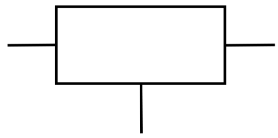
Voltage regulator



Electronic symbol for Voltage regulator

A **voltage regulator** is an electrical regulator designed to automatically maintain a constant voltage level.

It may use an electromechanical mechanism, or passive or active electronic components. Depending on the design, it may be used to regulate one or more AC or DC voltages.

With the exception of passive shunt regulators, all modern electronic voltage regulators operate by comparing the actual output voltage to some internal fixed reference voltage. Any difference is amplified and used to control the regulation element in such a way as to reduce the voltage error. This forms a negative feedback control loop; increasing the open-loop gain tends to increase regulation accuracy but reduce stability (avoidance of oscillation, or ringing during step changes). There will also be a trade-off between stability and the speed of the response to changes. If the output voltage is too low (perhaps due to input voltage reducing or load current increasing), the regulation element is commanded, *up to a point*, to produce a higher output voltage - by dropping less of the input voltage (for linear series regulators and buck switching regulators), or to draw input current for longer periods (boost-type switching regulators); if the output voltage is too high, the regulation element will normally be commanded to produce a lower voltage. However, many regulators have over-current protection, so that they will entirely stop sourcing current (or limit the current in some way) if the output current is too high, and some regulators may also shut down if the input voltage is outside a given range (see also: crowbar circuits).

Measures of regulator quality

The output voltage can only be held *roughly* constant; the regulation is specified by two measurements:

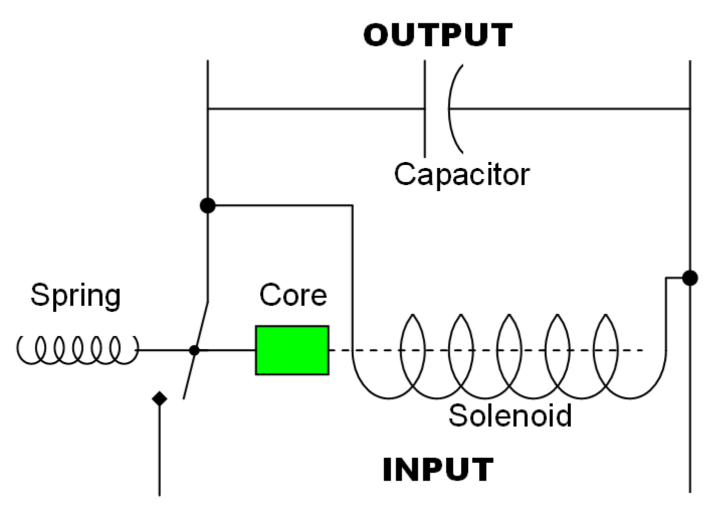
- **load regulation** is the change in output voltage for a given change in load current (for example: "typically 15mV, maximum 100mV for load currents between 5mA and 1.4A, at some specified temperature and input voltage").
- **line regulation** or **input regulation** is the degree to which output voltage changes with input (supply) voltage changes - as a ratio of output to input change (for example "typically 13mV/V"), or the output voltage change over the entire specified input voltage range (for example "plus or minus 2% for input voltages between 90V and 260V, 50-60Hz").

Other important parameters are:

