ON Semiconductor

Design Note – DN05060/D

Input Over Voltage Protection Circuit

Device	Application	Input Voltage	Output Power	Topology
NCL300001: NCP431 and NCS2220 or LM2903	Offline Power Conversion, LED lighting	90 – 315 Vac	Various	Various

Typical Shutdown Voltage	266 Vac
Typical Restart Voltage	253 Vac
Bias Current (LM2903)	1.25 mA
Bias Current (NCS2220A)	0.17 mA

Circuit Description

Overvoltage events on the power grid can be thought of in broad terms as impulse-like or “long term”. “Impulse” events are well understood and there are a range of surge suppression techniques (ex: TVS, MOV etc.) utilized by power supply designers.

Longer term excess voltage events are typically due to poor regulation or faults in the power grid and can exceed 300 Vac and last for hours or be less than 50 msec in duration. Some form of mitigation is required in order to provide a reliable system with a long service life. This is especially true in applications like outdoor LED lighting.

Essentially these long term events have limitless power capability and the first line of defense is to select components which are rated to withstand the anticipated stress. Depending on the magnitude of excess voltage, it may not be practical to use parts with suitable rating.

This design note describes an input voltage monitoring solution and is suitable for systems which can be disabled for the duration of the excess voltage event circumventing unnecessary stress on some components. Hysteresis provides more stable operation by lowering the input voltage threshold necessary to restore normal operation.

Typically, power converter input voltage is specified in terms of RMS voltage. The detection method used in this example circuit is based on peak voltage providing a simpler implementation. Throughout the remainder of this design note, conversion between RMS and peak voltages will be done assuming sinusoidal waveforms.

Even though the power converter is not operational during the overvoltage event, the monitoring circuit remains active to detect when the input voltage returns to normal levels so bias power must be supplied directly from the rectified ac source. The simplest method is via a linear regulator, and in this case a shunt configuration is appropriate and cost effective.

Any linear regulator will generate heat and the amount is proportional to the required current and the difference between input and output voltage. To minimize dissipation the circuit must draw minimal current. Since the comparator draws the majority of the current, careful consideration should be given to the tradeoff of cost and power consumption. High resistances are selected for dividers and pull-up devices to meet this end. Note that an appropriate number of resistors are needed in this shunt regulator to dissipate the power without exceeding component ratings.

The bias in this circuit performs two functions. Not only does this voltage provide the current to operate the circuit, it is also used as the main reference to establish the input over voltage threshold. A reference with tight tolerance is desirable to control accuracy of the shutdown threshold; however, once again there is a tradeoff between a low cost solution such as a zener diode and the more accurate NCP431 shunt regulator. Details on utilizing the more accurate NCP431 are shown in a later section. Moreover compared to an industry standard TL431, the NCP431 requires only 8% of the minimum operating current offering a more power efficient solution.

Circuit Operation

Figure 1 shows a solution based on the industry standard LM2903 comparator and a low current zener diode for the bias voltage. Two resistors, R1 and R2, are used to form the upper portion of the input divider due to maximum voltage rating of 200 volts for a 1206 surface mount resistor. Two resistors also provide finer resolution on setting the shutdown threshold. C1 is a noise filter for this initial divider. The peak detecting comparator U1A accepts the input from the first divider and compares it to a reference derived from the bias voltage. R6 provides hysteresis and noise immunity for the peak level sensing.

R8 is a pull up for the LM2903 open collector comparator output. D2 couples the peak detecting comparator to a simple resistor-capacitor timer formed by R9, R10 and C2. This R-C timer integrates over each half cycle of the ac line providing a more constant level indicative of the average ac input voltage. R10 provides quick response to high peak voltages on the input. R9 provides a slow response filling the gaps between half cycles of the applied voltage.

When U1A detects a peak voltage above the set threshold or trip level, C2 is pulled low. When C2 voltage falls below the threshold of the second comparator U1B, the output of this comparator switches to a high state turning on Q2. FET Q2 is connected to the appropriate control signal of the target power converter stopping all switching and reducing voltage stress in response to the excessive input voltage.

