Undervoltage/Overvoltage Lockout for VI-200/VI-J00 and Maxi, Mini, Micro Converters

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 / 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 6mA for the VI-200 / VI-J00 converters and 3mA 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 6V.

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.

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-JV0-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*
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>
<th>$R_1$ Rating (W)</th>
<th>$R_3$ Rating (W)</th>
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<td>0.25</td>
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<td>1.50</td>
<td>0.25</td>
</tr>
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</table>

**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 1.24V, 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 1V. 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 20kHz 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 0.3mA to sink 6mA from Gate IN / PC. This leads to the following formula for $R_1$:

$$R_1 = \frac{V_{IN(min)} - 4.9V}{0.3mA}$$

Where:

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

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 15mA limit of $U_1$. Power dissipation is governed by the following formula:

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

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 10kΩ. With the value of $R_4$ known, $R_3$ can be calculated as follows:

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

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:

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

$$R_5 = \frac{(4.36V) \cdot R_3 \cdot R_4}{I_{24V} \cdot (R_3 + R_4) - V_{UV(\text{off})} \cdot R_4}$$

Where:

$V_{UV(\text{off})}$ 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.

![Overvoltage Lockout Circuit Schematic](image)

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.

<table>
<thead>
<tr>
<th>Input Des.</th>
<th>$V_{OV(\text{off})}$ (V)</th>
<th>$V_{OV(\text{on})}$ (V)</th>
<th>Max. $V_{IN}$ (V)</th>
<th>$R_6$ (kΩ)</th>
<th>$R_8$ (kΩ)</th>
<th>$R_{13}$ (kΩ)</th>
<th>$R_{13}$ Rating (W)</th>
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<tr>
<td>V, W</td>
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<td>78.70</td>
<td>3.00</td>
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</tbody>
</table>

Notes:

1. Hysteresis is set at 4%.
2. All resistors are 0.25W unless otherwise specified.
Circuit Operation

When the input voltage transitions high, a 5.6V source is established by \( Z_2 \) at the emitter of \( Q_3 \). For voltages less than lockout, \( Q_3 \) is in cutoff since \( U_2 \) conducts minimal cathode current. Thus, \( Q_3 \) passes negligible current to the base of \( Q_2 \) cutting \( Q_2 \) off and allowing Gate IN / PC to go high.

When the input voltage as scaled by \( R_6 \) and \( R_7 \) increases above the reference of \( U_2 \), \( U_2 \) will pull the base of \( Q_2 \) low through \( R_{12} \). As \( Q_2 \) turns on, current flows into the base of \( Q_2 \) through \( R_6 \) causing it to conduct and pull Gate IN / PC low, thereby disabling the module.

\( R_8 \) adds positive feedback by coupling \( Q_3 \)'s collector to the reference of \( U_2 \). \( D_2 \) disables the feedback when Gate IN / PC is high.

\( C_2 \) acts as a low-pass filter with a 20kHz bandwidth that decouples high-frequency noise from the reference of \( U_2 \).

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

Solving For \( R_6 \)

A good starting value for \( R_7 \) is 10k\( \Omega \). With the value of \( R_7 \) known \( R_6 \) 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 \( R_6 \) can be calculated using the formula below:

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

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

Solving For \( R_8 \)

The feedback resistor \( R_8 \) can be calculated using the formula below:

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

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 $R_{13}$

The value of $R_{13}$ should be chosen so that the current through $Z_2$ is about 5mA at the overvoltage lockout point. It can be set using this formula:

$$R_{13} = \frac{V_{ovloff} - 5.6V}{5mA}$$

Power dissipation can be calculated as given below:

$$P_{R_{13}} = \frac{(V_{IN(min)} - 5.6V)^2}{R_{13}}$$

**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 ($U_2$) shunts the reference of $U_1$ forcing it to disable the module. $R_9$ is added to provide current to the cathode of $U_2$ when it is off so that $D_3$ can isolate it from the undervoltage circuit’s divider. $Z_2$ acts as a clamp to prevent damage to $U_2$. For detailed circuit operation please refer to the individual circuit descriptions.

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*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 0.25W 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_{OV}\text{(off)} (V)</th>
<th>V_{OV}\text{(on)} (V)</th>
<th>Max. V_{IN} (V)</th>
<th>R_{1} (k\Omega)</th>
<th>R_{3} (k\Omega)</th>
<th>R_{5} (k\Omega)</th>
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</table>
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 \( R_3, R_5 \) and \( R_9 \), 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 \( R_3 \):

\[
R_3 = R_3 \left( \frac{V_{UV(on)} - 1.24V}{1.24V} - 1 \right) - 8.06k\Omega
\]

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

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

Solving For \( R_5 \)

\( R_5 \) adds the proper amount of hysteresis to the circuit based on input noise. \( R_5 \) can be calculated as follows:

\[
R_5 = \frac{4.36V (R_3 + R_1) R_3}{1.24V (R_3 + R_4 + R_{10}) V_{UV(off)} R_4}
\]

Solving For \( R_9 \)

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

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