

Linear DC-DC Conversion Topology and Component Selection

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Compact DC-AC Inverter

ABSTRACT

It is often necessary to convert direct current at an available voltage to direct current at another specified voltage for sub-circuit usage. Some systems that are battery powered such as laptops and cellphones require high efficiency, compact conversion that is able to adjust for a voltage drop as the battery becomes discharged. For other systems that have a constant supply or in which some inefficiency is acceptable, linear conversion is preferred for its relatively simple implementation. This application note discusses linear DC-DC conversion methodology, why one methodology is chosen over another for a specific application, and provides examples to assist a user in selecting appropriate components for their circuit.

Keywords: linear, DC-DC, conversion, voltage divider, voltage decrease

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1 Introduction

Although generally more efficient, switched-mode DC-DC conversion can be bulkier, more complex, and require output harmonic filtering to meet emissions standards. Linear voltage conversion is advantageous when a lower voltage of the same polarity is necessary for test circuits and applications in which usage of inductors, capacitors, and/or transformers is not feasible because of space constraints. As excess power is dissipated into a resistor, heat dissipation may also need to be considered. However, when the voltage across the dissipating resistor is decreased – the potential difference between the input voltage and output voltage is decreased – the efficiency is increased. Linear converters are the strategic choice when applied appropriately.

2 Series Conversion

The first type of linear DC-DC conversion is series conversion. Fundamentally, the series topology consists of two series resistors – R_{series} , the resistor into which excess power is dissipated, and R_L , the load. These two resistors form a voltage divider dependent on their ohm values. The output across the load, V_{out} , is a ratio between the resistors multiplied by the input voltage, V_{in} , as follows:

$$V_{\text{out}} = \frac{R_L}{R_L + R_{\text{series}}} V_{\text{in}}$$

This two resistor method does not maintain V_{out} with fluctuations of V_{in} or R_L . For battery powered system or systems with variable load-ability, it is necessary to add a control system to compensate for fluctuations:

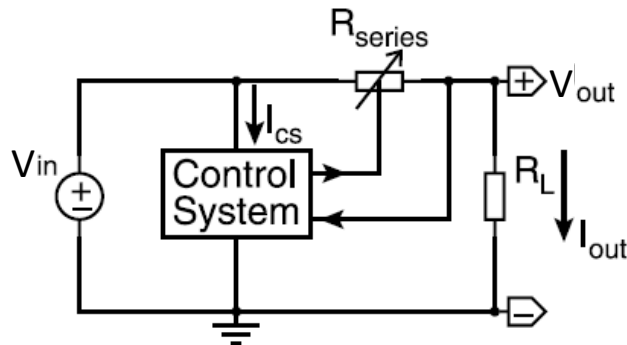


Figure 1. Series Conversion with Control System Overview

Normally, the control system power is provided by V_{in} and measures V_{out} as Figure 1 indicates. V_{out} may provide the system power, but a startup circuit would then be necessary. For series conversion with and without a control system, efficiency, η , can be calculated as:

$$\eta_{\text{cs}} = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{V_{\text{out}} I_{\text{out}}}{V_{\text{in}} (I_{\text{out}} + I_{\text{cs}})}$$

$$\eta_{\text{no_cs}} = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{V_{\text{out}}}{V_{\text{in}}}$$

3 Shunt Conversion

It may be beneficial to place the load in parallel with the voltage divider. In a shunt converter R_{shunt} is placed in series with a resistor R_{in} , and R_L is paralleled with R_{shunt} , V_{out} is as follows:

$$V_{out} = \frac{(R_{shunt} \parallel R_L)}{(R_{in} + R_{shunt} \parallel R_L)} V_{in}$$

As with series conversion a control system can be added to a shunt converter to compensate for input and output fluctuations:

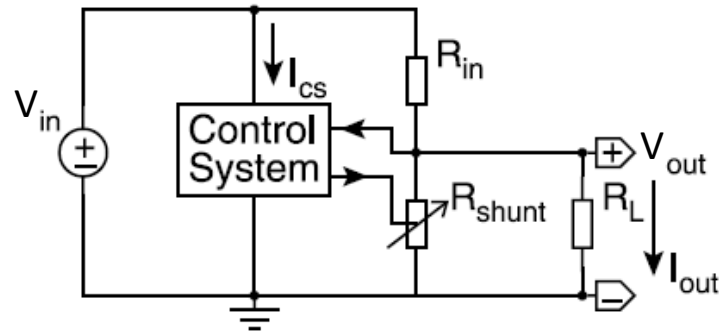


Figure 2. Shunt Conversion with Control System Overview

Unlike linear converters, shunt converters are self-starting and V_{out} may be used to power the control system as long as it provides the correct potential for the system. For series conversion with and without a control system, efficiency, η , can be calculated as:

$$\eta_{cs} = \frac{P_{out}}{P_{in}} = \frac{\frac{V_{out}^2}{R_L}}{\frac{V_{in}^2}{R_{in} + R_L \parallel R_{shunt}} + V_{in} I_{cs}} = \frac{V_{out}^2}{R_L} \frac{R_{in}}{I_{cs} R_{in} V_{in} + \frac{V_{in}^2}{R_{in} + R_L \parallel R_{shunt}} - V_{in} V_{out}}$$

$$\eta_{no_cs} = \frac{P_{out}}{P_{in}} = \frac{V_{out}}{V_{in}}$$

The maximum output power, P_{out_max} , for a shunt converter is found with:

$$P_{out_max} = \frac{V_{in} - V_{out}}{R_{in}} V_{out}$$

4 Choosing Series or Shunt

Both series and shunt converters have their advantages over each other:

