Introduction

For many applications it is necessary to disable a DC-DC converter when its input voltage goes outside a specified range. This note describes circuits that can be used to disable a Vicor converter based on programmable undervoltage or overvoltage set points. These circuits operate as comparators that monitor the input voltage and disable the converter via the Gate In or PC pin when the comparator trips. Configurable hysteresis is included in each circuit so that lockout will occur cleanly in the presence of noise.

Design Considerations

To disable a Vicor DC-DC converter the Gate In / PC pin should be pulled low. The modules require a switch capable of sinking a minimum of 6 mA for the VI-200/VI-J00 converters and 4 mA for Maxi, Mini, Micro converters. When Gate In / PC is allowed to go high in the absence of a fault condition it will rise to about 6 V.

VI-200/VI-J00 modules are capable of turning on at very low input voltages, i.e., lower than the voltage at which they can operate correctly. This necessitates the use of a lockout circuit (Figure 1) for applications where the input voltage may drop below low line. Vicor’s Maxi, Mini, Micro modules have built-in undervoltage and overvoltage protection. For these converters the following circuits should be implemented if lockout is required inside the preexisting range of the converter.

Figure 1: Undervoltage / overvoltage lockout block diagram

All input sources have some noise that could cause glitching at the transition point if it was fed directly into a comparator. Using positive feedback to add hysteresis to the circuit cleans up the transitions. For example, Figure 2 shows how this hysteresis will affect lockout of the VI-J00-CY module. The diagram shows a circuit configured for 4% hysteresis such that the converter cannot be enabled outside its normal operating range. Inside the hysteresis bands the status of Gate In / PC will depend on whether the input voltage is going into or out of range.

The hysteresis voltage bands will ensure clean transitions if they are greater than the maximum possible peak-to-peak change in input voltage. Their widths should be chosen based on the maximum anticipated noise and ripple.
Figures 3 and 4 show startup and shutdown waveforms for a converter configured for the lockout voltages in Figure 2. Gate In / PC shows clean transitions in spite of the slowly changing input.

For high-input-voltage modules care should be taken not to exceed either maximum power or maximum voltage ratings of the resistors. One way to achieve this is to replace a single resistor with a series of smaller resistors that share power and voltage.

Figure 2: Hysteresis diagram

Figure 3: VI-JV0-CY with input rising from undervoltage lockout to overvoltage lockout

Figure 4: VI-JV0-CY with input falling from overvoltage lockout to undervoltage lockout
### Undervoltage Lockout

Figure 5 shows the undervoltage lockout circuit schematic.

![Undervoltage Lockout Circuit Schematic](image)

### Resistor Values for VI-200/VI-J00 Converters

Table 1 lists standard lockout voltages for VI-200/VI-J00 family modules and resistor values. Use the formulas that follow for applications not listed.

<table>
<thead>
<tr>
<th>Input Des.</th>
<th>V_{UV(off)} (V)</th>
<th>V_{UV(on)} (V)</th>
<th>Max. V_{IN} (V)</th>
<th>R_1 (kΩ)</th>
<th>R_3 (kΩ)</th>
<th>R_5 (kΩ)</th>
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**Table 1:** Resistor values for common undervoltage thresholds.

**Notes:**
1. *Voltage ranges that allow the converter to support 75% load (brown out).
2. Hysteresis is set at 4%.
3. All resistors are 0.25 W unless otherwise specified.
Circuit Operation

As the input voltage ramps up $R_1$ feeds the base of $Q_1$ through zener $Z_1$. This turns $Q_1$ on, which pulls the Gate In / PC pin low and disables the module.

$Q_1$ remains on until the input voltage scaled by $R_3$ and $R_4$ reaches 1.24 V, the reference voltage of $U_1$ (TLV431). When this occurs $U_1$ shunts current from the cathode of $Z_1$ and pulls this point down to about 1 V. This in turn pulls the base of $Q_1$ low forcing it into cutoff and enabling the module. $R_2$ prevents $Z_1$ leakage from pulling $Q_1$ out of cutoff.

When the Gate In / PC pin goes high the feedback resistor ($R_5$) pulls up the reference of $U_1$ thereby adding hysteresis to the circuit. $D_1$ disables the feedback when Gate In / PC is low.