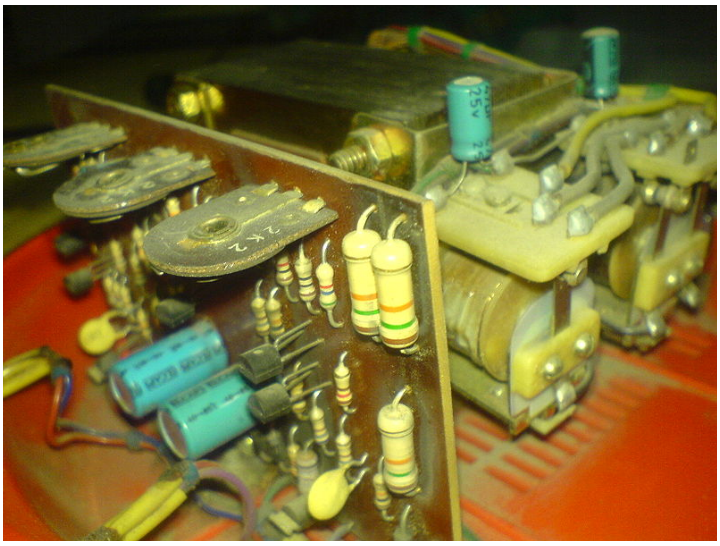
- **Temperature coefficient** of the output voltage is the change in output voltage with temperature (perhaps averaged over a given temperature range), while...
- **Initial accuracy** of a voltage regulator (or simply "the voltage accuracy") reflects the error in output voltage for a fixed regulator without taking into account temperature or aging effects on output accuracy.
- **Dropout voltage** - the minimum difference between input voltage and output voltage for which the regulator can still supply the specified current. A Low Drop-Out (LDO) regulator is designed to work well even with an input supply only a Volt or so above the output voltage.
- **Absolute Maximum Ratings** are defined for regulator components, specifying the continuous and peak output currents that may be used (sometimes internally limited), the maximum input voltage, maximum power dissipation at a given temperature, etc.
- **Output noise** (thermal white noise) and **output dynamic impedance** may be specified as graphs versus frequency, while output **ripple** noise (mains "hum" or switch-mode "hash" noise) may be given as peak-to-peak or RMS voltages, or in terms of their spectra.

- **Quiescent current** in a regulator circuit is the current drawn internally, not available to the load, normally measured as the input current while no load is connected (and hence a source of inefficiency; some linear regulators are, surprisingly, more efficient at very low current loads than switch-mode designs because of this).

Electromechanical regulators



Circuit design for a simple electromechanical voltage regulator.

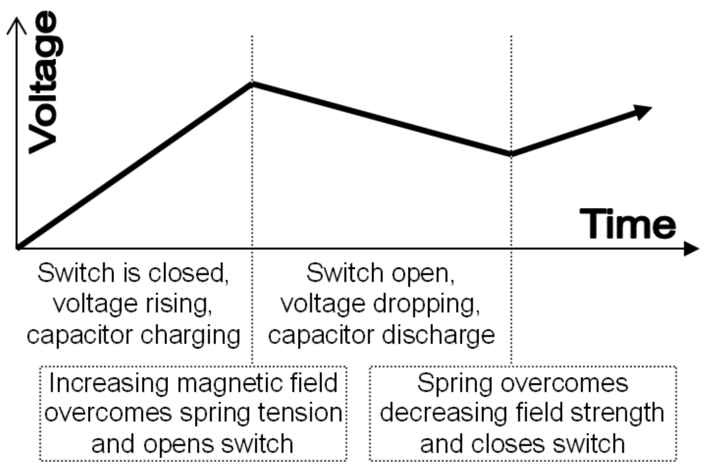

Interior of an old electromechanical voltage regulator.

In older electromechanical regulators, voltage regulation is easily accomplished by coiling the sensing wire to make an electromagnet. The magnetic field produced by the current attracts a moving ferrous core held back under spring tension or gravitational pull. As voltage increases, so does the current, strengthening the magnetic field produced by the coil and pulling the core towards the field. The magnet is physically connected to a mechanical power switch, which opens as the magnet moves into the field. As voltage decreases, so does the current, releasing spring tension or the weight of the core and causing it to retract. This closes the switch and allows the power to flow once more.

If the mechanical regulator design is sensitive to small voltage fluctuations, the motion of the solenoid core can be used to move a selector switch across a range of resistances or transformer windings to gradually step the output voltage up or down, or to rotate the position of a moving-coil AC regulator.

Early automobile generators and alternators had a mechanical voltage regulator using one, two, or three relays and various resistors to stabilize the generator's output at slightly more than 6 or 12 V, independent of the engine's rpm or the varying load on the vehicle's electrical system. Essentially, the relay(s) employed pulse width modulation to regulate the output of the generator, controlling the field current reaching the generator (or alternator) and in this way controlling the output voltage produced.

The regulators used for generators (but not alternators) also disconnect the generator when it was not producing electricity, thereby preventing the battery from discharging back into the generator and attempting to run it as a motor. The rectifier diodes in an alternator automatically perform this function so that a specific relay is not required; this appreciably simplified the regulator design.



