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Voltage drop

Abu Sayem[1], Abu Sayed[2], Md. Al Amin[3], Masum Rana[4], Tajmin Nahar[5]
[1-4] Department of Mecanical and Electrical Intregation, Jiangsu Agri-Animal Husbandry Vocational College, Taizhou, Jiangsu, China
[5] Department of Civil Construction, Hebei College of Industry & Technology, China

Abstract
Voltage drop describes how the energy supplied by a voltage source is reduced as electric current moves through the passive elements (elements that do not supply voltage) of an electrical circuit. The voltage drop across the internal resistance of the source, across conductors, across contacts, and across connectors is undesirable because some of the energy supplied is lost (dissipated). The voltage drop across the electrical load and across other active circuit elements is essential for supply of energy and so is not undesirable.

Keywords: voltage drop, voltage drop, in direct-current circuits: resistance, voltage drop in alternating-current circuits: impedance, conclusion

Introduction: Voltage drop

Voltage drop describes how the energy supplied by a voltage source is reduced as electric current moves through the passive elements (elements that do not supply voltage) of an electrical circuit. The voltage drop across the internal resistance of the source, across conductors, across contacts, and across connectors is undesirable because some of the energy supplied is lost (dissipated). The voltage drop across the electrical load and across other active circuit elements is essential for supply of energy and so is not undesirable.

For example, an electric space heater may have a resistance of ten ohms, and the wires which supply it may have a resistance of 0.2 ohms, about 2% of the total circuit resistance. This means that approximately 2% of the supplied voltage is lost in the wire itself. An excessive voltage drop may result in unsatisfactory performance of the space heater, and overheating of the wires and connections.

National and local electrical codes may set guidelines for the maximum voltage drop allowed in electrical wiring to ensure efficiency of distribution and proper operation of electrical equipment. The maximum permitted voltage drop varies from one country to another [1]. In electronic design and power transmission, various techniques are employed to compensate for the effect of voltage drop on long circuits or where voltage levels must be accurately maintained. The simplest way to reduce voltage drop is to increase the diameter of the conductor between the source and the load, which lowers the overall resistance. In power distribution systems, a given amount of power can be transmitted with less voltage drop if a higher voltage is used. More sophisticated techniques use active elements to compensate for excessive voltage drop.

Voltage drop in direct-current circuits: resistance- Consider a direct-current circuit with a nine-volt DC source; three resistors of 67 ohms, 100 ohms, and 470 ohms; and a light bulb—all connected in series. The DC source, the conductors (wires), the resistors, and the light bulb (the load) all have resistance; all use and dissipate supplied energy to some degree. Their physical characteristics determine how much energy. For example, the DC resistance of a conductor depends upon the conductor's length, cross-sectional area, type of material, and temperature.

If the voltage between the DC source and the first resistor (67 ohms) is measured, the voltage potential at the first resistor will be slightly less than nine volts. The current passes through the conductor (wire) from the DC source to the first resistor; as this occurs, some of the supplied energy is "lost" (unavailable to the load), due to the resistance of the conductor. Voltage drop exists in both the supply and return wires of a circuit. If the voltage drop across each resistor is measured, the measurement will be a significant number. That represents the energy used by the resistor. The larger the resistor, the more energy used by that resistor, and the bigger the voltage drop across that resistor.

Ohm's Law can be used to verify voltage drop. In a DC circuit, voltage equals current multiplied by resistance. Also, Kirchhoff's circuit laws state that in any DC circuit, the sum of the voltage drops across each component of the circuit is equal to the supply voltage.

Voltage drop in alternating-current circuits: impedance in alternating-current circuits, opposition to current flow occurs because of resistance, just as in direct-current circuits. However, alternating current circuits also include a second kind of opposition to current flow: reactance. The sum of oppositions to current flow from both resistance and reactance is called impedance.

Electrical impedance is commonly represented by the variable Z and measured in ohms at a specific frequency. Electrical impedance is computed as the vector sum of electrical resistance, capacitive reactance, and inductive reactance.

The amount of impedance in an alternating-current circuit depends on the frequency of the alternating current and the magnetic permeability of electrical conductors and electrically isolated elements (including surrounding elements), which varies with their size and spacing.

Analogous to Ohm's law for direct-current circuits, electrical impedance may be expressed by the formula. So, the voltage drop in an AC circuit is the product of the current and the impedance of the circuit.

