# Brief 14: Ferroresonant Transformer Output Performance Under Dynamic Supply Conditions

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Capacitor Energizing
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Lightning Transient
Momentary Interruption
Motor Starting
Other Faults
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Sag/Swell
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Unbalance

## Background

This is the second Brief in a four-part series on the performance of the ferroresonant, or constant voltage, transformer (CVT). In widespread use as a power conditioning device for sensitive electronic equipment, the CVT has the ability to maintain a relatively constant output voltage during ±20% steady-state variations in the input voltage. However, during dynamic conditions, the CVT may jump in and out of an effective regulating mode as illustrated in Figure 1. Notice that the CVT enters the regulating mode of operation at some value of increasing input voltage and drops out of the regulating mode at some lower value of decreasing input voltage. This phenomenon is referred to as "jump resonance" and is a factor in CVT output performance during dynamic supply voltage conditions. See IEEE Standard 449-1990 for further discussion and typical schematics of various CVTs.

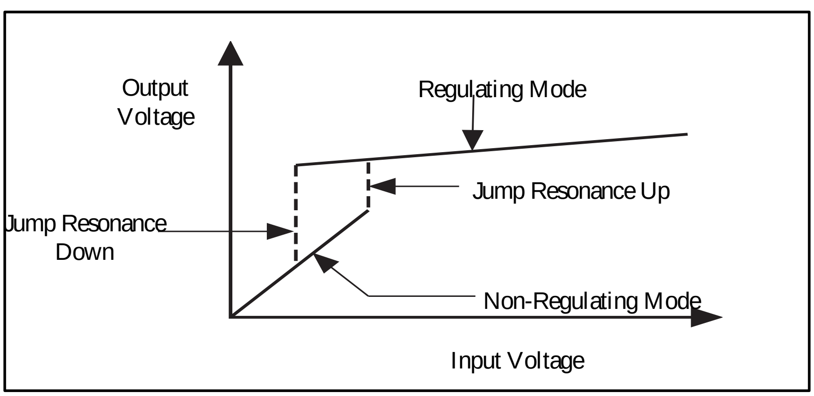


**Figure 1: Output Voltage Versus Input Voltage for CVT with Jump Resonance**

## Objective

The objective of the tests performed at the EPRI Power Electronics Applications Center (PEAC) Power Quality Test Facility was to characterize the electrical performance of a ferroresonant transformer during power system disturbances such as momentary interruptions, sags, phase shifts, capacitor switching, and lightning strikes.

**Test Setup**

One typical 1000-VA, 120-V, single-phase ferroresonant transformer was tested. The transformer was energized for over thirty minutes before each test to stabilize its operating temperature. For all tests, the CVT was connected to a purely resistive full load. A digital storage oscilloscope was used to monitor and record the transformer input and output ac voltages. Because designs and components vary among manufacturers, the performance of single-phase ferroresonant transformers varies slightly from manufacturer to manufacturer.

**Test Results**

Regulation Performance Tests

Voltage Interruption: The CVT was subjected to voltage interruptions lasting from 0.5 to 5 cycles and adjusted in 0.5-cycle increments. Each interruption was created by switching from the normal supply voltage source to an open circuit. Figure 2 shows the input and output voltages of the transformer during a 3-cycle interruption.

