

# technical brief

## Testing a Transformer-Based Ride-Through Device for Voltage Sags and Interruptions

*Power Quality Measurements and Testing Target*

### Background

Industrial facilities often contain electronic equipment and control circuits that are sensitive to variations in the ac input voltage. A typical way to desensitize such equipment and circuits is to install a constant voltage transformer (CVT). Unlike conventional transformers, the CVT allows the core to become saturated with magnetic flux, which maintains a relatively constant output voltage during input voltage variations such as under-voltages and voltage sags. The magnetic shunt shown in Figure 1 provides a path from the primary winding to the secondary winding for flux that would be lost in the core of conventional transformers. The resonating winding and capacitor shape the transformer output into a sinusoidal waveform.

One of the drawbacks of using a CVT is its inability to protect equipment from voltage interruptions. A traditional CVT can regulate equipment voltage with a  $\pm 3\%$  change in output voltage even during a  $\pm 20\%$  change in input voltage. During voltage sags that last less than 30 cycles, a fully loaded CVT can regulate the voltage within  $\pm 10\%$  for sags down to 70% of nominal voltage. This regulation performance improves as the load on the CVT decreases. For example, tests conducted at EPRI Power Electronic Applications Center (PEAC) Corporation revealed that a CVT loaded at 40% of its rated maximum load was able to regulate voltage to the load within  $\pm 10\%$  for sags down to 50% of nominal. To protect equipment against voltage sags below that threshold and against outages, energy-storage devices such as uninterruptible power supplies are needed.

Uninterruptible Power Products, Inc. (UPPI), a Wisconsin-based company, has introduced a prototype ride-through device that protects equipment from deep voltage sags and brief power interruptions. As shown in Figure 2, the UPPI PowerRide Ride-Through Device (RTD) is designed to protect single-phase process controls. Unlike traditional CVTs, the RTD uses all three phases of supply voltage as its input. This enables the RTD to access energy in unsagged phases of the supply voltage during one- or two-phase voltage sags and interruptions—even when fully loaded.

### Objective

EPRI PEAC tested the prototype RTD to determine its ability to protect process controls during single-phase, two-phase, and three-phase voltage sags and interruptions. PEAC acquired a 1-kV, 480-V RTD from UPPI for testing in its power quality laboratory. A number of voltages and input configurations are available; the prototype acquired for testing was designed to be connected to a three-phase source in a delta configuration.

### Test Approach

The project team first created the following protocol for testing the RTD:

1. Install the RTD into the test circuit shown in Figure 3.
2. Connect the portable sag generator to monitor the input and output of the RTD.
3. Load the RTD to 25% of its rated output VA by toggling on the appropriate number of components in the Industrial Load Bank (ILB) and switching a variable resistor into the

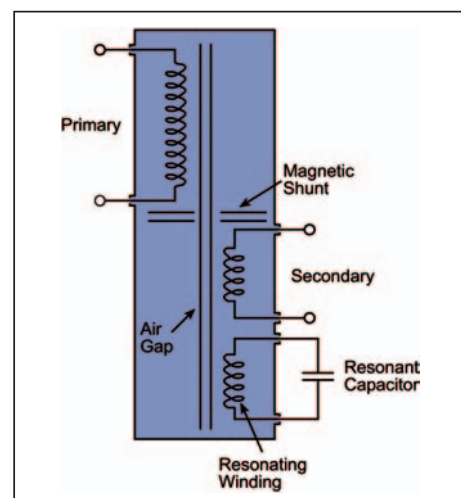


Figure 1. Components of a traditional constant voltage transformer

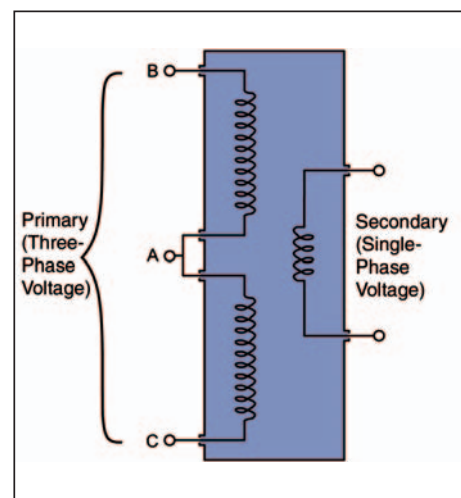


Figure 2. Prototype ferroresonant transformer—the UPPI PowerRide RTD

circuit as needed to increase the loading. The ILB consists of a mixture of 6 industrial control components: ice-cube relays, motor starters, contactors,

a programmable logic controller, a linear dc power supply, and a switch-mode power supply.