Brownout (electricity)

A brownout is an intentional or unintentional drop in voltage in an electrical power supply system. Intentional brownouts are used for load reduction in an emergency [1]. The reduction lasts for minutes or hours, as opposed to short-term voltage sag (or dip). The term brownout comes from the dimming experienced by incandescent lighting when the voltage sags. A voltage reduction may be an effect of disruption of an electrical grid, or may occasionally be imposed in an effort to reduce load and prevent a power outage, known as a blackout [2].

In some media reports the term *brownout* refers to an intentional or unintentional power outage or blackout of some areas rather than to a drop in voltage

Effects Different types of electrical apparatus will react in different ways to a sag. Some devices will be severely affected, while others may not be affected at all.

The heat output of any resistance device, such as an electric space heater, is equal to the true power consumption, which is an increasing function of the applied voltage. If the resistance stays constant, power consumption is proportional to the square of the applied voltage. Therefore, a significant reduction of heat output will occur with a relatively small reduction in voltage. An incandescent lamp will dim due to lower heat creation in the filament, as well as lower conversion of heat to light. Generally speaking, no damage will occur but functionality will be impaired.

Commutated electric motors, such as universal motors, will run at reduced speed or reduced torque. Depending on the motor design, no harm may occur. However, under load, the motor may draw more current due to the reduced back-EMF developed at the lower armature speed. Unless the motor has ample cooling capacity, it may eventually overheat and burn out.

An induction motor will draw more current to compensate for the decreased voltage, which may lead to overheating and burnout. If a substantial part of a grid's load is electric motors, reducing voltage may not actually reduce load and can result in damage to customers' equipment.

An unregulated direct current supply will produce a lower output voltage for electronic circuits. The output ripple voltage will decrease in line with the usually reduced load current. In a CRT television, the reduced output voltage can be seen as the screen image shrinking in size and becoming dim and fuzzy.

A linear direct current regulated supply will maintain the output voltage unless the brownout is severe and the input voltage drops below the drop out voltage for the regulator, at which point the output voltage will fall and high levels of ripple from the rectifier/reservoir capacitor will appear on the output.

A switched-mode power supply which has a regulated output will be affected. As the input voltage falls, the current draw will increase to maintain the same output voltage and current, until such a point that the power supply malfunctions.

Brownouts can cause unexpected behaviour in systems with digital control circuits. Reduced voltages can bring control signals below the threshold at which logic circuits can reliably detect which state is being represented. As the voltage returns to normal levels the logic can latch at an incorrect state; even can't happen states become possible. The seriousness of this effect and whether steps need to be taken by the designer to prevent it depends on the nature of the equipment being controlled; for instance, a brownout may cause a motor to begin running backwards.

Voltage divider

In electronics, a voltage divider (also known as a potential divider) is a passive linear circuit that produces an output voltage (V_{out}) that is a fraction of its input voltage (V_{IN}). Voltage division is the result of distributing the input voltage among the components of the divider. A simple example of a voltage divider is two resistors connected in series, with the input voltage applied across the resistor pair and the output voltage emerging from the connection between them.

Resistor voltage dividers are commonly used to create reference voltages, or to reduce the magnitude of a voltage so it can be measured, and may also be used as signal attenuators at low frequencies. For direct current and relatively low frequencies, a voltage divider may be sufficiently accurate if made only of resistors; where frequency response over a wide range is required (such as in an oscilloscope probe), a voltage divider may have capacitive elements added to compensate load capacitance. In electric power transmission, a capacitive voltage divider is used for measurement of high voltage.

A voltage divider referenced to ground is created by connecting two electrical impedances in series, as shown in Figure 1. The input voltage is applied across the series impedances Z_1 and Z_2 and the output is the voltage across Z_2. Z_1 and Z_2 may be composed of any combination of elements such as resistors, inductors and capacitors.

If the current in the output wire is zero then the relationship between the input voltage, V_{IN}, and the output voltage, V_{out}, is:

Proof (using Ohm's Law)

The transfer function (also known as the divider's voltage ratio) of this circuit is:

In general this transfer function is a complex, rational function of frequency.

A resistive divider is the case where both impedances, Z_1 and Z_2, are purely resistive (Figure 2).

Substituting $Z_1 = R_1$ and $Z_2 = R_2$ into the previous expression gives:

If $R_1 = R_2$ then

If V_{out}=6V and V_{IN}=9V (both commonly used voltages), then: and by solving using algebra, R_2 must be twice the value of R_1.

To solve for R1:

To solve for R2:

Any ratio V_{out}/V_{in} greater than 1 is not possible. That is, using resistors alone it is not possible to either invert the voltage or increase V_{out} above V_{IN}.

Consider a divider consisting of a resistor and capacitor as shown in Figure 3.