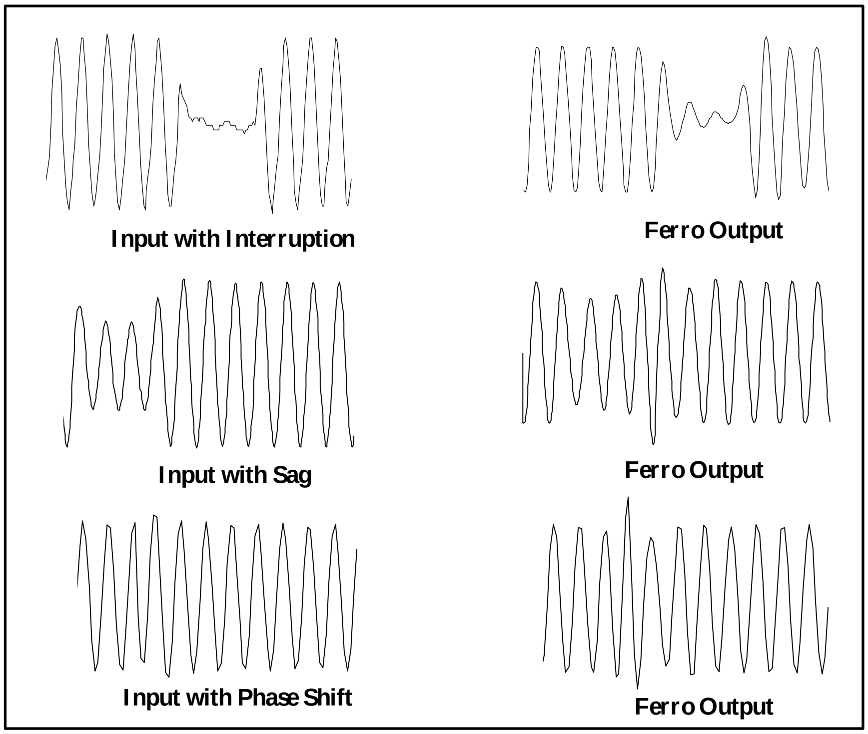


**Figure 2: CVT Output Responses to Input Voltage Interruption, Sag, and Phase Shift**

During the 3-cycle interruption, the CVT dropped out of the regulating mode (see Figure 1), and the output voltage decreased as the resonating capacitor in the CVT discharged. When the input voltage returned to normal, an overshoot occurred on the output voltage as the resonating capacitor recharged. Note that the transformer does not act as an uninterruptible power supply, which is designed to eliminate the effect of an interruption, but it does slightly decrease the effect of an interruption by reducing it to a voltage sag.

Voltage Sag: To simulate a fault in the utility distribution, the input voltage to the CVT was decreased to 90%, 70%, and 58% of Vnominal for 1, 2, 3, 4, and 5 cycles. The variations in the output voltages were measured and recorded for each applied voltage sag. Figure 2 shows the input and output voltage waveforms for 58%-Vnominal sags lasting 3 cycles. In general, the input voltage sags produced output voltage sags having approximately the same duration but smaller sag depth. For example, during the 58%-Vnominal sag, the CVT stayed in the regulating mode and reduced the effect of the sag to an output voltage sag of approximately 20% Vnominal lasting 3 cycles. Again, the recharging of the resonating capacitor caused an overshoot when the input voltage returned to normal.

Voltage Phase Shift: To simulate the effects of a large load being switched off near the end of a long feeder, the input voltage of the CVT was shifted forward 10 degrees while the input and output voltages were monitored and recorded. The phase shift occurred at the positive peak of the input voltage (see Figure 2). The resulting phase shift in the input voltage caused the output voltage to briefly swell.

Filtering and Suppression Performance Tests

Oscillating Transient: A transient caused by capacitor switching was simulated with a 500-Hz Ring Wave with a peak magnitude of 1 per unit and a duration of 10 ms. The Ring Wave was applied to the positive peak of the input voltage. Figure 3 shows the input voltage with the Ring Wave transient and the output voltage with a small impulsive transient.

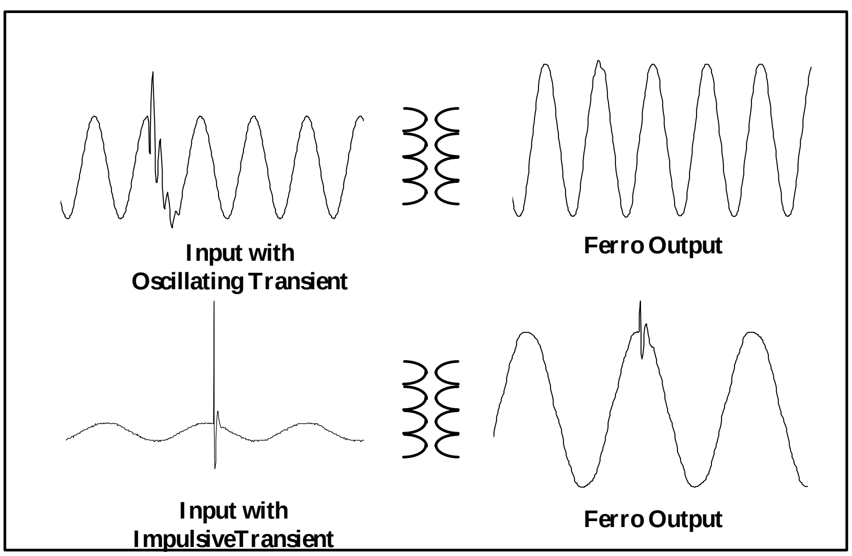


**Figure 3: CVT Output Responses to Input Voltages with Oscillating and Impulsive Transients**

Impulsive Transient: To simulate a lightning strike, a 2-kV, 1.2/50-µs Combination Wave (as described in ANSI C62.41-1991) was applied to the positive peak of the input voltage. As shown in Figure 3, the transformer significantly damped and filtered the surge.

**Discussion**

The ferroresonant transformer can practically eliminate oscillating transients caused by capacitor switching and can significantly damp impulsive transients caused by lightning. It can moderately mitigate but not eliminate the effects of momentary voltage interruptions and sags, which are common power system phenomena. However the CVT is naturally sensitive to utility voltage phase shifts. Because of jump resonance, the performance of the CVT during voltage disturbances was largely dependent upon the type of disturbance. Brief changes in input voltage did not significantly affect the output because the CVT did not move out of the regulating mode.

**Significance**

To ensure full protection of sensitive loads, CVTs may need to be coupled with other devices designed to mitigate dynamic disturbances. The next two Briefs in the ferroresonant transformer series will show how different types of loads affect the CVT performance and discuss changes in the characteristics of protected loads when a CVT is installed.