I. Operating Principles of Widely Used Transformers

Power distribution transformers, as well as the power supply transformers of individual pieces of equipment and appliances, provide isolation. Isolation means that the transformer primary voltage and current, the input to the transformer, is physically separated from the transformer secondary current and voltage, the output of the transformer. Energy is transferred from the transformer primary to the transformer secondary via the changing magnetic field which links the transformer primary and secondary windings. When the transformer primary current changes, it causes the magnetic flux or magnetic lines of force to change. This changing magnetic flux or magnetic field causes a voltage to be induced across the secondary windings. When an electrical load is connected across the secondary windings of the transformer, the voltage induced into the secondary windings will cause a current to flow through the connected load. There is no direct physical connection between the primary and secondary. The common magnetic field connects the primary and secondary. The set of current, magnetic field, and induced voltage relationships is often referred to as transformer action. Transformer action denotes that transformers operate by mutual inductance. The relationship between the voltages, currents, and number of turns of wire on the transformer primary and secondary for an ideal, lossless, or 100 per cent efficient transformer are shown in Figure 1 and Equation 1 below.

![Simplified Transformer Diagram](image-url)
Equation 1. Transformer Relationships.

\[ \frac{n_1}{n_2} = \frac{E_1}{E_2} = \frac{I_2}{I_1} \]

- \( n_1 \) = the number of turns of wire on the primary
- \( n_2 \) = the number of turns of wire on the secondary
- \( E_1 \) = the voltage across primary
- \( E_2 \) = the voltage across secondary
- \( I_1 \) = the current through the primary
- \( I_2 \) = the current through the secondary

When \( n_1 \) is greater than \( n_2 \), we have a voltage step down transformer. For example, if \( n_1 = 400 \), \( n_2 = 200 \) and \( E_1 = 480 \) volts; from Equation 1 and solving for \( E_2 \), we have:

\[ E_2 = \frac{(E_1 \times n_2)}{(n_1)} = \frac{(480 \; V \times 200)}{(400)} = \frac{96,000 \; V}{(400)} = 240 \; volts \]

Note that the voltage is stepped down from 480 volts to 240 volts. From Equation 1, observe that when the voltage is stepped down the current is stepped up and vice versa. The ratio of primary power to secondary power is equal to one for a lossless transformer. Transformers can not create energy. The number of turns on the transformer primary and secondary can be varied to obtain desired voltage or current step up or step down. Transformers are also available with multiple taps or connections at different points along the primary and/or secondary windings. These transformers can be used to correct constant under or over voltage supply conditions by utility engineers or facility managers. For example, if a facility is receiving a constant 204 volts and it requires a constant 240 volts, a suitably adjusted multiple tapped transformer will allow the low voltage condition to be corrected by selecting the correct tap.

Electronic tap-switching voltage regulators utilize the multiple tapped primary winding principle to maintain a relatively constant voltage to a load under changing input voltage conditions. Typically, voltage sensing and control circuitry monitor the transformer secondary voltage and electronically switches taps on the primary winding in an attempt to maintain a constant output voltage. Electronic tap-switching voltage regulators are suitable for reducing supply voltage problems which are of relatively long duration such as utility brownouts caused by high peak demand. Because of their slow response time, which may be several electrical cycles, they are unable to respond to shorter fluctuations and to transients. Tap-switching voltage regulators create transients when they change taps at points other than the zero crossing of the output current waveform. Any abrupt current change in an electrical circuit produces an abrupt change in the magnetic flux linking the circuit. The changing magnetic flux produces an induced voltage in the circuit. The self-induced voltage is of a polarity which opposes the change in current which produced it. This is indicated by the negative sign in Equation 2 below.

Equation 2. Induced Voltage Formula.

\[ E = -L \frac{di}{dt}, \]  
\[ E = \text{self-induced or back emf in volts} \]
\[ L = \text{self-inductance in henrys} \]
\[ \frac{di}{dt} = \text{the time rate of change of the current in the circuit}. \]

Suppose the primary current in an isolation transformer powering a sensitive load is suddenly interrupted. Example 1 below, demonstrates the calculation of an isolation transformer collapsing field transient. These transients are generated by the collapsing magnetic field of a transformer when the primary current is interrupted (i.e., the transformer is switched off, a power failure, a breaker trips, a fuse clears, etc.). They are generated when the primary current is interrupted at any point on current sine wave except at a current zero crossing point. Thus, the odds greatly favor transient creation as there are only two zero crossings for each complete three hundred and sixty degree sinusoidal cycle of the current waveform.