<u>Series Conversion</u>	<u>Shunt Conversion</u>
Efficiency is [ideally] independent of output power – high efficiency with low voltage division	Efficiency is maximized when output power is maximized
	More practical with higher voltage division
	More practical for low output power
Fewer resistors to dissipate power	

Table 1. Highlighted Series and Shunt Differences

For a shunt converter it is important to operate at maximum output power for the highest possible efficiency. If not operating at maximum power, a series converter is preferred. However, shunt converters are more practical for higher voltage division circuitry and when low output power is demanded.

5 Series Example

Assume the following values are required:

V_{in}	12 VDC
V_{out}	7.5 VDC
R_L	1 kΩ

Table 2. Series Example Values

The desired control system consists of an operational amplifier with a NPN BJT acting as R_{series} . The reference voltage, V_{ref} , for the OpAmp will be the same as the OpAmp power supply of 5 VDC. Two resistors, R_{f1} and R_{f2} , will be placed in series to perform the voltage division. The load will be paralleled with both resistors.

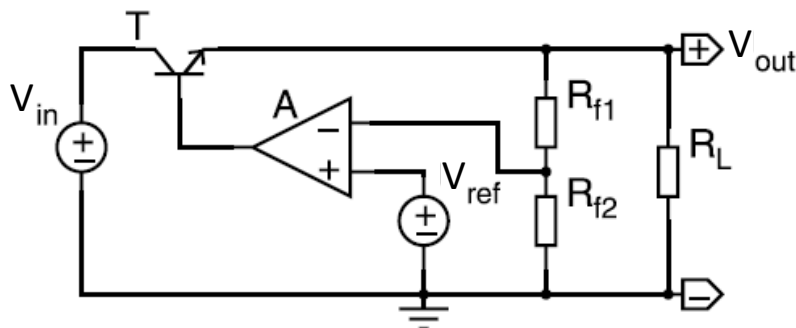


Figure 3. Series Example Circuit

With this configuration the output voltage can be calculated as:

$$V_{out} = \frac{R_{f1} + R_{f2}}{R_{f2}} V_{ref}$$

A stock resistor of 1 k Ω will be chosen for R_{f2} :

$$7.5 = \frac{R_{f1} + 1000}{1000} 5$$

This results in R_{f1} with a value of 500 Ω . For simplicity, assume that the OpAmp operates under ideal conditions. With the 0V-0A property, the efficiency of this circuit is approximated as:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_{out}}{V_{in}} = \frac{7.5}{12} = 62.5\%$$

6 Shunt Example

Assume the following values are required:

V_{in}	12 VDC
V_{out}	3.3 VDC
R_L	1 k Ω

Table 3. Shunt Example Values

The desired control system is a simple Zener diode used as voltage regulator. The Zener Diode will be put into the circuit in place of R_{shunt} .

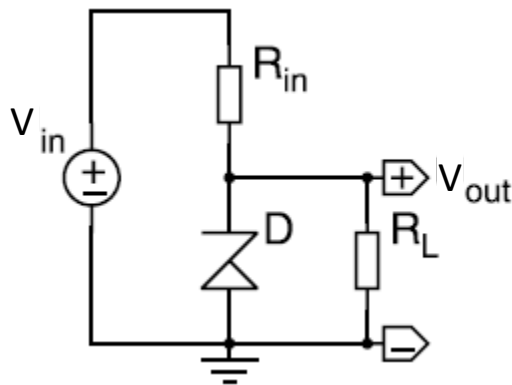


Figure 4. Shunt Example Circuit

With this configuration the output voltage can be calculated as:

$$V_{out} = \frac{(R_{shunt} || R_L)}{(R_{in} + R_{shunt} || R_L)} V_{in}$$

The input resistance must be found. Assume a standard maximum Zener impedance of 30 Ω :

$$3.3 = \frac{(30 || 1000)}{(R_{in} + 30 || 1000)} 12$$

This results in a value of 77 Ω for R_{in} . Because of fluctuations in the Zener impedance in which it may be lower, select a resistor available that is slightly smaller for R_{in} . The efficiency and maximum output power can be calculated as:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_{out}}{V_{in}} = \frac{3.3}{12} = 27.5\%$$

$$P_{out_max} = \frac{V_{in} - V_{out}}{R_{in}} V_{out} = \frac{12 - 3.3}{77} 3.3 = 373 \text{ mW}$$

7 Conclusion

For DC-DC conversion in which the potential difference is small, linear converters are an excellent option because of their relatively high efficiency with small voltage division. Series and shunt conversion are simple topologies that become slightly more complicated when adding in a voltage regulation control system, but still remain easily implementable. Heat dissipation considerations may be necessary when operating at lower efficiency. Overall, linear conversion provides a suitable choice for circuits with continuous inputs and proper thermal constraints.

8 References

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