Paralleling DC Power Supplies with Droop

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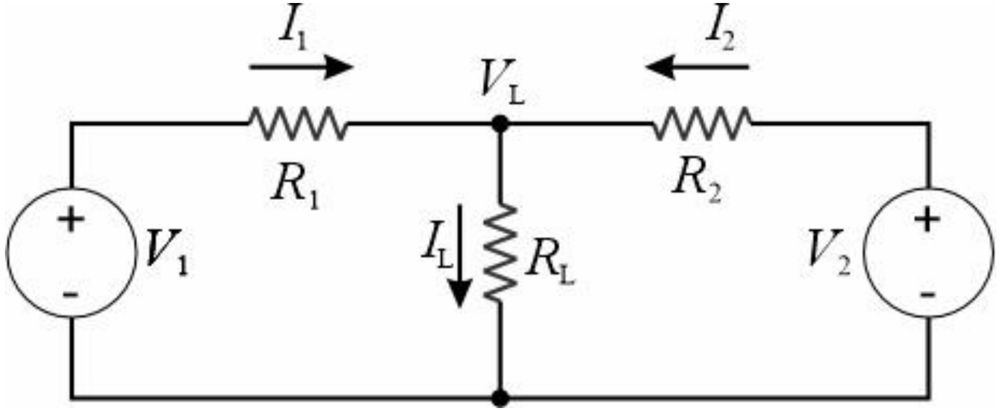
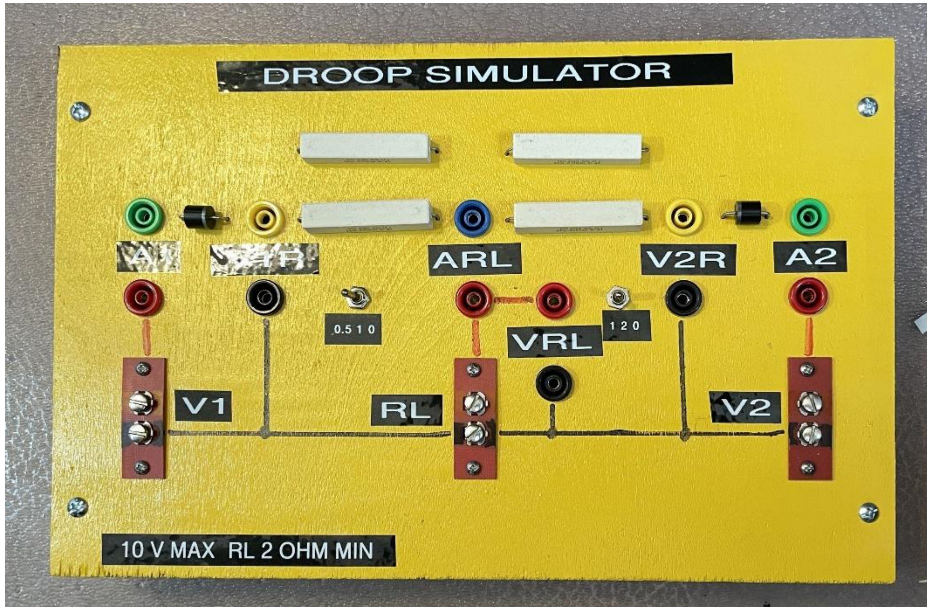
Introduction

- Droop is a technique for allowing two power supplies to share power when paralleled.
- Each power supply has a steady state characteristic where the voltage it regulates to is a function of either the power or current.
  - Normally the relationship is linear: the voltage decreases as load increases
  - If current is used, the droop characteristic is equivalent to a resistor.
- With a linear droop, the droop characteristic is often specified in terms of a percentage drop in voltage (referenced to the nominal no load voltage) at full load.