Example 1. What is the magnitude of the collapsing field transient created by the interruption of a
twenty ampere current which collapses in 0.0021 seconds (approximately, one-eighth of a cycle)? The mutual inductance, which relates the induced voltage in the secondary to the rate of change of current in the primary, is 0.1 henries. From Equation 2 and the given information:

\[ E = -L \frac{di}{dt}, \text{ where} \]
\[ L = 0.1 \text{ henries} \]
\[ di = 20 \text{ amperes} \]
\[ dt = 0.0021 \text{ seconds (approximately one-eighth of a cycle)} \]

Substituting the given values into Equation 2, we have:

\[ E = - (0.1 \text{ henries}) \frac{20 \text{ amperes}}{0.0021 \text{ seconds}} \]
\[ E = - 952 \text{ volts, which is lethal to sensitive electronics.} \]

The above example demonstrates that even small mutual inductances, small transient currents, and slow pulse decay times are capable of generating destructive transients.

There are a variety of other isolation transformer designs available which are sold to reduce noise problems. These include saturated transformers, ferroresonant transformers, and ultra-isolation transformers.

Saturated transformers are designed to saturate their magnetic transformer core. When the transformer magnetic core is saturated, further increases in the magnetic flux linking the primary and secondary windings are limited as additional increases in primary current occur. Thus, normal mode transients can be reduced. At full transformer saturation, primary transients which increase the peak primary current will not be able to produce proportional increases in the magnetic flux linking the secondary. Without a proportional increase in magnetic flux, there will not be a proportional increase in the voltage of the secondary side of the transformer due to the transients in the primary circuit. The AC excitation of the transformer by the alternating primary current causes the flux density in the transformer's magnetic core to increase as the current increases and decrease as the current decreases. When the current sine wave crosses the zero point and increases in the negative direction, the flux density will also change polarity or direction. The transformer's flux density depends upon the peak value of the primary current at any instant for its magnitude. The polarity of the flux density is determined by the polarity of the primary current. At the positive peak of the current sine wave, the flux density will achieve its maximum positive value and the transformer will be saturated if it is properly loaded. When the negative peak of the primary current sine wave occurs, the flux density will attain its maximum negative value. Transient currents, which appear at the transformer primary in between the positive and negative current peaks, will be able to produce changes in the flux density. This will cause transient voltages to appear across the transformer secondary windings by normal transformer action. Since it is unlikely that a significant percentage of transients will appear at the positive current peak of 90 degrees or the current negative peak of 270 degrees, it is reasonable to expect that a significant portion of the transients will appear at the secondary. Even when operating exactly as designed, saturated transformers provide no common mode noise or common mode transient protection.

Transformers can pass transients and noise directly from their primary to secondary via primary to secondary parasitic capacitive coupling. This **parasitic capacitive coupling** is an undesired consequence of transformer construction. Two conductors which are separated by an insulator or dielectric form a capacitor or condenser. The insulator or dielectric can be the insulating varnish on the wires of the primary and secondary transformer windings, air, mica, or a variety of plastic films and other materials selected to achieve special capacitor or condenser characteristics. Equation 3 below, demonstrates that the current flow through a capacitor is dependent upon the capacitance (measured in farads) and the rate of change of voltage with respect to time.
Equation 3. Capacitor Current.

\[ I = C \frac{dv}{dt}, \text{ where} \]
\[ I = \text{the current through the capacitor} \]
\[ C = \text{capacitance in farads} \]
\[ \frac{dv}{dt} = \text{the rate change of voltage with respect to time} \]

As the capacitance increases, the current also increases for a constant \( \frac{dv}{dt} \). And, as \( \frac{dv}{dt} \) increases, for a constant capacitance, the current will also increase. For a DC voltage, (a constant or unchanging voltage) \( \frac{dv}{dt} \) is zero and the current is also zero. Thus, capacitors block direct currents. As \( \frac{dv}{dt} \) increases or, as sinusoidal frequency increases, the current also increases for a constant capacitance. Thus, a capacitor blocks DC and passes AC. Because a capacitor is constructed with conductors separated by an insulator, no physical current actually flows through the capacitor's insulator or dielectric. As the voltage across the capacitor increases, electrical charges of opposite polarity build up on the opposing conductors. This build up of opposite charges creates an electric field between the two conductors. The electric field strength, which is usually measured in volts per meter, is proportional to the charge stored in the capacitor, and is also proportional to the voltage across the terminals of the capacitor. Thus, capacitors are capable of storing electrical energy.