4. Apply 480 V of three-phase power to the test circuit.
5. Initiate a voltage sag from phase A to neutral down to 70% of nominal (336 V) for one cycle and record the following parameters before, during, and after the voltage sag:
  - RTD input voltage
  - RTD output voltage
  - RTD output current
  - logical state (on or off) of all ILB components
6. Repeat step 5 for durations of 6, 10, 20, 30, 60, and 120 cycles.
7. Repeat steps 5 and 6 for sag magnitudes of 60, 50, 40, 30, and 0% of nominal.
8. Repeat steps 5, 6, and 7 for RTD loading of 50, 75, and 100% of its rated output VA.
9. Repeat steps 5, 6, 7, and 8 for phase-to-neutral sags on
  - phase B
  - phase C
  - phases A and B
  - phases B and C
  - phases C and A
  - all three phases

### Test Results

Ice-cube relays and motor starters are notoriously weak links in industrial processes. Figures 4, 5, 6, and 7 show two relays and two motor starters

included in the ILB control components, both of which are sensitive to voltage sags. These weakest links were targeted as good indicators of the RTD's performance during the sag and interruption testing.

The test results reveal that the performance of the prototype RTD depended on the phase configuration of the voltage sag or interruption (single-, two-, or three-phase) and, to a much lesser extent, on the loading of the RTD output. Figures 8, 9, 10, and 11 show the voltage-sag magnitudes at which any one of the control components in the ILB tripped during six-cycle voltage sags. The control components in the ILB were monitored to determine whether the RTD successfully supported them. If any of the components dropped out (tripped off-line) during a voltage sag, then that particular data point (sag magnitude, sag duration, percent loading, and configuration of sagged phases) would be assigned an x in the results table. Otherwise, no x would be assigned.

During most voltage sags that did not upset control components, the output of the RTD was well regulated, as shown in Figure 12. However, the output of the RTD was elevated during some voltage sags, and there was a significant dc offset. Figure 13 shows the elevated voltage and dc offset during a 10-cycle two-phase voltage sag to 60% of nominal on phases A and B. This output voltage had no negative effects on the process controls in the ILB.

### Conclusion

The prototype RTD protected the connected process controls from most of the applied voltage sags and interruptions. Performance greatly depended on the phase configuration of the voltage sags. For example, single-phase voltage sags applied to phase B or C had no effect on the connected loads, even when the applied voltage dipped to zero V. Two-phase sags caused the loads to trip when phase A was involved. The RTD performed like typical CVTs during three-phase voltage sags.

To get the most out of the RTD, the most trouble-free phases will have to be determined. For example, if most voltage sags occur on phase A or B, then the center tap on the transformer primary should be connected to phase C.

Although this prototype transformer promises to retail at a cost of about 30% more than the cost of a traditional single-phase CVT, the cost differential may be greatly reduced by a reduction in size. Because their performance depends greatly upon loading, traditional CVTs must be oversized for the connected load. As shown in Figure 14, the performance of a typical CVT declines steadily as its loading increases. However, the performance of the tested RTD depends much less on loading, as shown in Figure 15. A smaller but more loaded RTD should be able to perform as well as a derated traditional CVT, practically equalizing the cost of the two technologies.