Comparing with the general case, we see Z_1 = R and Z_2 is the impedance of the capacitor, given by where X_C is the reactance of the capacitor, C is the capacitance of the capacitor, *j* is the imaginary unit, and ω (omega) is the radian frequency of the input voltage.

This divider will then have the voltage ratio:

The product τ *(tau) = RC* is called the *time constant* of the circuit.

The ratio then depends on frequency, in this case decreasing as frequency increases. This circuit is, in fact, a basic (first-order) lowpass filter. The ratio contains an imaginary number, and actually contains both the amplitude and phase shift information of the filter. To extract just the amplitude ratio, calculate the magnitude of the ratio, that is:

Inductive divider

Inductive dividers split AC input according to inductance:
The above equation is for non-interacting inductors; mutual inductance (as in an autotransformer) will alter the results.
Inductive dividers split DC input according to the resistance of the elements as for the resistive divider above.

Capacitive divider

Capacitive dividers do not pass DC input.
For an AC input a simple capacitive equation is:
Any leakage current in the capactive elements requires use of the generalized expression with two impedances. By selection of parallel R and C elements in the proper proportions, the same division ratio can be maintained over a useful range of frequencies. This is the principle applied in compensated oscilloscope probes to increase measurement bandwidth.

Loading effect

The output voltage of a voltage divider will vary according to the electric current it is supplying to its external electrical load. The effective source impedance coming from a divider of Z_1 and Z_2, as above, will be Z_1 in parallel with Z_2 (sometimes written Z_1 // Z_2), that is: $(Z_1 Z_2) / (Z_1 + Z_2) = HZ_1$.
To obtain a sufficiently stable output voltage, the output current must either be stable (and so be made part of the calculation of the potential divider values) or limited to an appropriately small percentage of the divider's input current. Load sensitivity can be decreased by reducing the impedance of both halves of the divider, though this increases the divider's quiescent input current and results in higher power consumption (and wasted heat) in the divider. Voltage regulators are often used in lieu of passive voltage dividers when it is necessary to accommodate high or fluctuating load currents.

Applications

Voltage dividers are used for adjusting the level of a signal, for bias of active devices in amplifiers, and for measurement of voltages. A Wheatstone bridge and a multimeter both include voltage dividers. A potentiometer is used as a variable voltage divider in the volume control of many radios.

Sensor measurement

Voltage dividers can be used to allow a microcontroller to measure the resistance of a sensor [1]. The sensor is wired in series with a known resistance to form a voltage divider and a known voltage is applied across the divider. The microcontroller's analog-to-digital converter is connected to the center tap of the divider so that it can measure the tap voltage and, by using the measured voltage and the known resistance and voltage, compute the sensor resistance. An example that is commonly used involves a potentiometer (variable resistor) as one of the resistive elements. When the shaft of the potentiometer is rotated the resistance it produces either increases or decreases, the change in resistance corresponds to the angular change of the shaft. If coupled with a stable voltage reference, the output voltage can be fed into an analog-to-digital converter and a display can show the angle. Such circuits are commonly used in reading control knobs. Note that it is highly beneficial for the potentiometer to have a linear taper, as the microcontroller or other circuit reading the signal must otherwise correct for the non-linearity in its calculations.

High voltage measurement

Fig 1

High voltage resistor divider probe

A voltage divider can be used to scale down a very high voltage so that it can be measured by a volt meter. The high voltage is applied across the divider, and the divider output—which outputs a lower voltage that is within the meter's input range—is measured by the meter. High voltage resistor divider probes designed specifically for this purpose can be used to measure voltages up to 100 kV. Special high-voltage resistors are used in such probes as they must be able to tolerate high input voltages and, to produce accurate results, must have matched temperature coefficients and very low voltage coefficients. Capacitive divider probes are typically used for voltages above 100 kV, as the heat caused by power losses in resistor divider probes at such high voltages could be excessive.

Logic level shifting

A voltage divider can be used as a crude logic level shifter to interface two circuits that use different operating voltages. For example, some logic circuits operate at 5V whereas others operate at 3.3V. Directly interfacing a 5V logic output to a 3.3V input may cause permanent damage to the 3.3V circuit. In this case, a voltage divider with an output ratio of 3.3/5 might be used to reduce the 5V signal to 3.3V, to allow the circuits to interoperate without damaging the 3.3V circuit. For this to be feasible, the 5V source impedance and 3.3V input impedance must be negligible, or they must be constant and the divider resistor values must account for their impedances. If the input impedance is capacitive, a purely resistive divider will limit the data rate. This can be roughly overcome by adding a capacitor in series with the top resistor, to make both legs of the divider capacitive as well as resistive.

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