Current based Droop for two dc sources

- Each supply is modeled by a no-load (open circuit) voltage and a droop resistance.
  - In real power supplies, the droop resistance is virtual – no physical resistor is needed.
  - Droop % = $\frac{I_{n\_rated} R_n}{V_{n\_nominal}}$
  - Each source is assumed to prevent reverse power (such as using a series diode)
- The supply currents I_1 and I_2 must be non-negative.
  - Sources have unidirectional power flow
  - If $V_1 \frac{R_L}{R_L+R_1} > V_2$ then $I_2 = 0, V_L = V_1 \frac{R_L}{R_L+R_1}$
  - If $V_2 \frac{R_L}{R_L+R_1} > V_1$ then $I_1 = 0, V_L = V_2 \frac{R_L}{R_L+R_1}$
- If both I_1 and I_2 are non-negative
  - $V_L = \frac{\left(\frac{V_1}{R_1}+\frac{V_2}{R_2}\right)}{\left(\frac{1}{R_L}+\frac{1}{R_1}+\frac{1}{R_2}\right)}$, $I_1 = \frac{V_1 - V_L}{R_1}$, $I_2 = \frac{V_2 - V_L}{R_2}$

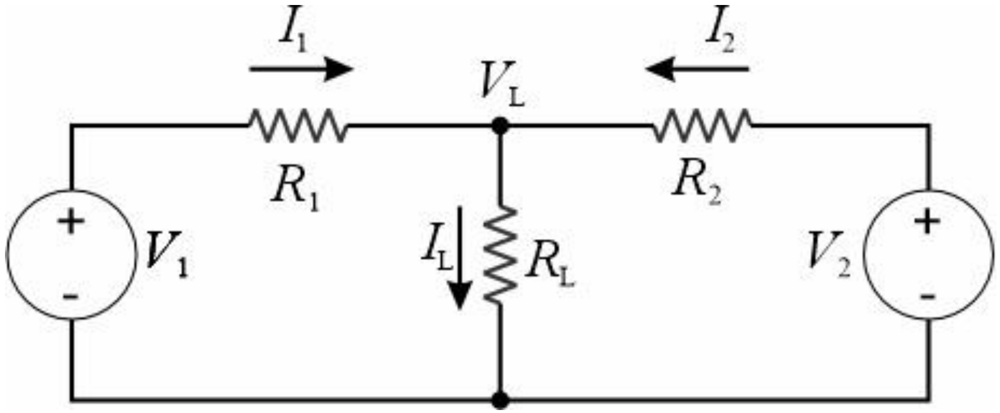




Equal No Load Voltages and Resistances
Vary the Load

- Set $V_1 = V_2 = 10\, Volts$
- Set $R_1 = R_2 = 1\, ohm$

R_L	V_L	I_1	I_2	I_L
Ohm	Volts	Amps	Amps	Amps
10	9.52	0.48	0.48	0.95
5	9.09	0.91	0.91	1.82
3.3	8.68	1.32	1.32	2.63
2.5	8.33	1.67	1.67	3.33



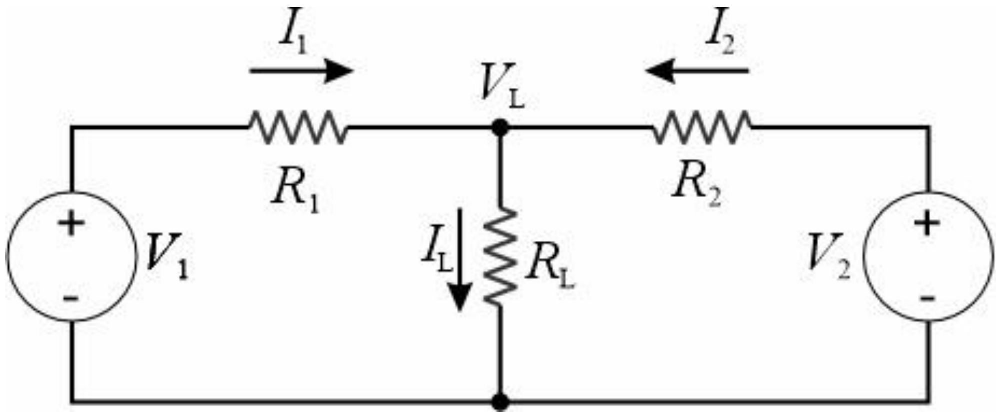
$$V_L = \frac{\left(\frac{V_1}{R_1}+\frac{V_2}{R_2}\right)}{\left(\frac{1}{R_L}+\frac{1}{R_1}+\frac{1}{R_2}\right)}, I_1 = \frac{V_1 - V_L}{R_1}, I_2 = \frac{V_2 - V_L}{R_2}$$