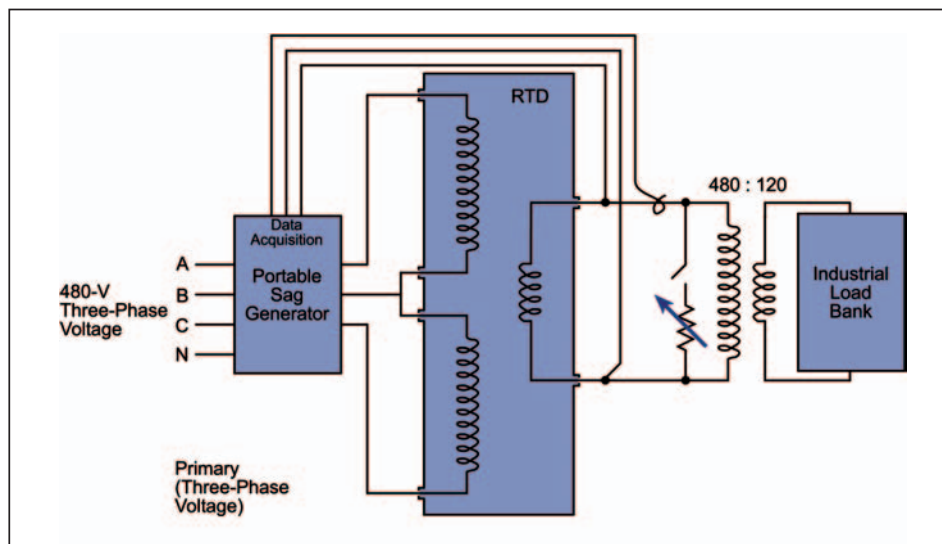


Figure 3. Test circuit

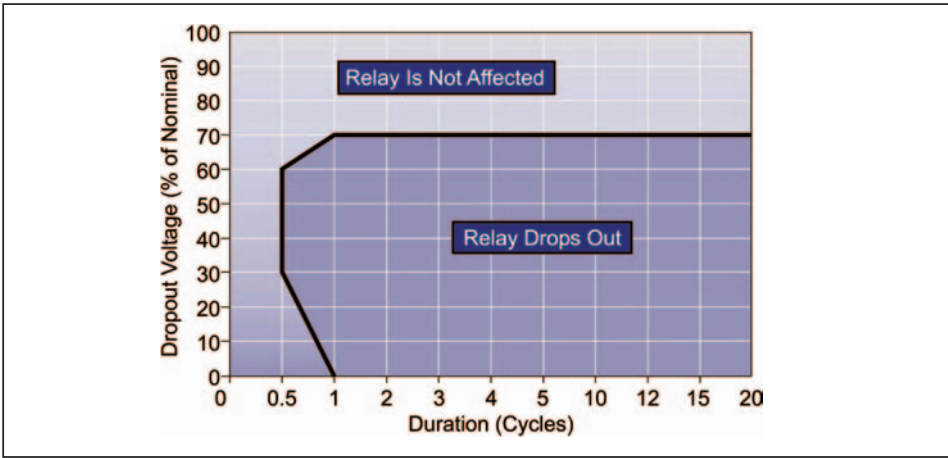


Figure 4. Ride-through of an ice-cube relay installed in the ILB

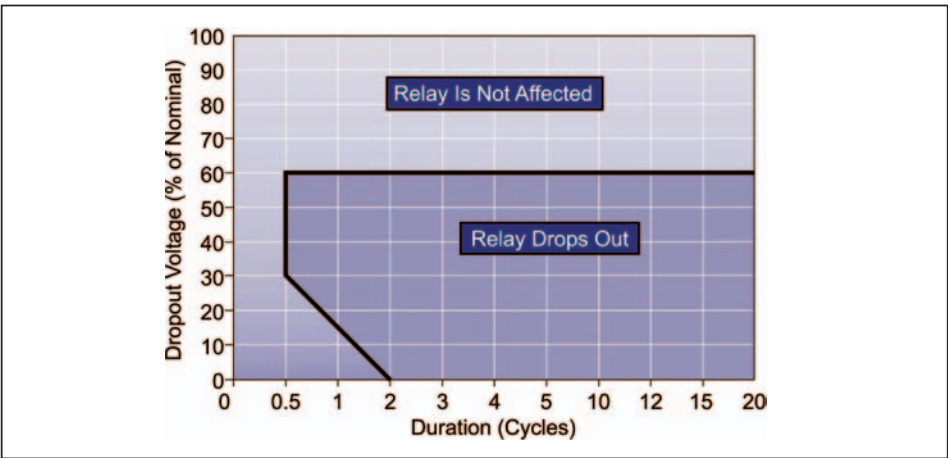


Figure 5. Ride-through of an ice-cube relay installed in the ILB

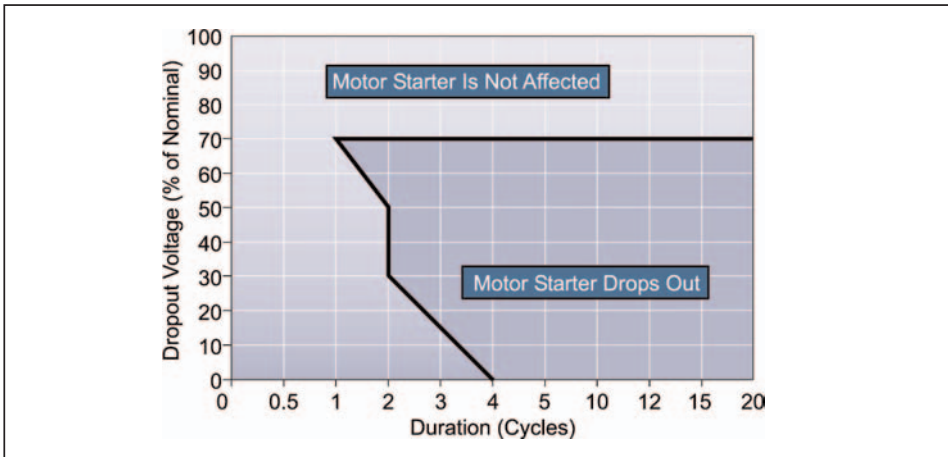


Figure 6. Ride-through of a motor starter installed in the ILB

