UNRAVELING THE MYTHS OF LOW ENERGY ELECTRICAL IGNITION

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Abstract – What is the level of electrical power that can create ignition? What size resistance comprises a high-resistance connection? Will arcing result from low-energy ignition? Can Class 2 transformers cause ignition?

Answers to the first three questions identify the electrical parameters involved in low electrical energy fires. Class 2 power supplies are very common electrical sources for low electrical energy. The common perception is these supplies are inherently safe, and are incapable of being a source of ignition. By design, the transformers are safe except under a near-short condition.

Results of experimental research provide fascinating new insight into these issues. The electrical energy required for ignition is surprisingly low.

INTRODUCTION

High impedance connections are the key to low energy electrical failures and potential ignition. The range of impedance is short circuit with impedance near zero to open circuit with near infinite impedance.

A connection should be very close to a short circuits (Z = 0). NFPA 921, *Guide for Fire and Explosion Investigations*, published by the National Fire Protection Association, affirms the most common electrical cause of fire is poor electrical connections. [1]

What are the causes of a poor connection? Loose blade connectors, loose screws, corrosion, and oxidation are contributors to poor connections. In addition, inadvertent loss of insulation may allow an unintentional connection. This connection may have either low or high impedance.

Two configurations of low energy ignitions are investigated. First, ignition due to high resistance is analyzed. Next, Class 2 power supplies are analyzed as a potential source of energy.

CALCULATIONS

Only three electrical parameters are measured directly. These are *voltage*, *current*, and *time*. Similarly three things can be calculated. *Power* is the product of voltage and current. *Impedance* is the ratio of voltage and current. *Time shift* is the delay in time between when the voltage is maximum and the current is maximum. Because of the interaction between the relationships, if we measure two terms, we can calculate others.

Meters can be constructed that apply a voltage, measure a current, and display the results as resistance, the heating component of impedance.

Conversion of electrical energy to heat or other energy forms is dependent on the energy relationships. Electrical energy is simply the product of the voltage, current, and time.

IMPEDANCE

Impedance is the opposition to electrical current flow. Impedance is calculated from a rearrangement of Ohm's law. Impedance is simply the ratio of the voltage potential over the current flow rate.

$$Z = \frac{V}{I}$$

As noted, there are boundary limits on impedance. These are open circuit and short circuit. The impedance operating limit of a supply is the voltage rating of the supply divided by the current rating.

For example a 12 V transformer that can supply 800 milliamps operates into an impedance of 15 Ohms.

$$Z = \frac{V}{I} = \frac{12V}{0.8A} = 15\Omega$$

Any impedance of the circuit that is less than 15 Ohms would draw excessive current. Compare that to the capacity of a standard receptacle which can supply a load impedance as low as 6 Ohms.

$$Z = \frac{V}{I} = \frac{120V}{20A} = 6\Omega$$

Normally, a fuse or circuit breaker is installed that will trip on the excessive current. However, these protective devices are time related and will not operate instantaneously for relatively small overloads.

The risk of excessive heat or fire increases when the load impedance is in the range of rated impedance to near short circuit. The greatest risk is impedance slightly greater than short circuit.

RISK

NFPA 921 is the industry guide for investigations of fires. This document recognizes that poor connections and high impedance connections are a significant source of electrical fires. Excerpts from three sections of the guide illustrate the understanding.

> ***8.9.2.3 Poor Connections.*** *When a circuit has a poor connection such as a loose screw at a terminal, increased resistance causes increased heating at the contact, which promotes formation of an oxide interface. The oxide conducts current and keeps the circuit functional, the resistance of the oxide at that point is significantly greater than in the metals. A spot of heating develops at that oxide interface that can become hot enough to glow. If combustible materials are close enough to the hot spot, they can be ignited…*

> ***8.9.6 High-Resistance [Impedance] Faults.*** *Depending on the nature of the fault and the extent of the fire damage, evidence of a high resistance fault may be difficult to find after a fire. Examples of high resistance faults are an energized conductor coming into contact with a poorly grounded object, or a poor plug blade-to-receptacle connection…*

Figure 1: High impedance connection with oxidation

> ***8.10.4 Overheating Connections.*** *Connection points are the most likely place for overheating to occur on a circuit. The most likely cause of the overheating will be a loose connection or the presence of resistive oxides at the point of connection…*

High-resistance faults are long lived events in which the fault current is not high enough to trip the circuit overcurrent protection, at least in the initial stages.

First a clarification needs to be made about definitions. High impedance is generally considered to be large quantity of Ohms. However, a high impedance connection is a coupling with any impedance greater than near zero.

An excellent electrical connection will also consist of an excellent mechanical grip. The impedance will be at or near zero.

Any resistance greater than zero will create heat.

CLASS 2 POWER SUPPLIES

Class 2 power supplies include those little black boxes that plug into the wall and provide power to all sorts of electronic devices. They are frequently referred to as wall-warts.

Figure 2: Class 2 power supply

Class 2 power supplies convert 120 VAC power to less than 30 volts with limited current availability. The perception is these are safe devices that cannot shock or cause a fire.

Any shock that happens to occur is below the threshold that can cause injury. Therefore, the devices are safe from shock injury.

Fires are a different issue. In the hundreds of fires we analyze each year, Class 2 power supplies are frequently a component of the incident.