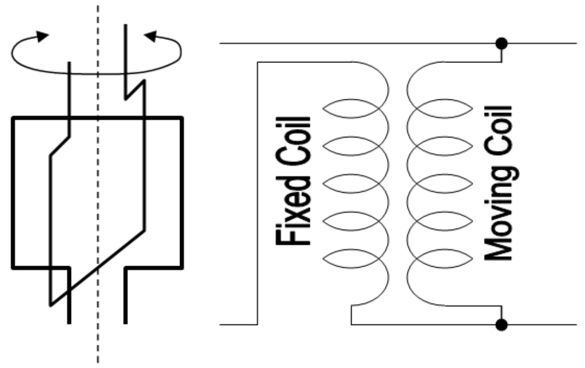
Graph of voltage output on a time scale.

More modern designs now use *solid state* technology (transistors) to perform the same function that the relays perform in electromechanical regulators.

Electromechanical regulators are used for mains voltage stabilisation—see Voltage regulator#AC voltage stabilizers below.

Coil-rotation AC voltage regulator

This is an older type of regulator used in the 1920s that uses the principle of a fixed-position field coil and a second field coil that can be rotated on an axis in parallel with the fixed coil.



Basic design principle and circuit diagram for the rotating-coil AC voltage regulator.

When the movable coil is positioned perpendicular to the fixed coil, the magnetic forces acting on the movable coil balance each other out and voltage output is unchanged. Rotating the coil in one direction or the other away from the center position will increase or decrease voltage in the secondary movable coil.

This type of regulator can be automated via a servo control mechanism to advance the movable coil position in order to provide voltage increase or decrease. A braking mechanism or high ratio gearing is used to hold the rotating coil in place against the powerful magnetic forces acting on the moving coil.

AC voltage stabilizers

Electromechanical

Magnetic mains regulator

Electromechanical regulators, usually called voltage stabilizers, have also been used to regulate the voltage on AC power distribution lines. These regulators operate by using a servomechanism to select the appropriate tap on an autotransformer with multiple taps, or by moving the wiper on a continuously variable autotransfomer. If the output voltage is not in the acceptable range, the servomechanism switches connections or moves the wiper to adjust the voltage into the acceptable region. The controls provide a deadband wherein the controller will not act, preventing the controller from constantly adjusting the voltage ("hunting") as it varies by an acceptably small amount.

Constant-voltage transformer

An alternative method is the use of a type of saturating transformer called a **ferroresonant transformer** or **constant-voltage transformer**. These transformers use a tank circuit composed of a high-voltage resonant winding and a capacitor to produce a nearly constant average output with a varying input. The ferroresonant approach is attractive due to its lack of active components, relying on the square loop saturation characteristics of the tank circuit to absorb variations in average input voltage. Older designs of ferroresonant transformers had an output with high harmonic content, leading to a distorted output waveform. Modern devices are used to construct a perfect sinewave. The ferroresonant action is a flux limiter rather than a voltage regulator, but with a fixed supply frequency it can maintain an almost constant average output voltage even as the input voltage varies widely.

The ferroresonant transformers, which are also known as Constant Voltage Transformers (CVTs) or ferros, are also good surge suppressors, as they provide high isolation and inherent short-circuit protection.

A ferroresonant transformer can operate with an input voltage range ±40% or more of the nominal voltage.

Output power factor remains in the range of 0.96 or higher from half to full load.

Because it regenerates an output voltage waveform, output distortion, which is typically less than 4%, is independent of any input voltage distortion, including notching.

Efficiency at full load is typically in the range of 89% to 93%. However, at low loads, efficiency can drop below 60% and no load losses can be as high as 20%. The current-limiting capability also becomes a handicap when a CVT is used in an application with moderate to high inrush current like motors, transformers or magnets. In this case, the CVT has to be sized to accommodate the peak current, thus forcing it to run at low loads and poor efficiency.

Minimum maintenance is required. Transformers and capacitors can be very reliable. Some units have included redundant capacitors to allow several capacitors to fail between inspections without any noticeable effect on the device's performance.

Output voltage varies about 1.2% for every 1% change in supply frequency. For example, a 2-Hz change in generator frequency, which is very large, results in an output voltage change of only 4%, which has little effect for most loads.