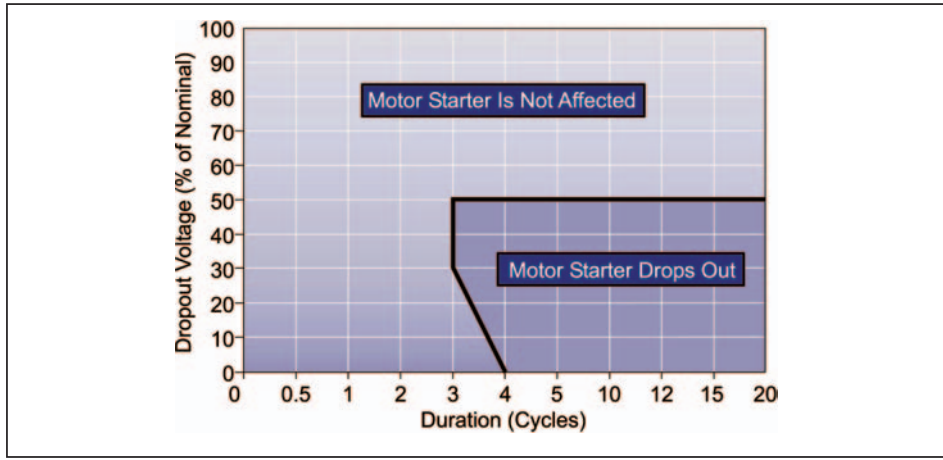


Figure 7. Ride-through of a motor starter installed in the ILB

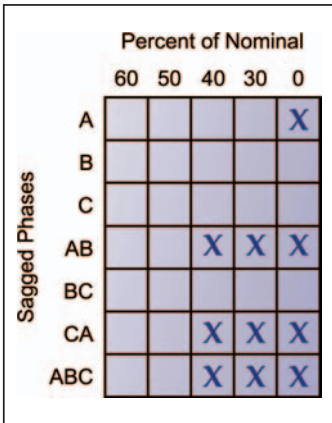


Figure 8. Trip points for 25% loading

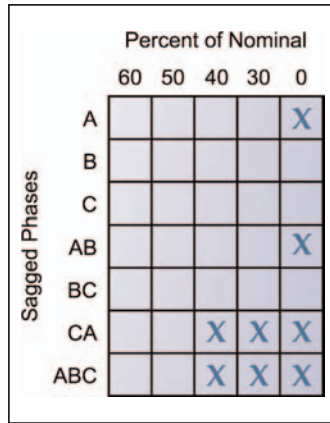


Figure 9. Trip points for 50% loading

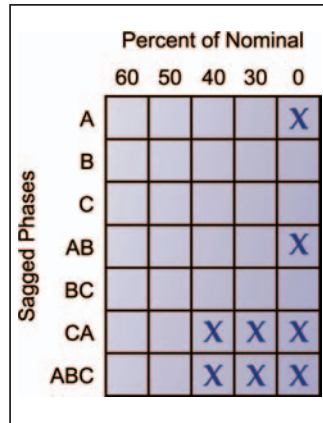


Figure 10. Trip points for 75% loading