The second comparator also turns on Q1 forming a conducting path for R7. This resistor increases the hysteresis for the first comparator lowering the detection threshold. The value of R7 is adjusted to provide the desired input line voltage level below which the power converter will be allowed to restart.

As long as the peak detecting comparator U1A senses input voltage above the reset threshold, D2 will keep C2 discharged, and the second comparator will maintain Q2 in a conducting state forcing the power converter off.

When the first comparator no longer detects excessive peak voltages corresponding to normal RMS voltage levels, C2 will begin to charge through R9. After a delay, the second comparator will switch to a low state providing hysteresis through R13 for stable detection.

Subsequently, Q2 will switch off allowing the power converter to restart. Q1 will also switch off raising the first comparator threshold back to the higher trip level corresponding to the RMS input voltage threshold to shut down the power converter.

Bias Setup

Energy to power the detection circuit must be derived from the rectified ac input. By its nature, bias power is supplied when the circuit is operating at high input voltage. A series connection of resistors is used to deliver the required current dividing the voltage and power stress amongst multiple devices. Maintaining each device within ratings enhances reliability. Collectively, this series connection of resistors is referred to as R15.

The design example of Figure 1 is based on the MMSZ4689 5.1 volt zener with 5% tolerance. Note this low current zener diode is specified at 50 µA bias current which avoids significant dissipation compared to a MMSZ5231 which is guaranteed 5% at 20 mA bias current.

The required bias current is largely dependent on the selected comparator. The LM2903 dual comparator draws about 1 mA bias current. The remaining circuitry draws about 0.25 mA depending on resistor values plus 50 µA for the zener diode, totaling 1.25 mA for this circuit. A lower power solution based on the NCS2220 comparator is discussed in a later section.

The current supplied by R15 is dependent on the input voltage. As the ac input voltage is reduced, the available bias current will reduce. By the nature of the application, full performance of this circuit is required only at elevated input voltage. However, the circuit must not interfere with power supply operation down to the minimum operating input voltage of the system. Empirical testing shows full bias current is required at approximately 250 volts to avoid false operation.

In this case, R15 = (250 – 5.1) / 1.25 mA = 196 k ohms is the maximum resistance value. During an excessive input event of say 310 Vac less 2 volts in the bridge rectifier, the peak voltage will be 308 * 1.414 = 436 Vdc. Subtracting the 5.1 volt bias leaves 434.9 Vdc applied across R15.

Dissipation in R15 follows 434.9 squared divided by 196 k = 0.96 watts. Using the typical 125 mW allowable stress per 1206 resistor, this means 8 resistors are required to handle the dissipation. 196 k divided by 8 equals 24.5 k ohm per resistor. Therefore, R15 is comprised of 8 resistors of 24.5 k ohm each.

Optionally, a two watt through-hole resistor could be used for R15. Specific types are available which are rated for higher operating voltage.

Improved Accuracy

The bias voltage is used as the reference to establish shutdown or trip voltage. Any deviation in the bias voltage will directly reflect in accuracy of the trip voltage. The MMSZ4689 low current zener provides a simple bias regulator, but carries with it a 5% tolerance as well as variation due to current through the device.

Changing to the NCP431 shunt regulator reduces the error to 1% or even 0.5% depending on the version selected.

The NCP431 requires 100 µA bias current. This is a relatively small increase in current and dissipation. Capacitor C3 must be less than 200 pF to ensure stability.

Figure 2 shows the implementation of the NCP431 in place of the zener diode. Each particular application should evaluate these tradeoffs between accuracy, dissipation, and cost.

Design Example

A design example is presented based on the NCL30001 High Efficiency, Single Stage, High Power Factor LED driver. A similar approach could be used for any off-line power converter.

The circuit of Figure 1 is used in this example, The goal is to disable the converter when the input voltage exceeds 266 V ac. Normal operation shall be restored when the input voltage reaches 253 V ac.

The NCL30001 can be disabled through the 'Vff' function of pin 5. Pulling this pin below 0.45 volts activates the brown out function. The drain of Q2 in Figure 1 will be connected to NCL30001 pin 5. When an over voltage event is detected, Q2 will pull pin 5 below the threshold causing the controller to shut off all switching. Figure 3 shows a schematic detailing connection.