$C_1$ acts as a low-pass filter with a 20 kHz bandwidth that decouples high-frequency noise from the reference of $U_1$.

Formulas for Customized UV Lockout Voltages and Maxi, Mini, Micro Converters

Solving For $R_1$

$R_1$ should be selected so that the base of $Q_1$ is fed enough current to saturate it but not more than $U_1$ is capable of sinking. Assuming $R_2$ is large enough to be neglected and the worst case Beta of $Q_1$ is 20, then $R_1$ should provide at least 0.3 mA to sink 6 mA from Gate In / PC. This leads to the following formula for $R_1$:

$$R_1 = \frac{V_{IN(min)} - 5.5 V}{0.3 mA}$$

Where:

$V_{IN(min)}$ is the minimum voltage at which the converter should be disabled, typically 6 V or one third the converter’s minimum input voltage whichever is less.

At high line the current though $R_1$ is then:

$$I_{R1(HL)} = \frac{V_{HL} - 1V}{R_1}$$

Where:

$V_{HL}$ is the maximum operating voltage of the module.

$IR_{1(HL)}$ should not exceed the 15 mA limit of $U_1$. Power dissipation is governed by the following formula:

$$P_{R1} = \frac{(V_{IN(max)} - 1V)^2}{R_1}$$

Where:

$V_{IN(max)}$ is the maximum input voltage the circuit can withstand.

Solving For $R_3$

A good starting value for $R_4$ is 10 kΩ. With the value of $R_4$ known, $R_3$ can be calculated as follows:

$$R_3 = R_4 \left( \frac{V_{UV(on)}}{1.24 V} - 1 \right)$$

Where:

$V_{UV(on)}$ is the voltage at which the module is enabled as the input voltage transitions low to high (See Figure 2).

The power dissipated in $R_3$ can be calculated using the formula below:

$$P_{R3} = \left( \frac{V_{IN}}{R_3 + R_4} \right)^2$$

Solving For $R_5$

$R_5$ should be set to add the proper amount of hysteresis to the circuit based on input noise. It can be calculated using this formula:

$$R_5 = \frac{(4.36 \times V)R_3 R_4}{1.24 V (R_3 + R_4) - V_{UV(off)} R_4}$$

Where:

$V_{UV(off)}$ is the voltage at which the module is disabled as the input voltage transitions high to low (See Figure 2).
Overvoltage Lockout
Figure 6 shows the overvoltage lockout circuit schematic.

Reference designations are continued from the undervoltage lockout schematic of Figure 5 so that the circuits can be cascaded without confusion.

Resistor Values for VI-200/VI-J00 Converters
Table 2 lists common lockout voltages for VI-200/VI-J00 family modules and resistor values. Use the formulas that follow for applications not listed.

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<th>Input Des.</th>
<th>V_{OV(off)} (V)</th>
<th>V_{OV(on)} (V)</th>
<th>Max. V_{in} (V)</th>
<th>R_6 (k\Omega)</th>
<th>R_8 (k\Omega)</th>
<th>R_{13} (k\Omega)</th>
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Table 2: Resistor values for common overvoltage thresholds.

Notes:
1. Hysteresis is set at 4%.
2. All resistors are 0.25 W unless otherwise specified.
Circuit Operation
When the input voltage transitions high, a 5.6 V source is established by Z2 at the emitter of Q3. For voltages less than lockout, Q3 is in cutoff since U2 conducts minimal cathode current. Thus, Q3 passes negligible current to the base of Q2 cutting Q2 off and allowing Gate In / PC to go high.

When the input voltage as scaled by R6 and R7 increases above the reference of U2, U2 will pull the base of Q3 low through R12. As Q3 turns on, current flows into the base of Q2 through R6 causing it to conduct and pull Gate In / PC low, thereby disabling the module.

R8 adds positive feedback by coupling Q3’s collector to the reference of U2. D2 disables the feedback when Gate In / PC is high.

C2 acts as a low-pass filter with a 20 kHz bandwidth that decouples high-frequency noise from the reference of U2.