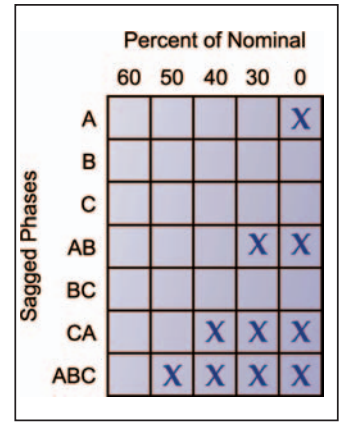


Figure 11. Trip points for 100% loading

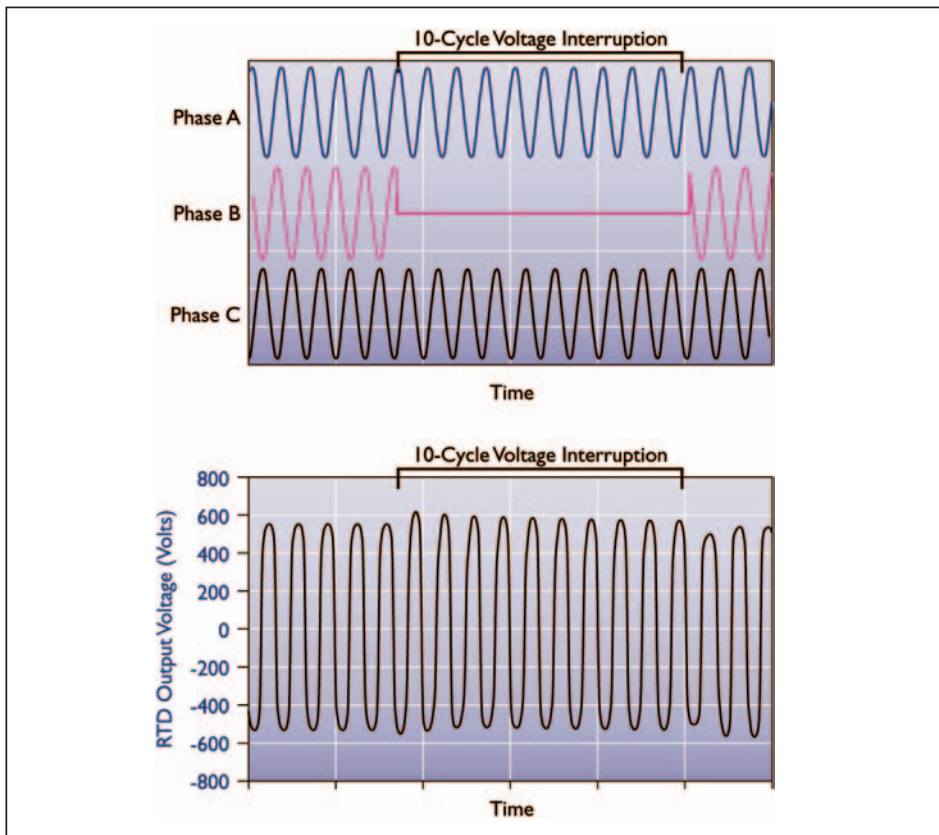


Figure 12. Voltage regulation of RTD output

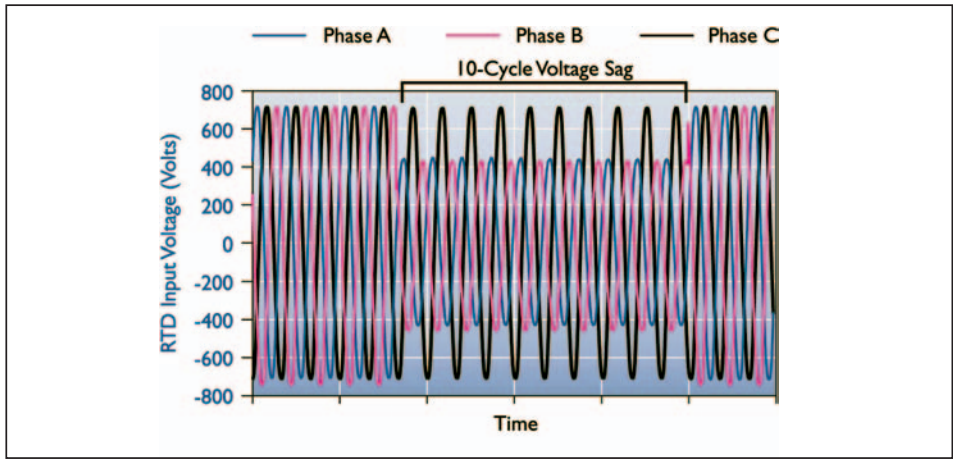


Figure 13. Elevated output voltage and dc offset (bottom) during a 10-cycle two-phase sag to 60% of nominal on phases A and B (top)