Figure 4 shows the applied input voltage in yellow transitioning from 260 V ac to 270 V ac. This step was selected for clarity, noting that the circuit actually responds at 268 V ac. The blue trace shows the gate voltage of Q2 rising which initiates a shutdown of the NCL30001 controller.

The input voltage must be reduced to below 253 V ac to restore operation. A delay of approximately 40 ms is used to ensure the input voltage has returned to the proper level and the Over Voltage monitor is not responding to normal zero crossing events.

Figure 5 shows the response of the circuit to a reduction of input voltage from 268 V ac to 253 V ac. The blue trace shows the gate of Q2 dropping after a delay.

The circuit provides clean transitions from excessive input voltage to shut down state and back to normal operation when required. The hysteresis and delay of the circuit provide robust protection.

Reduced Current/Dissipation

Dissipation and effect on system efficiency may be a concern in some applications. While the LM2903 dual comparator is a cost effective solution, the bias current is about 1 mA. This introduces significant power loss given the circuit must be powered by a linear regulator from a high voltage source.

ON Semiconductor offers another dual comparator which draws less than 3.5% of the LM2903 bias current. The NCS2220 comparator draws only 34 µA. Details for this circuit are shown in Figure 2.

In addition, the NCS2220 will sink and source current which eliminates two resistors, R8 and R14. The solution requires less board space, fewer components and reduced bias current.

If the NCS2220 comparator is used with the NCP431 higher accuracy reference, the typical bias current is reduced to about 14% of the circuit shown in Figure 1. Dissipation is reduced from 0.94 to 0.13 watts. A typical implementation requires only 2 bias resistors compared to 8 of the 1206 size surface mount resistors.

A design example based on a 60 watt output power supply will help put these numbers in perspective. If this power supply had an efficiency of 85%, then the input power would be 60 / 0.85 = 70.59 watts.

Adding the Input Over Voltage Protection circuit of Figure 1 increases the input power by 0.94 watts. As a consequence, the efficiency of this power supply will drop from 85% to 83.9%.

If the Input Over Voltage Protection circuit of Figure 2 was incorporated, the input power increase is only 0.13 watts. The power supply efficiency would be 84.8%. The circuit of Figure 2 represents an improvement of about 1% for this example power supply compared to the circuit of Figure 1.

A Bill of Materials is presented in Figure 6 below showing all parts including options for lower power comparator and higher accuracy operation.

Design Tool

A design tool is available at the ON Semiconductor website. This Excel® spreadsheet helps establish shut off and start up voltages. In addition, the designer can select which type of comparator and reference to use and guidance is given on selecting the bias resistors.

Conclusion

Many applications be it lighting, communications, or computing which are exposed to poor power quality may benefit from a protection solution which does not involve more expensive or lossy semiconductor components. Since this solution does disable the power converter during the over voltage event it may not be suitable for critical applications which cannot be interrupted.

The monitor circuit will automatically restore normal operation when the input voltage returns acceptable levels. This design does not use any electrolytic capacitors which enhances reliability and reduces PCB space.