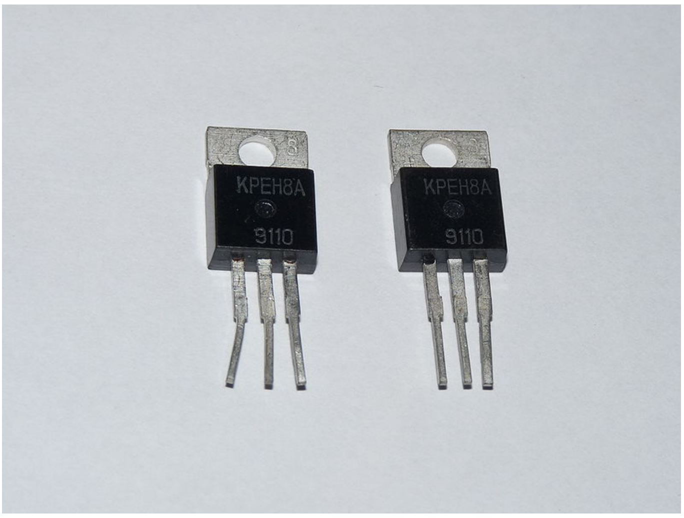
It accepts 100% single-phase switch-mode power supply loading without any requirement for derating, including all neutral components.

Input current distortion remains less than 8% THD even when supplying nonlinear loads with more than 100% current THD.

Drawbacks of CVTs (constant voltage transformers) are their larger size, audible humming sound, and high heat generation.

DC voltage stabilizers

Many simple DC power supplies regulate the voltage using a *shunt regulator* such as a zener diode, avalanche breakdown diode, or voltage regulator tube. Each of these devices begins conducting at a specified voltage and will conduct as much current as required to hold its terminal voltage to that specified voltage. The power supply is designed to only supply a maximum amount of current that is within the safe operating capability of the shunt regulating device (commonly, by using a series resistor). In shunt regulators, the voltage reference is also the regulating device.



KPEH8A stabilizers

If the stabilizer must provide more power, the shunt regulator output is only used to provide the standard voltage reference for the electronic device, known as the voltage stabilizer. The voltage stabilizer is the electronic device, able to deliver much larger currents on demand.

Active regulators

Active regulators employ at least one active (amplifying) component such as a transistor or operational amplifier. Shunt regulators are often (but not always) passive and simple, but always inefficient because they (essentially) dump the excess current not needed by the load. When more power must be supplied, more sophisticated circuits are used. In general, these active regulators can be divided into several classes:

- Linear series regulators
- Switching regulators
- SCR regulators

Linear regulators

Linear regulators are based on devices that operate in their linear region (in contrast, a switching regulator is based on a device forced to act as an on/off switch). In the past, one or more vacuum tubes were commonly used as the variable resistance. Modern designs use one or more transistors instead, perhaps within an Integrated Circuit. Linear designs have the advantage of very "clean" output with little noise introduced into their DC output, but are most often much less efficient and unable to step-up or invert the input voltage like switched supplies. All linear regulators require a higher input than the output. All linear regulators are subject to the parameter of dropout voltage.

Entire linear regulators are available as integrated circuits. These chips come in either fixed or adjustable voltage types.

Switching regulators

Switching regulators rapidly switch a series device on and off. The duty cycle of the switch sets how much charge is transferred to the load. This is controlled by a similar feedback mechanism as in a linear regulator. Because the series element is either fully conducting, or switched off, it dissipates almost no power; this is what gives the switching design its efficiency. Switching regulators are also able to generate output voltages which are higher than the input, or of opposite polarity — something not possible with a linear design.

Like linear regulators, nearly-complete switching regulators are also available as integrated circuits. Unlike linear regulators, these usually require one external component: an inductor that acts as the energy storage element. (Large-valued inductors tend to be physically large relative to almost all other kinds of componentry, so they are rarely fabricated within integrated circuits and IC regulators — with some exceptions.[1])

Comparing linear vs. switching regulators

The two types of regulators have their different advantages:

- Linear regulators are best when low output noise (and low RFI radiated noise) is required
- Linear regulators are best when a fast response to input and output disturbances is required.
- At low levels of power, linear regulators are cheaper and occupy less printed circuit board space.
- Switching regulators are best when power efficiency is critical (such as in portable computers), *except* linear regulators are more efficient in a small number of cases (such as a 5V microprocessor often in "sleep" mode fed from a 6V battery, *if* the complexity of the switching circuit and the junction capacitance charging current means a high quiescent current in the switching regulator).
- Switching regulators are required when the only power supply is a DC voltage, and a higher output voltage is required.
- At high levels of power (above a few watts), switching regulators are cheaper (for example, the cost of removing heat generated is less).