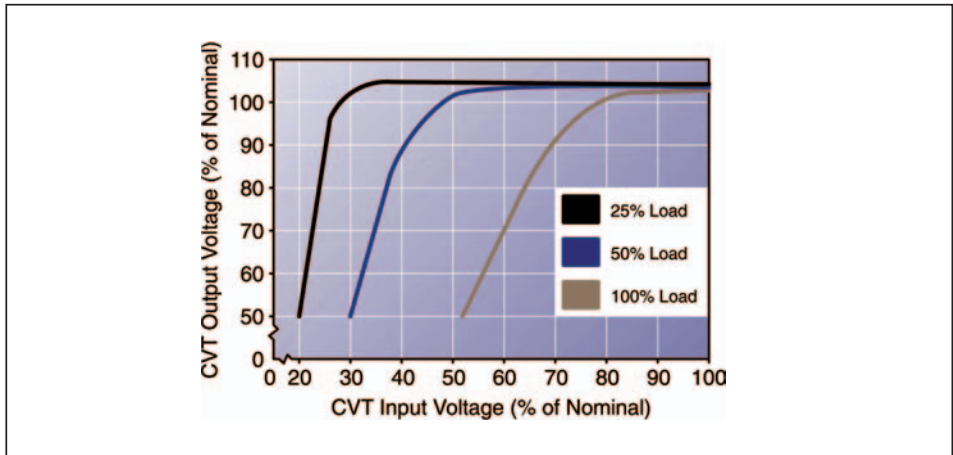


Figure 14. CVT output voltage versus input voltage at 25%, 50%, and 100% of rated load

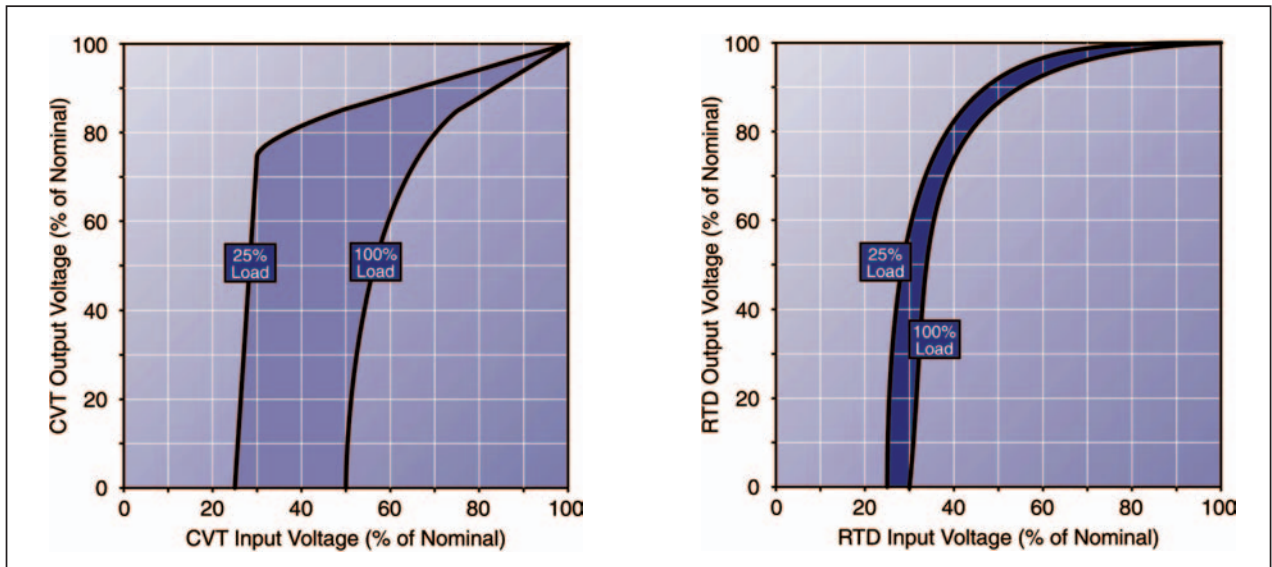


Figure 15. RTD output voltage versus input voltage at 25%, 50%, and 100% of rated load