DN05060/D

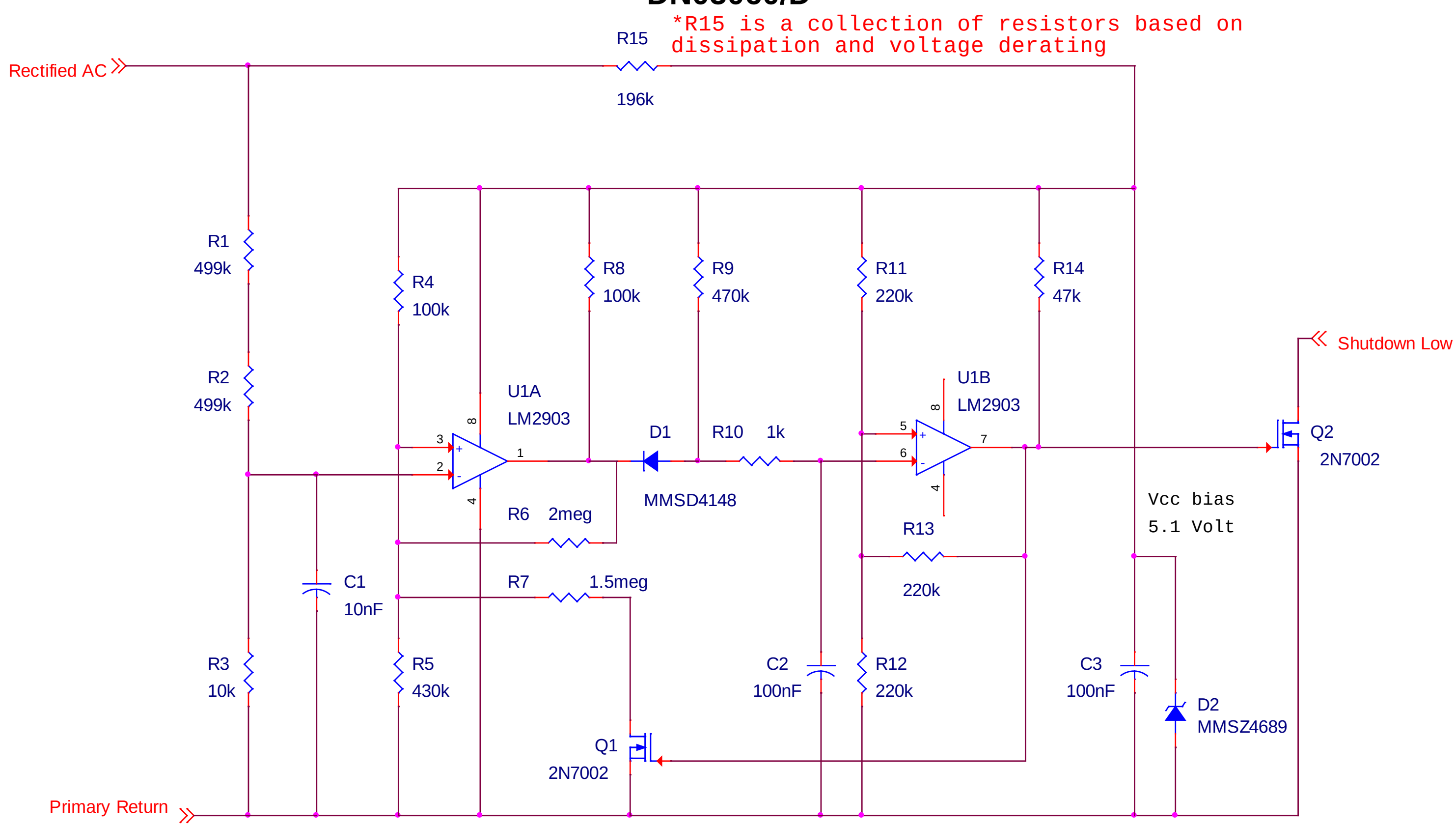

Figure 1. LM2903 Schematic

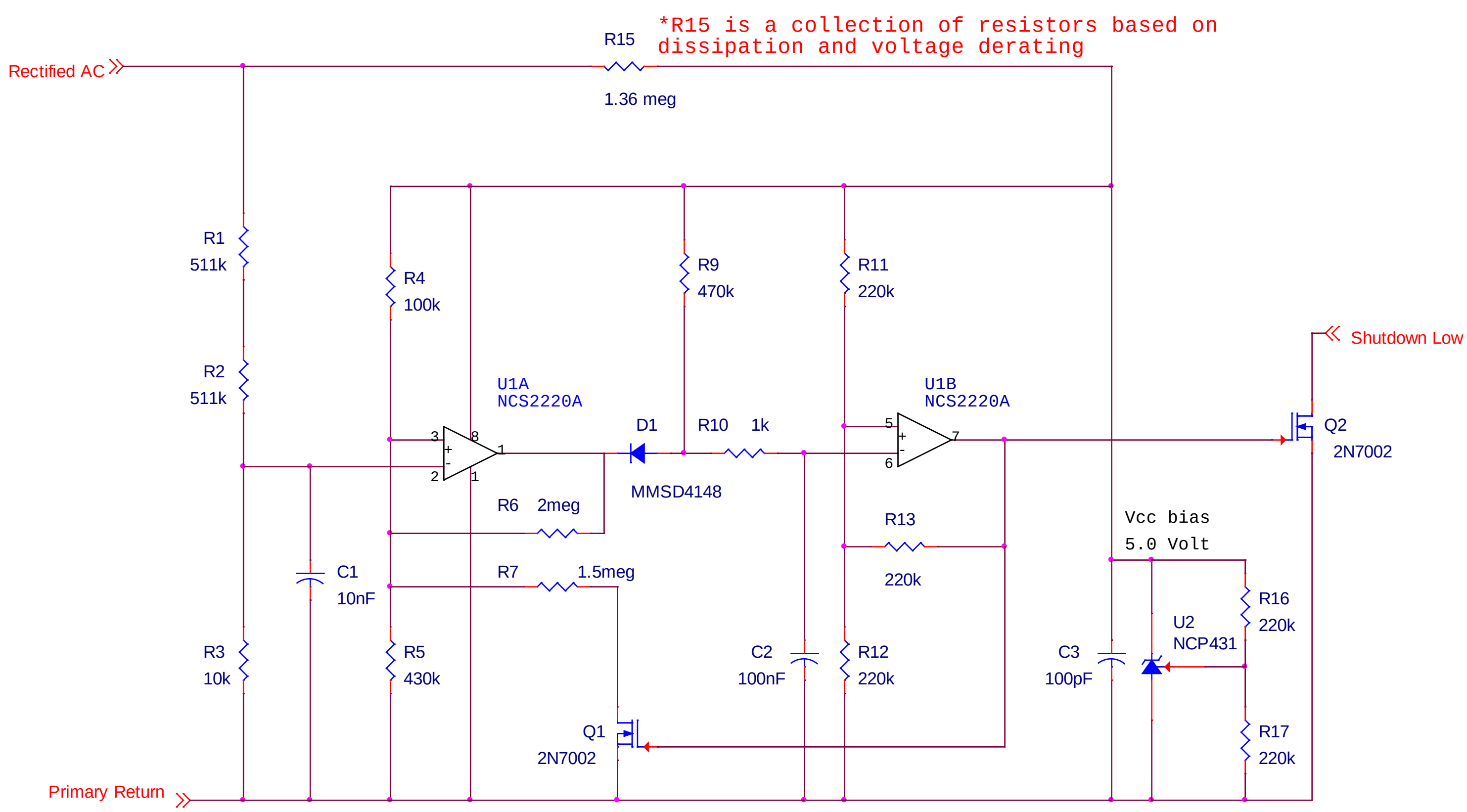

Figure 2. NCS2220A Schematic

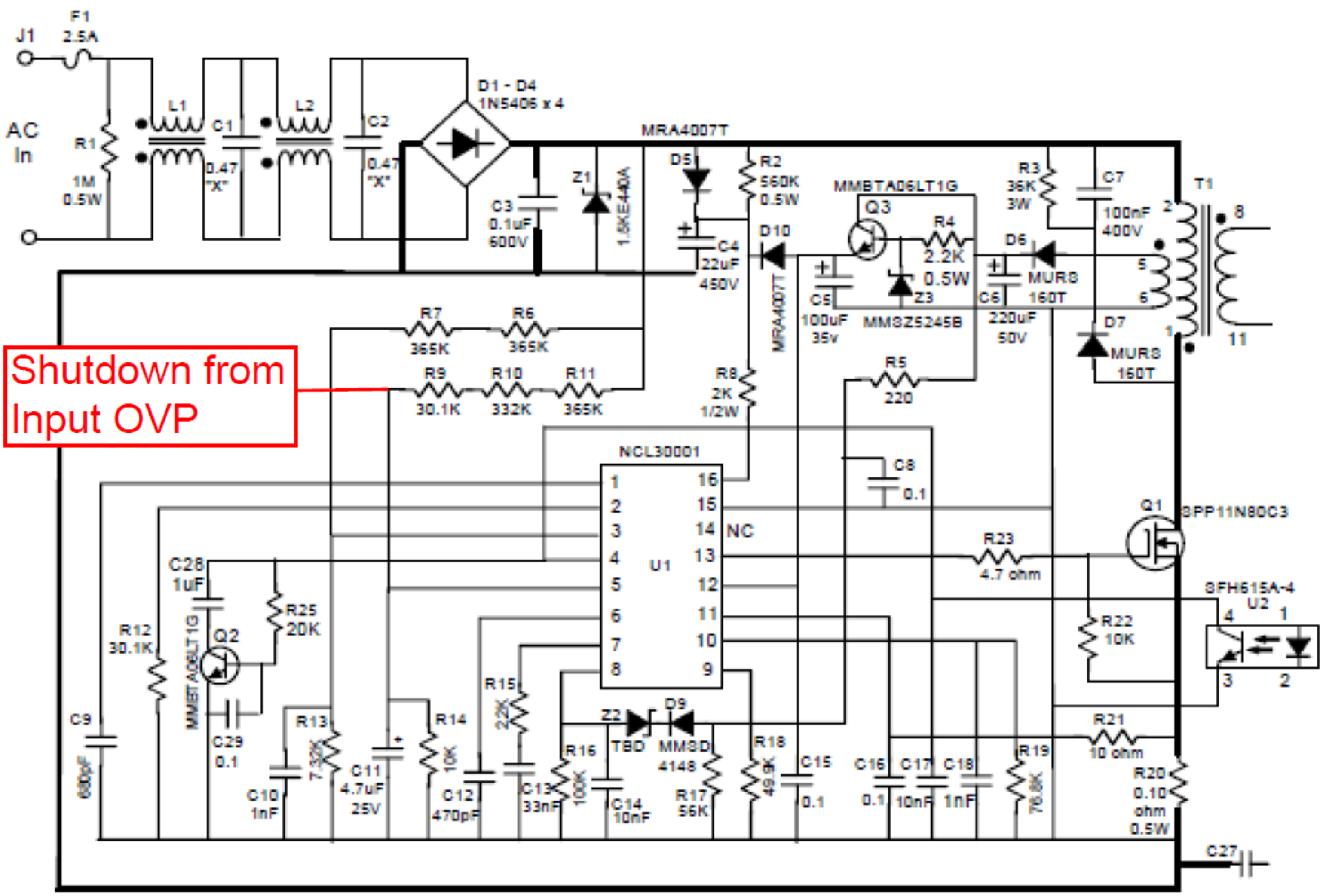

Figure 3. NCL30001 schematic showing connection to Input OVP circuit

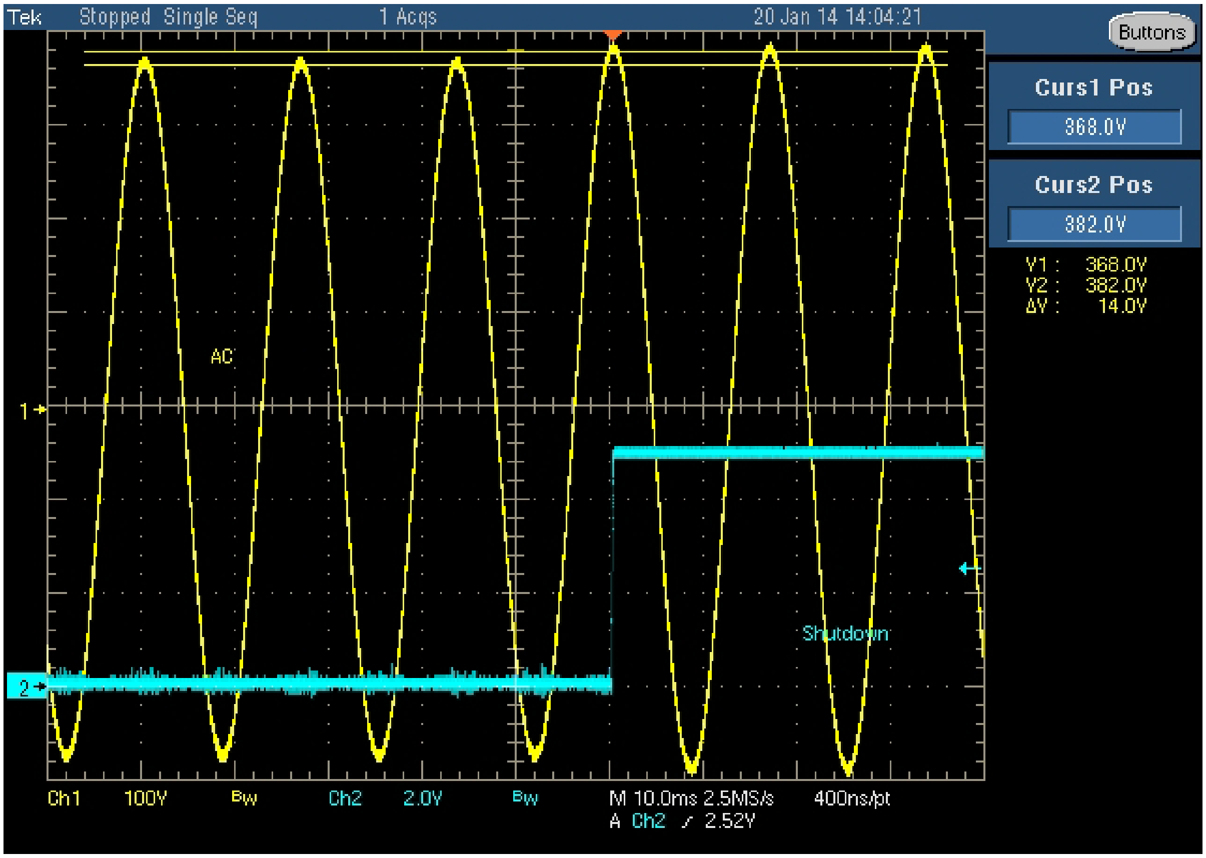

Figure 4. Circuit responding to excessive input voltage

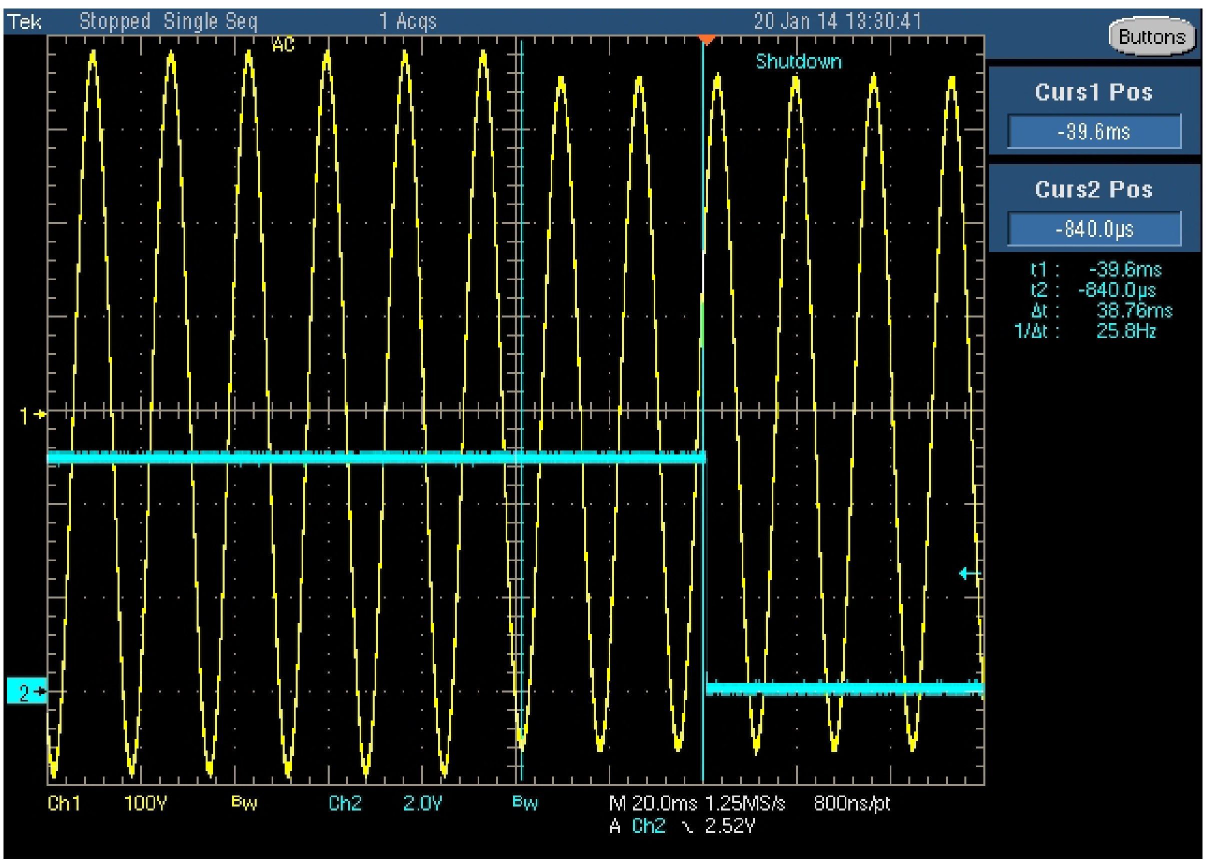