Returning to the discussion of saturated transformers, they will pass transients and noise from the primary to secondary via the parasitic capacitance between the primary turns and the secondary turns, as well as by normal transformer action when the transformer is not fully saturated. Additionally, saturated transformers must be carefully selected and operated at their rated load to provide the design benefits. Again, no protection against common mode noise is provided and by transformer action a rapidly collapsing magnetic field due to a power failure, or fuse clearing can generate lethal transients at the secondary which will be applied to sensitive connected loads.

Ultra-isolation transformers are capable of achieving substantial reductions in primary to secondary parasitic capacitance by wrapping the primary winding and secondary winding in conductive nonferrous metal foil, such as copper or aluminum and bonding it to ground. This will reduce the parasitic capacitance but will not effect normal transformer action. This is true because copper and aluminum are nonmagnetic materials. Now the primary winding parasitic capacitance is formed between the primary winding and the grounded primary metal foil forming a capacitor with one lead grounded. This tends to short circuit high frequency noise to ground. The same arrangement can be employed for the secondary winding. When properly operated and loaded, ultra-isolation transformers will saturate and provide some common and normal mode noise protection and some transient protection. Ultra-isolation transformers are frequency sensitive and load sensitive. If they are not operated in saturation, they provide little benefit. Additionally, ultra isolation transformers tend to be large, noisy, and they generate heat. The generated heat is a double negative as the heat generation increases utility power bills and the air conditioning systems must work harder to remove the heat which increases utility power bills a second time. Short-term power losses, drop outs, fuse clearings and similarly rapid current changes in an ultra-isolation transformer will generate transients according to Equation 2 as previously mentioned.

Ferroresonant transformers are also known as constant-voltage transformers or ferroresonant voltage regulators. Typically they utilize a combination of magnetic components (such as a specially designed transformer) and a capacitor. The combination is tuned to the input power frequency. They are used to regulate the output voltage as the input voltage changes. Open-loop (no feedback system) ferroresonant voltage regulators do not sample their own output voltage to automatically correct it for slow variations in input voltage. The regulating ability of open-loop ferroresonant regulators is dependent upon the frequency stability of the power source, the magnetic characteristics of the design, and the load impedance. Highly capacitive loads may detune the ferroresonant regulators causing loss of voltage stability and regulation. Closed-loop (with a feedback system) ferroresonant voltage regulators utilize feedback to adjust their output voltage. By feedback, we mean that the actual output voltage is compared to a reference voltage in the control circuitry of the closed-loop regulator. Based upon the comparison, the output voltage is increased or decreased as required.
When properly designed, sized, and operated with the correct load some reduction in normal mode transients should occur. Typically, ferroresonant transformers are not effective against common mode transients. They are also capable of generating harmonics because their output is not a pure sine wave. The output must be properly filtered to remove undesired harmonics. Ferroresonant transformers will also generate collapsing field transients.

Another family of voltage regulating transformers is the boost and buck transformers. These transformers are constructed in such a manner that the primary windings are capable of increasing (boosting) or decreasing (buck) the magnetic flux linking the transformer secondary. This increases or decreases the secondary voltage as the input voltage or load on the secondary changes, providing voltage regulation. A variety of boost and buck regulators are available including those which employ solid-state control circuitry, such as thyristors, to improve voltage regulation. Typically, transients will pass from the primary to the secondary of a boost and buck transformer because of the normal transformer action and parasitic capacitive coupling between the primary and secondary windings.

II. Isolation Transformer Transient Response Tests.

A TCM brand medical grade toroidal core (donut shaped magnetic core) isolation transformer with a static shield and a standard T-U brand laminated core (the core is shaped like Figure 1 and built with a series of steel plates stacked on top of each other or laminated together) laboratory type isolation transformer were each subjected to standard ANSI/IEEE C62.41-1991 transient test waveforms. Normal mode (line-to-neutral) frequency response measurements to MIL-STD-220A were also made.

