was an inventor as imaginative and prolific as Edison and left a legacy of inventions. Unfortunately, he died without leaving details and proof of some very intriguing concepts still being studied. And we were provided with our standard AC power source.

Basic DCPS

Most devices use relatively low DC voltages, such as 5 V, 10 V, 12 V, and 15 V, both positive and negative in some applications. The latest electronic circuits require only 3 V, designed to utilize certain types of batteries.

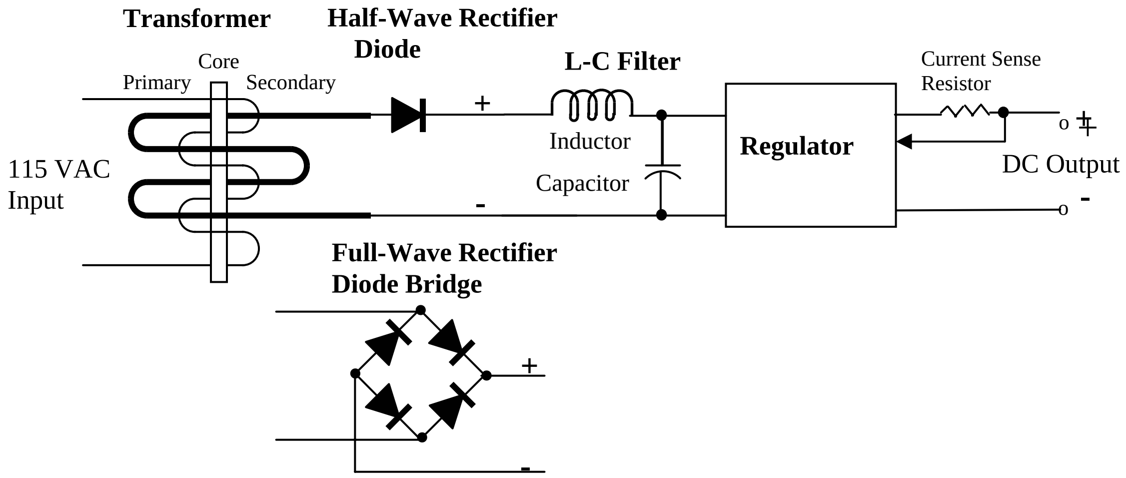

Figure 1: Basic DC Power Supply Schematic Diagram

A basic DCPS is shown schematically in Figure 1. Its component functions are:

> <u>Transformer</u>: Steps the voltage down or up to an AC voltage level suitable for producing the desired DC output voltage,
> <u>Rectifier</u>: Converts the AC wave to DC.
> <u>Filter</u>: Smoothes the AC ripple in the rectified waveform.
> <u>Regulator</u>: Keeps the DC output voltage nearly constant in spite of variations in the AC input voltage and load current.

Transformer

A transformer consists of a metal core - usually iron or ferrite, a ceramic ferromagnetic material - around which are wound at least two coils of wire, a primary winding and one or more secondary windings. A varying magnetic field is created in the core material by the AC input on the primary winding, in turn causing an AC voltage to be induced in the secondary winding. The secondary voltage is related to the primary voltage by the ratio of winding turns, as:

$$\text{Vsec} = \text{Vpri} \times \text{Nsec}/\text{Npri}$$

Where:

Vsec is the voltage available from the secondary.
Vpri is the voltage applied to the primary.
Nsec is the number of turns in the secondary winding.
Npri is the number of turns in the primary winding.

Example: A secondary voltage of 10 Vrms is desired with primary voltage of 120 Vrms and 120 turns in the primary.

Nsec = Npri x Vsec / Vpri = 120 x 1 … rns, secondary winding

Wir … suitable
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c

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