Figure 5. Restoring normal operation for normal input voltage

Ref	Qty	Type	Value	Description	Tol (+/-)	Footprint	Manufacturer	Manufacturer Part Number	Sub Allowed
C1	1	Cap	10nF	50V Ceramic X7R	10%	0603	TDK	C1608X7R1H103K080AA	Yes
C2	1	Cap	100nF	50V Ceramic X7R	10%	0603	TDK	C1608X7R1H104K080AA	Yes
C3	1	Cap	100nF	50V Ceramic X7R	10%	0603	TDK	C1608X7R1H104K080AA	Yes
D1	1	Diode	MMSD4148	100V, 200mA	-	SOD-123	ON Semiconductor	MMSD4148T1G	No
D2	1	Diode	MMSZ4689	Low current, 5.1V	5%	SOD-123	ON Semiconductor	MMSZ4689T1G	No
Q1 Q2	2	Tran	2N7002	NFET, 60V, 7.5Ω	-	SOT-23	ON Semiconductor	2N7002LT1G	No
R1 R2	2	Res	499k	1/4W	1%	1206		-	Yes
R3	1	Res	10k	1/10W	1%	0603			Yes
R4 R8	2	Res	100k	1/10W	1%	0603			Yes
R5	1	Res	430k	1/10W	1%	0603			Yes
R6	1	Res	2 meg	1/10W	1%	0603			Yes
R7	1	Res	1.5 meg	1/10W	1%	0603			Yes
R9	1	Res	470k	1/10W	1%	0603			Yes