Figures 2, 3, and 4 below provide the normal mode let-through voltages at the secondary of the TCM brand isolation transformer for applied A3 and B3 ring waves and the B2 combination wave (8 X 20 µsec impulse).

As shown in Figure 2, below, the TCM (medical grade isolation transformer) when subjected to an ANSI/IEEE Std. C62.41-1991, Category A3 Ring Wave (oscillatory frequency of 100 kHz, 6,000 V, 200 A) produced a let-through voltage of 2,230 volts (2.23 kV). This high magnitude of let-through voltage is capable of disrupting, damaging and possibly destroying costly and sensitive electronic systems. Additionally, the cumulative effect of such transients degrades the electrical distribution system insulation and the loads which are connected to the distribution system.

The A3 Ring Wave is typical of an outlet level transient. That is, it is not a severe standard ANSI/IEEE transient. The voltage attenuation ratio and attenuation in decibels (db) for this A3 Ring Wave is:


Voltage Attenuation Ratio = \( \frac{V_{out}}{V_{in}} = \frac{2,230 \text{ V}}{6,000 \text{ V}} = 0.3717 \)

Equation 5. Attenuation in db.

Attenuation (db) = \(-20 \log_{10} \left( \frac{V_{out}}{V_{in}} \right)\), where the “-” sign is used to convert the attenuation in db to a positive number.

Attenuation (db) = \(-20 \log_{10} (0.3717) = -20 \log_{10} (-0.4298) = 8.60 \text{ db}\). Note that
isolation transformer manufacturers typically specify attenuation in the 40 db range and up. This specification is a frequency domain characteristic. Due to the measurement techniques employed, the advertised attenuation will not be realized (in either the time domain or frequency domain) in actual practice.

Figure 2. TCM transformer output of 2,230 volts (2.23 kV) for the applied A3 Ring Wave transient (100 kHZ, 6,000 V, 200 A).

Figure 3. below presents the oscilloscope trace for the output transient of 2.30 kV for the Category B3 Ring Wave input transient (100 kHz, 6kV, 500 A).

As shown in Figure 4 below, the TCM isolation transformer does not provide transient protection by reducing transients to a safe level. The TCM isolation transformer functioned as a transient amplifier increasing the amplitude of the B2 impulse from 4,000 volts to 5,750 volts. The TCM isolation transformer is not a transient cure.
Figure 4. TCM transformer output of 5,750 volts (5.75 kV) for the applied B2 Impulse (4,000 V, 2,000 A, 8 X 20 µsec). This is an example of transient voltage amplification (i.e., 4,000 V in and 5,750 V out).

The isolation transformer to the left is the T-U transformer.

Figures 5, 6, and 7, below, provide the normal mode (line-to-neutral) let-through voltages at the secondary of the T-U brand isolation transformer for applied A3 and B3 ring waves and the B2 combination wave (8 X 20 µsec. impulse).

Figure 5. T-U Transformer Output for an applied A3 Ring Wave (100 kHz, 6,000 V, 200 A)
As shown in Figures 5, 6 and 7, the T-U isolation transformer does not provide transient protection by reducing transients to a safe level. The T-U isolation transformer functioned as a transient amplifier increasing the amplitude of the A3 ring wave from 6,000 volts to 8,780 volts, the B3 ring wave from 6,000 volts to 8,890 volts and the B2 impulse from 4,000 volts to 6,560 volts. Clearly, the T-U isolation transformer is not a transient cure.
### III. Isolation Transformer Transient Response Summary and Comparison with the Surge Suppression Incorporated® CKL1S1

Table 1 below provides the comparative transient suppression effectiveness or let-through voltages, for the TCM and T-U isolation transformers and the Surge Suppression Incorporated® CKL1S1.