SCR regulators

Regulators powered from AC power circuits can use silicon controlled rectifiers (SCRs) as the series device. Whenever the output voltage is below the desired value, the SCR is triggered, allowing electricity to flow into the load until the AC mains voltage passes through zero (ending the half cycle). SCR regulators have the advantages of being both very efficient and very simple, but because they can not terminate an on-going half cycle of conduction, they are not capable of very accurate voltage regulation in response to rapidly-changing loads.

Combination (hybrid) regulators

Many power supplies use more than one regulating method in series. For example, the output from a switching regulator can be further regulated by a linear regulator. The switching regulator accepts a wide range of input voltages and efficiently generates a (somewhat noisy) voltage slightly above the ultimately desired output. That is followed by a linear regulator that generates exactly the desired voltage and eliminates nearly all the noise generated by the switching regulator. Other designs may use an SCR regulator as the "pre-regulator", followed by another type of regulator. An efficient way of creating a variable-voltage, accurate output power supply is to combine a multi-tapped transformer with an adjustable linear post-regulator.

Voltage stabilizer

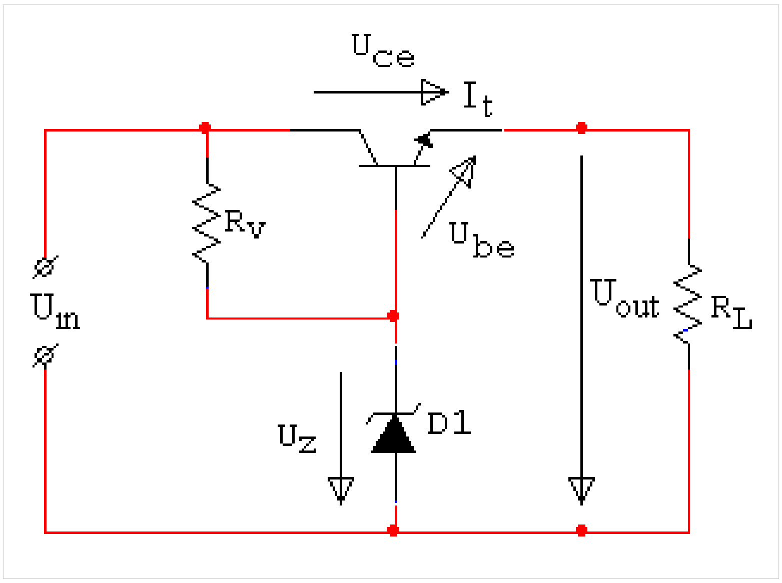
A **voltage stabilizer** is an electronic device able to deliver relatively constant output voltage while input voltage and load current changes over time.

The voltage stabilizer is the *shunt regulator* such as a Zener diode or avalanche diode. Each of these devices begins conducting at a specified voltage and will conduct as much current as required to hold its terminal voltage to that specified voltage. Hence the shunt regulator can be viewed as the limited power parallel stabilizer. The shunt regulator output is used as a voltage reference.

The Zener diode and avalanche diode have opposite threshold voltage dependence on temperature. By connecting these two devices sequentially, it is possible to construct a voltage reference with improved thermal stability. Sometimes (mostly for the voltages around 5.6 V) both effects are combined in the same diode.