R10	1	Res	1k	1/10W	1%	0603			Yes
R11 R12 R13	3	Res	220k	1/10W	1%	0603			Yes
R14	1	Res	47k	1/10W	1%	0603			Yes
R15	8	Res	24k	1/4W	5%	1206			Yes
U1	1	Comp	LM2903	Dual Comparator	-	SOIC8	ON Semiconductor	LM2903DG	No

Optional Components when implementing low power comparator and higher accuracy reference of Figure 2

Ref	Qty	Type	Value	Description	Tol (+/-)	Footprint	Manufacturer	Manufacturer Part Number	Sub Allowed
C3*	1	Cap	100pF	50V Ceramic X7R	10%	0603	TDK	C1608C0G2A101K080AA	Yes
R1 R2*	2	Res	511k	1/4W	1%	1206		-	Yes
R15*	2	Res	680k	1/4W	5%	1206		-	Yes
R16 R17*	2	Res	220k	1/10W	1%	0603		-	Yes
U1*	1	Comp	NCS2220A	Dual Comparator	-	UDFN8	ON Semiconductor	NCS2220AMUT1G	No
U2*	1	Reg	NCP431	Low Current Ref	-	SOT-23	ON Semiconductor	NCP431AVSNT1G	No

Figure 6 Bill of Materials

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