Equal sharing for all loads

Equal No Load Voltages, Unequal Resistances Vary the Load

- Set $V_1 = V_2 = 10\,Volts$
- Set $R_1 = 0.5\,ohm,\ R_2 = 1ohm$

R_L	V_L	I_1	I_2	I_L
Ohm	Volts	Amps	Amps	Amps
10	9.68	0.65	0.32	0.97
5	9.38	1.25	0.63	1.88
3.3	9.08	1.83	0.92	2.75
2.5	8.82	2.35	1.18	3.53



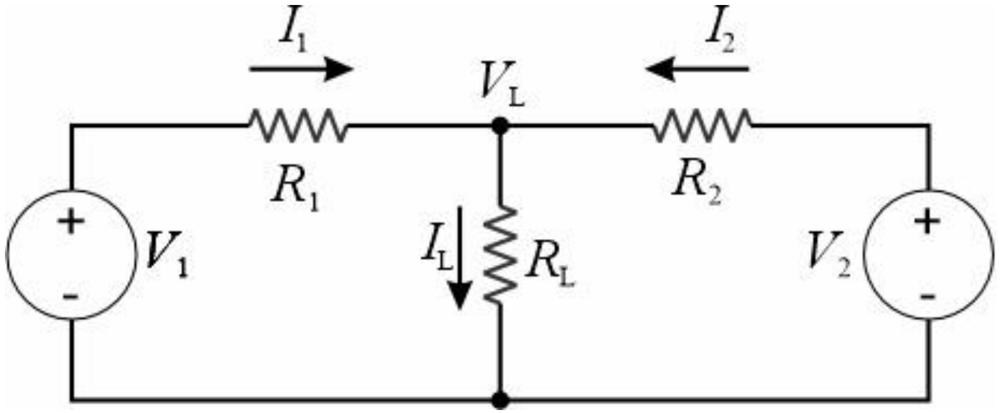
$$V_L = \frac{\left(\frac{V_1}{R_1}+\frac{V_2}{R_2}\right)}{\left(\frac{1}{R_L}+\frac{1}{R_1}+\frac{1}{R_2}\right)},\ I_1 = \frac{V_1 - V_L}{R_1},\ I_2 = \frac{V_2 - V_L}{R_2}$$

Same sharing fraction for all loads

Unequal No Load Voltages, Equal Resistances Vary the Load

- Set $V_1 = 10\ Volts, V_2 = 11\ Volts$
- Set $R_1 = R_2 = 1.0\ ohm$

R_L	V_L	I_1	I_2	I_L
Ohm	Volts	Amps	Amps	Amps
10	10.00	0.00	1.00	1.00
5	9.55	0.45	1.45	1.91
3.3	9.12	0.88	1.88	2.76
2.5	8.75	1.25	2.25	3.50



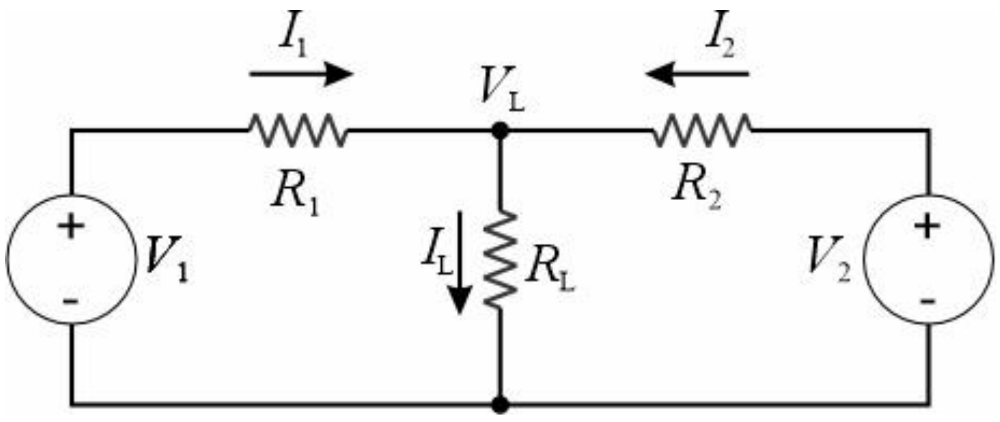
$$V_L = \frac{\left(\frac{V_1}{R_1}+\frac{V_2}{R_2}\right)}{\left(\frac{1}{R_L}+\frac{1}{R_1}+\frac{1}{R_2}\right)},\ I_1 = \frac{V_1 - V_L}{R_1},\ I_2 = \frac{V_2 - V_L}{R_2}$$