Simple voltage stabilizer

In the simplest case emitter follower is used, the base of the regulating transistor is directly connected to the voltage reference:

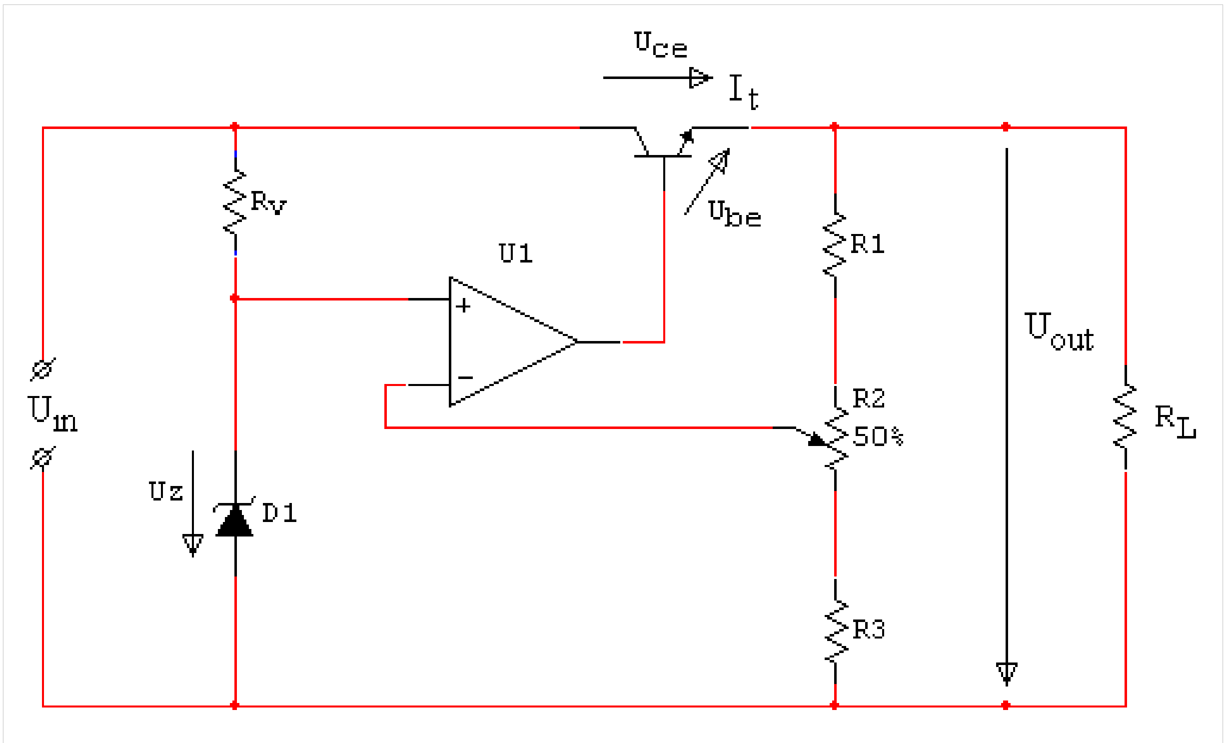


The stabilizer uses the power source, having voltage U_{in} that may vary over time. It delivers the relatively constant voltage U_{out}. The output load R_L can also vary over time. For such a device to work properly, the input voltage must be larger than the output voltage and Voltage drop must not exceed the limits of the transistor used.

The output voltage of the stabilizer is equal to U_Z - U_{BE} where U_{BE} is about 0.7v and depends on the load current. If the output voltage drops below that limit, this increases the voltage difference between the base and emitter (U_{be}), opening the transistor and delivering more current. Delivering more current through the same output resistor R_L increases the voltage again.

Voltage stabilizer with an operational amplifier

The stability of the output voltage can be significantly increased by using the operational amplifier:



In this case, the operational amplifier opens the transistor more if the voltage at its inverting input drops significantly below the output of the voltage reference at the non-inverting input. Using the voltage divider (R1, R2 and R3) allows choice of the arbitrary output voltage between U_z and U_{in}.

See also

- Constant current regulator
- DC to DC converter
- Voltage regulator module
- Third brush dynamo
- Power supply

External links

- Designing Regulated Power Supplies [2]
- Electrostatic Precipitator Knowledge Base [3]
- Generator Voltage Regulators [4]

References

[1] http://www.national.com/pf/LM/LM2825.html
[2] http://knol.google.com/k/max-iskram/electronic-circuits-design-for/1f4zs8p9zgq0e/4
[3] http://www.neundorfer.com/knowledge_base/electrostatic_precipitators.aspx
[4] http://www.dieselgeneratorsmiami.com/powergeneral/26/automatic-voltage-regulators.html