<table>
<thead>
<tr>
<th>Products / Let-through Voltages:</th>
<th>TCM Isolation Transformer</th>
<th>T-U Isolation Transformer</th>
<th>Surge Suppression Incorporated® CKL1S1 (3 wire + ground, 120/240 V, split phase, 40 kA per mode, SWT)</th>
<th>Average Per Cent Improvement With CKL1S1</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSI/IEEE C62.41-1991 Standard Transient Test Waveforms. All tests are in the line-to-neutral mode. Transients are applied at the 90° point of the power frequency sine wave unless otherwise indicated.</td>
<td>1,390 V</td>
<td>2,880 V *</td>
<td>28 V @ 270°</td>
<td>7,525 %</td>
</tr>
<tr>
<td>A1 Ring wave (100kHz, 2,000V, 67A)</td>
<td>1,390 V</td>
<td>2,880 V *</td>
<td>28 V @ 270°</td>
<td>7,525 %</td>
</tr>
<tr>
<td>A2 Ring wave (100kHz, 4,000V, 133A)</td>
<td>1,890 V</td>
<td>6,080 V *</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>A3 Ring wave (100kHz, 6,000V, 200A)</td>
<td>2,230 V</td>
<td>8,780 V *</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>B1 Ring wave (100kHz, 2,000V, 167A)</td>
<td>1,420 V</td>
<td>2,980 V*</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>B2 Ring wave (100kHz, 4,000V, 333A)</td>
<td>1,940 V</td>
<td>6,210 V *</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>B3 Ring wave (100kHz, 6,000V, 500A)</td>
<td>2,300 V</td>
<td>8,980 V *</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>B1 Impulse (2,000V, 1,000A, 8X20µs)</td>
<td>3,300 V *</td>
<td>3,190 V *</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>B2 Impulse (4,000V, 2,000A, 8X20µs)</td>
<td>5,750 V *</td>
<td>6,560 V *</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>B3/C1 Impulse (6,000V, 3,000A, 8X20µs)</td>
<td>Failed, insulation breakdown</td>
<td>9,800 V *</td>
<td>390 V @ 90°</td>
<td>2,413 %</td>
</tr>
</tbody>
</table>

* Note: The let-through voltage outputs exceeded the transient voltages inputs for these cases.

While isolation transformers are widely sold as transient cures, the test data in Table 1 above shows that these isolation transformers are not transient cures. And, they can actually make the transient situation worse. For the B2 and B3/C1 impulses, the isolation transformers functioned as transient amplifiers increasing the amplitude of the applied transient. The CKL1S1 reduced the transients to harmless levels, while the isolation transformers passed lethal transients. The improvement obtained in transient suppression with the CKL1S1 as shown in the average per cent improvement column above demonstrates the superior performance of the CKL1S1 and the danger of attempting to solve a transient problem with an isolation transformer.

### VI. Isolation Transformer Frequency Response Tests

The normal mode (line-to-neutral) secondary or output frequency response data (attenuation in decibels at the indicated frequencies) for the TCM and T-U isolation transformers and the Surge Suppression Incorporated® CKL1S1 are provided in Table 2. The measurements are to MIL-STD-220A, the 50 ohm insertion loss measurement technique. This is the standard for EMI/RFI filter attenuation.
measurements. MIL-STD-220A uses a 50 ohm resistive signal generator internal impedance and a 50 ohm resistive load impedance. While this standard provides a yardstick to compare EMI/RFI filters, the data is essentially meaningless for ac power distribution systems. Typically, the ac power source has a complex (resistive, inductive and capacitive) internal impedance on the order of milliohms and the complex load impedance is on the order of ohms. Thus, under MIL-STD-220A, an attenuation of 40 dB becomes an attenuation of 0 dB at normal ac power distribution impedance levels. Suppose that a home draws 100 amperes and that the internal impedance of the source (serving transformer) is 50 ohms resistive. This means that the source would dissipate: 

\[ P(\text{in watts}) = i^2 r = (100 \text{ A})^2(50 \text{ ohms}) = 500,000 \text{ watts}. \]

This would melt down the transformer and make electrical energy distribution, as we know it, impossible. The point is that “attenuation figures” for filters and transformers should be viewed with skepticism. The exact measurement techniques and their relevance to ac power distribution systems must be clearly understood.

Surge Suppression Incorporated® CKL1S1 attenuation data is provided in Table 2 below per MIL-STD-220A (the 50 ohm insertion loss method). The CKL1S1 is 120/204 V, split phase, 3-wire plus ground, 40,000 peak surge amperes per mode (IEEE 8X20 µs impulse), panel mounted transient voltage surge suppressor (TVSS). The CKL1S1 is also a sine wave tracking TVSS and is a logical alternative to 120/240 V isolation transformers which supply a load or secondary current of up to 800 amperes where transient suppression and noise attenuation is desired.

