# Introduction to Voltage Regulators

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## Introduction

Voltage regulation is the process of holding a voltage steady under conditions of changing applied voltage and changing load current. Many electronic systems require a stable power supply voltage and use voltage regulators to accomplish that.

There are two types of voltage regulators, shunt and series. The name comes from where the control element (typically a transistor) is placed. Except for the special case of a Zener diode shunt regulator which is open-loop, virtually all voltage regulators are closed-loop high-gain proportional control systems.

## Shunt regulators

In shunt regulation a resistor is typically placed in series with the load and the unregulated voltage. The resistor is small enough so that the load could always receive somewhat more than the maximum current it would ever need. The shunt regulator is placed across the load and conducts excess current around the load such that the voltage across the load remains a constant as the load draws the actual current at any given time. A common shunt regulator is a Zener diode which is an example of an open loop system. Feedback control can also be used to drive the current through the control element (a transistor) across the load. Shunt regulators are generally only used for low power applications because they can be very inefficient. However, shunt regulators have an inherent fault current limiting feature and also can regulate even if the load is forcing current into the regulator rather than drawing current from it. Shunt regulators also have an interesting feature that the input current is constant – independent of load current (except if a load fault occurs – but that is a special case not in normal operation). Thus shunt regulators are very good at isolating a load with rapid and large current fluctuations.

## Series regulators

In series regulation the control element is placed between the unregulated voltage source and the load and the current through the element is controlled so that the voltage across the load is held constant. A feedback control system is used where the difference between the output voltage and a reference voltage is applied to a high gain amplifier that drives the current control element such as to maintain the setpoint output voltage. The majority of voltage regulators are of the series type.

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## Voltage regulation metrics

The purpose of a voltage regulator is to maintain a constant voltage across a load regardless of variations in the applied input voltage and variations in the load current. Two metrics, line regulation and load regulation, are used to quantify the performance of a voltage regulator.

**Line regulation** refers to the ability of the voltage regulator to reject variations in the applied voltage (often referred to as the line voltage because it is usually derived from the AC power line) and is expressed as a percentage. Ideally, the line regulation would be zero percent meaning that the output voltage is perfectly independent of the line voltage. The equation for line regulation is as follows. Note that line voltage can also mean the DC input voltage for some applications. Line regulation always refers to whatever the input of interest is. Line regulation is expressed in percent and the ideal value is zero meaning that the output voltage is completely independent of the input voltage.

$$Line\ regulation = \frac{V_{O\ @\ highest\ line\ voltage} - V_{O\ @\ lowest\ line\ voltage}}{V_{O\ @\ nominal\ line\ voltage}} \times 100\% \tag{1}$$

The nominal line voltage is typically the mid point between the highest and the lowest. As an example an AC line operated power supply produces an output voltage of 12.13 VDC when the AC line voltage is 125 VAC and an output voltage of 11.95 VDC when the AC line voltage is 115 VAC. The nominal or average output is (12.13 +11.95)/2 = 12.04. Using Equation 1 the line regulation is (12.13 – 11.95)/12.04 x 100% = 1.5%. Good voltage regulators have a line regulation of well under one percent.

**Load regulation** refers to the ability of a voltage regulator to maintain a constant voltage as the load current varies and is expressed as a percentage. Ideally, the load regulation would be zero percent meaning that the output voltage is perfectly independent of the load current. The equation for load regulation is as follows.

$$Load\ regulation = \frac{V_{O\ @\ no\ load} - V_{O\ @\ full\ load}}{V_{O\ @\ full\ load}} \times 100\% \tag{2}$$

As an example the output of a voltage regulator is 5.04 volts at no load and 4.92 volts at full load. The load regulation is (5.04 – 4.92)/4.92 x 100% = 2.4%.

The **output resistance** (also known as source resistance) of a voltage regulator is a close cousin of its load regulation. Figure 1 illustrates how the output voltage of a regulator typically changes as a function of load current. Initially, the slope is quite linear but once the load current becomes higher than the design then the voltage will often drop rapidly with an increase in current. We measure the output resistance only on the linear portion of the plot in the normal operating region. It is meaningless to use a point in the overload area as that will result in an artificially high output resistance.

$$R_O = \frac{V_{NO\_LOAD} - V_{FULL\_LOAD}}{I_{FULL\_LOAD} - I_{NO\_LOAD}} \tag{3}$$

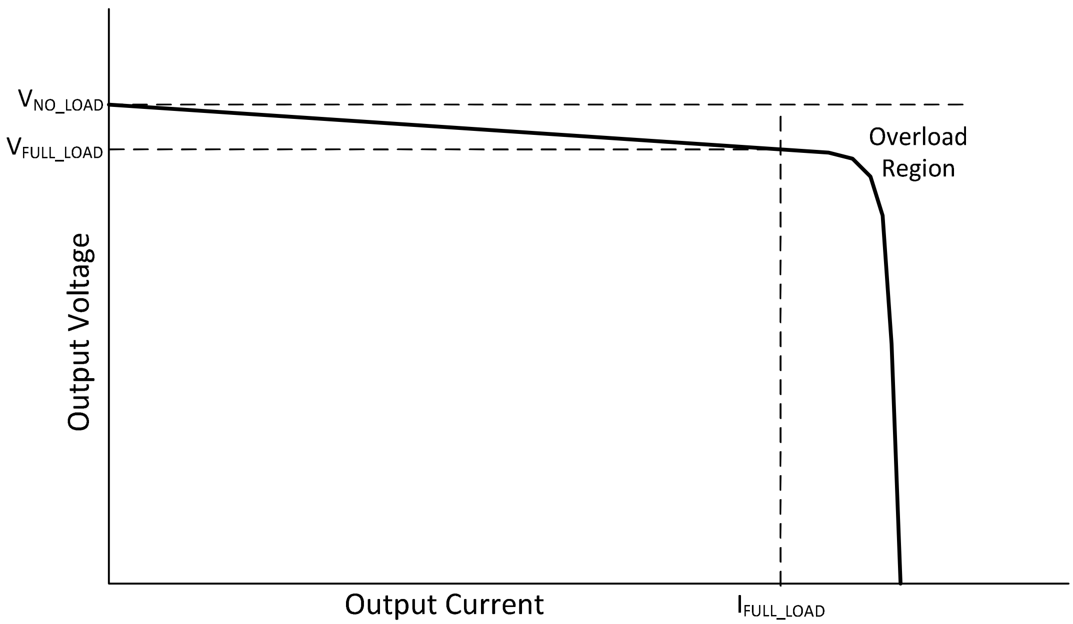


Figure 1: Typical voltage versus load current plot

Although the no-load and full-load values are used we can pick any pair of load points within the linear operating region. As an example, the output of a voltage regulator is 5.04 volts at no load (i.e. zero load current) and 4.92 volts at the full output current of 5 amperes. The output resistance of the regulator is (5.04 – 4.92) / (5 – 0) = **0.024 ohms**. It is not always convenient to measure the output at the full load current. We could use two different loads as in the following example. The output of a voltage regulator is 12.34 volts at a load current of 0.58 amperes and 11.56 volts at a load current of 2.4 amperes. Its output resistance is (12.34 – 11.56)/(2.4 – 0.58) = **0.43 ohms**.

It is possible for $R_O$ to be negative – an undesirable characteristic often caused by poor layout design in the regulator wiring resulting in inadvertent positive feedback. With negative output resistance the output voltage increases with the load current.