Formulas for Customized OV Lockout Voltages and Maxi, Mini, Micro Converters

Solving For R6
A good starting value for R7 is 10 kΩ. With the value of R7 known R6 can be calculated as follows:

\[ R_6 = R_7 \left( \frac{V_{OV(off)}}{1.24V} - 1 \right) \]

Where:
\( V_{OV(off)} \) is the voltage at which the module is disabled as the input voltage transitions low to high (See Figure 2).

Dissipation in R6 can be calculated using the formula below:

\[ P_{R6} = \left( \frac{V_{IN(max)}^2}{R_6 + R_7} \right) R_6 \]

Where:
\( V_{IN(max)} \) is the maximum input voltage the circuit can withstand.

Solving For R8
The feedback resistor R8 can be calculated using the formula below:

\[ R_8 = \frac{(3.76 V)R_6 R_7}{1.24 V (R_6 + R_7) - V_{OV(on)} R_7} \]

Where:
\( V_{OV(on)} \) is the voltage at which the module is enabled as the input voltage transitions high to low (See Figure 2).

Solving For R13
The value of R13 should be chosen so that the current through Z2 is about 5 mA at the overvoltage lockout point. It can be set using this formula:

\[ R_{13} = \frac{V_{OV(off)} - 5.6 V}{5 \text{ mA}} \]

Power dissipation can be calculated as given below:

\[ P_{R13} = \frac{(V_{IN(max)} - 5.6 V)^2}{R_{13}} \]
Undervoltage/Overvoltage Lockout

Circuit Description/Operation
The circuit in Figure 7 combines the undervoltage and overvoltage circuits. When an overvoltage event occurs the second regulator (U2) shunts the reference of U1 forcing it to disable the module. R9 is added to provide current to the cathode of U2 when it is off so that D3 can isolate it from the undervoltage circuit’s divider. Z2 acts as a clamp to prevent damage to U2. For detailed circuit operation please refer to the individual circuit descriptions.

Figure 7: Undervoltage/overvoltage lockout circuit schematic
Resistor Values for VI-200/VI-J00 Converters

Table 3 lists common lockout voltages for VI-200/VI-J00 family modules and resistor values. Use the formulas that follow for applications not listed.

Notes:
1. * Voltage ranges that allow the converter to support 75% load (brown out).
2. Hysteresis is set at 4% of the respective lockout voltages.
3. All resistors are 0.25 W unless otherwise specified.

<table>
<thead>
<tr>
<th>Input Des.</th>
<th>$V_{UV\text{off}}$ (V)</th>
<th>$V_{UV\text{on}}$ (V)</th>
<th>$V_{DO\text{off}}$ (V)</th>
<th>Max. $V_{IN}$ (V)</th>
<th>$R_1$ (kΩ)</th>
<th>$R_3$ (kΩ)</th>
<th>$R_5$ (kΩ)</th>
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Table 3: Resistor values for common undervoltageovervoltage thresholds.

Notes:
1. * Voltage ranges that allow the converter to support 75% load (brown out).
2. Hysteresis is set at 4% of the respective lockout voltages.
3. All resistors are 0.25 W unless otherwise specified.
Formulas for Customized UV/OV Lockout Voltages and Maxi, Mini, Micro Converters

For this circuit, the zener voltages have been selected such that most of the resistor values need not be recalculated. With the exception of \( R_9 \) and \( R_3 \), resistor values can be found by using the equivalent resistors calculated for the stand-alone undervoltage and overvoltage circuits.

**Solving For \( R_3 \)**

The formula below gives the value of \( R_3 \):

\[
R_3 = R_4 \left( \frac{V_{UV(on)}}{1.24} - 1 \right) - 8.06 \text{ kΩ}
\]

The power dissipated in \( R_3 \) can be calculated using the formula below:

\[
P_{R_3} = \frac{(V_{IN(max)} - 1.7 V)^2}{R_3}
\]

**Solving For \( R_9 \)**

The value of \( R_9 \) can be calculated as follows:

\[
R_9 = \frac{V_{UV(off)} - 5.6 V}{100 \text{ μA}}
\]

For more information, please contact Vicor's Applications Engineers at 1-800-927-9474 or vicorpower.com/support/ for worldwide assistance.