Increasing the voltage of one source creates an offset in current provided

Unequal No Load Voltages (Auctioneering), Equal Resistances, Vary the Load

- Set $V_1 = 10\ Volts, V_2 = 8\ Volts$
- Set $R_1 = R_2 = 1.0\ ohm$

R_L	V_L	I_1	I_2	I_L
Ohm	Volts	Amps	Amps	Amps
10	9.09	0.91	0.00	0.91
5	8.33	1.67	0.00	1.67
3.3	7.82	2.18	0.18	2.37
2.5	7.50	2.50	0.50	3.00



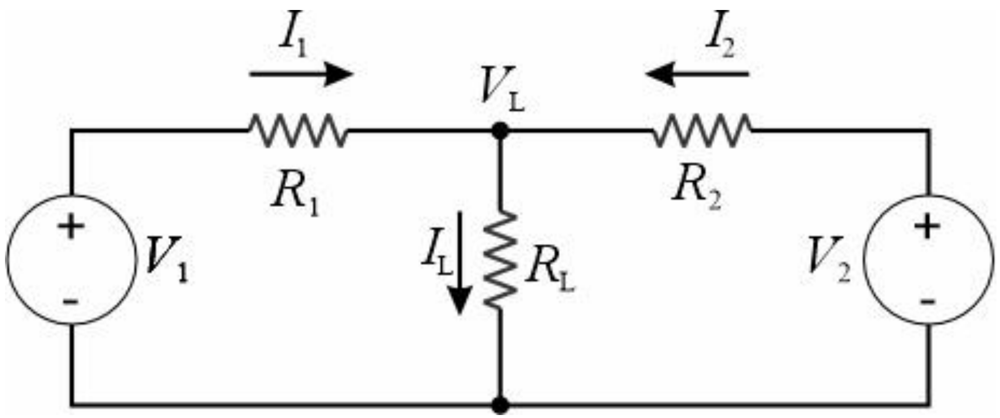
$$V_L = \frac{\left(\frac{V_1}{R_1}+\frac{V_2}{R_2}\right)}{\left(\frac{1}{R_L}+\frac{1}{R_1}+\frac{1}{R_2}\right)},\ I_1 = \frac{V_1 - V_L}{R_1},\ I_2 = \frac{V_2 - V_L}{R_2}$$

If voltage sources are significantly different, the lower voltage source will only contribute at high power levels.
Alternately, if at lower power levels, the lower voltage source will only contribute if the higher voltage source drops offline.

Peak Shaving (Energy Storage) Example

- Set $V_1 = 10\,Volts, V_2 = 8\,Volts$
- Set $R_1 = 1.0\,ohm, R_2 = 0\,ohm$

R_L	V_L	I_1	I_2	I_L
Ohm	Volts	Amps	Amps	Amps
10	9.09	0.91	0.00	0.91
5	8.33	1.67	0.00	1.67
3.3	8.00	2.00	0.42	2.42
2.5	8.00	2.00	1.20	3.20



$$V_L = \frac{\left(\frac{V_1}{R_1}+\frac{V_2}{R_2}\right)}{\left(\frac{1}{R_L}+\frac{1}{R_1}+\frac{1}{R_2}\right)}, \quad I_1 = \frac{V_1 - V_L}{R_1}, \quad I_2 = \frac{V_2 - V_L}{R_2}$$

Minimum Load Voltage fixed, Load current for Source 1 limited

Droop In AC Systems

- Frequency droop as a function of real power
  - As real power supplied by source increases, the frequency decreases
  - Enables sharing of real power among multiple generators
- Voltage droop as a function of current, apparent power, or reactive power
  - As current, apparent power, or reactive power increases, voltage decreases
  - Enables sharing of reactive power among multiple generators
    - If current or apparent power is used, assumes the real power is shared appropriately.

Wrap up