<table>
<thead>
<tr>
<th>Products/Attenuation in Decibels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
</tr>
<tr>
<td>10 kHz</td>
</tr>
<tr>
<td>100 kHz</td>
</tr>
<tr>
<td>1 MHz</td>
</tr>
<tr>
<td>10 MHz</td>
</tr>
<tr>
<td>100 MHz</td>
</tr>
</tbody>
</table>

Table 2. Frequency Responses For The TCM, T-U And CKL1S1

Isolation transformers are widely sold as noise cures. As shown above, the CKL1S1 performs well when compared to isolation transformers. At lower frequencies, noise tends to pass from the primary of a transformer to secondary by normal transformer action. At higher frequencies, primary to secondary parasitic capacitive coupling tends to be dominating noise transfer mechanism.

Isolation transformers are correctly applied to eliminate detrimental ground loops (common mode problems) and to establish a new neutral-to-ground bond where permitted by the National Electrical Code (NFPA 70). A ground loop is formed when two or more points (or pieces of electrical equipment) in an electrical system that are normally at ground potential are connected by electrical paths so that they are not at the same ground potential. This occurs when “dedicated ground rods” and bonding to building steel creates different physical and electrical ground points in a system. Additionally, the connection of systems to data, control, telco lines and CATV can create ground loops due to their different physical and electrical grounding points. Ground loop elimination techniques are often used to float laboratory equipment especially when high voltages are in use. In order to guarantee all ground loops are broken each piece of equipment requires its own isolation transformer. A simpler and less costly cure when floating equipment is not required is to establish proper surge reference grounds (ground
windows and local ground windows). An example of a local ground window is the application of a corded sine wave tracking TVSS with RI-11 telco protection. The AC and telco lines are referenced to the same ground potential allowing the computer, modem, monitor, printer, and telco lines to be properly referenced and protected against the same local ground reference.

V. Transformer and Regulator Transient Creation and Transmission Mechanisms with Recommended Protection Methods

There are a variety of transformers and transformer based devices in use in electrical distribution systems. Because the basic operating principles of the transformer apply to these devices, their behavior when subjected to transients will be similar to the transformers described above. Table 3 lists the more common transformers and transformer based devices, their transient behavior, and provides a recommended transient protection strategy.

<table>
<thead>
<tr>
<th>Regulator or Transformer Type</th>
<th>Creates Collapsing Field Transients?</th>
<th>Passes Transients by Transformer Action?</th>
<th>Passes Transients via Parasitic Capacitance?</th>
<th>Recommended Protection for Transformer of Sensitive Connected Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility power distribution transformers</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Transformer protection as supplied by utility. User service entrance and interior distribution system should be protected.</td>
</tr>
<tr>
<td>Electronic tap-switching regulators. Note: Transients will be created unless switching occurs at current zero crossing.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Provide protection at secondary or output. And, if electronic tap-changing control circuitry is failing, also protect the primary or input with true all mode protection.</td>
</tr>
<tr>
<td>Saturated isolation transformers</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Provide protection at the secondary or output.</td>
</tr>
<tr>
<td>Ultra-isolation transformers</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Provide protection at the secondary or output.</td>
</tr>
<tr>
<td>Ferroresonant transformers or regulators</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Provide protection at the secondary or output. Use threshold clamping surge suppressors. Do not use sine wave tracking units.</td>
</tr>
<tr>
<td>Boost and buck transformers and regulators</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Provide protection at the secondary or output.</td>
</tr>
<tr>
<td>Facility distribution transformers (i.e. step-down, step-up, Wye to Delta, Delta to Wye, Delta to Wye, Wye to Wye)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Provide protection at the secondary or output. When a transformer feeds a panel or panels apply protection at the panel to maximize protection from transformer pass through transients, transformer generated transients, and transients fed back to the panel(s) from connected loads.</td>
</tr>
</tbody>
</table>

Table 3. Transformer and Regulator Transient Creation and Transmission Mechanisms with Recommended Protection Methods
Never rule out transient or noise problems when a transformer or transformer based device is in use. Transients can be amplified by transformer based devices. Transients and noise can pass through transformers and transformer based devices. Additionally, transformer based devices can create collapsing field transients. Establish proper surge reference grounds (ground windows and local ground windows) per ANSI/IEEE Std. 1100-1999, the Emerald Book, and reference your Surge Suppression Incorporated® surge and transient suppressors (AC, telco, data, and coax) to these surge reference grounds.

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