Conventional wisdom of engineers and investigators is the supply cannot cause a fire. We too fell into that trap until we saw incidences with other indications. Those provoked the research that led to a broader understanding of Class 2 power supply failures.

STANDARDS

Class 2 power supplies are built under Underwriters Laboratory (U/L) standards UL 1310, *UL Standard for Safety Class 2 Power Units* and UL 1585, *UL Standard for Safety Class 2 and Class 3 Transformers*.[2,3]

The standard U/L test includes wrapping the transformer in cheesecloth. The transformer is then run at rated load, and under short circuit conditions. The parameters of the test dictate that the cloth cannot ignite during operation of the device. This is an appropriate test for the device, but does not represent what happens during actual operation under near short circuit conditions at the end of the cord.

The installation of these transformers is governed by NPFA 70, *National Electrical Code* article 725. [4] We have previously written papers about the benefits of installations using NEC 725 [5,6].

NEC 725 develops the size of the wire, the routing of the wire, and the interaction with other circuits. This predominantly has to do with the safety of the installation. Since the devices are voltage and current limited, the predominant issue is shock safety. A wall-wart has its own cord and connector so much of NEC 725 does not apply.

Neither the UL standards nor the NEC declares that a Class 2 supply will not start a fire. The standards limit the risk. Then common perception has perpetuated the myth that Class 2 transformers cannot provide adequate energy for ignition.

DESIGN

The most common source of electrical ignition is resistance resulting in excessive current where that current is not desired. This is commonly referred to as a *fault*. Normally, a fuse or other overload device is installed that will trip on the excessive current and prevent ignition.

Class 2 transformers use a different very clever approach. The wire in the transformer is sized small enough that the wire impedance limits the available current, while the output voltage is limited by standards.

The operation of the Class 2 is further impacted by the impedance. The devices have very poor voltage regulation, resulting in significantly decreasing voltage with increasing load.

At open circuit, the voltage may be almost twice the nominal voltage, i.e. a 12 Volt supply may deliver 23 Volts on the terminals. However, no current flows externally and no heat is generated. At near zero Volts from the transformer, little heat can be generated. Therefore, fire risk is minimal.

The size of the transformer wire and the poor voltage regulation teams to make an excellent device, when the transformer is operating within its design limits.

AC-DC

Class 2 power supplies have two configurations – direct current (DC) or alternating current (AC).

A power supply with AC output is simply a transformer consisting of a laminated iron core with two windings, one for input and one for output. A 120 VAC to 12 VAC transformer has 10 times as many coils or turns in the primary winding as in the secondary. The size of the winding wire is selected to limit the current so that a fuse is not required.

A power supply with DC output consists of the transformer plus a rectifier circuit. Typically the rectifier is 4 small diodes and a capacitor on a printed circuit board.

RESEARCH

A series of physical tests were conducted using various transformers and electrical supplies connected to known impedance. There were two objectives.

1. Illustrate that a high impedance connection could cause a fire.

2. Determine if a Class 2 transformer has sufficient energy to cause a fire.

Loose connections can be created, but the resistance is difficult to control. Furthermore, oxidation is impossible to replicate. Nevertheless, a control resistance is required to analyze failure energy.

The impedance was controlled by using 1 Ohm, 1/8 watt carbon film resistors. This design has very low mass and represents nearly true thermal conversion of electrical energy. Combinations were used to obtain various resistances.

A thermocouple was affixed to the resistors to provide an accurate measure of temperature.

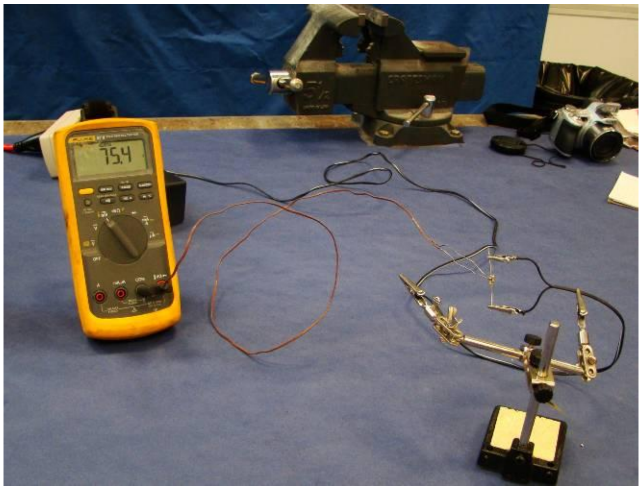

Figure 3: Resistors with thermocouple

Paper was wrapped around the resistor heat source. Paper is a cellulose material and can be used as an analog for other materials. Because of the very small contact area, the material will reach the temperature of the resistors in seconds.

HIGH IMPEDANCE CONNECTION FIRE

A series of physical procedures were conducted using various transformers to determine the potential failure vehicles. The first procedure uses an independent power source that is not likely to fail.

Procedure	Test 7
Power Supply	120VAC Variac - 3W residual power
Resistance	4- 1Ω resistors in parallel
Measured power	1.7 V drop →11.6 W
Result	visible flame to cellulose
Class 2 Effect	na
Resistor Effect	charred not failed
Thermocouple	in contact with resistors
Temperature	520°F

As expected, flame resulted from a low energy connection.

The impedance was ¼ Ohms which is representative of a high-impedance connection, even though the numerical resistance is low. The total electrical power converted to heat was 11.6 Watts, which is clearly a low energy ignition.

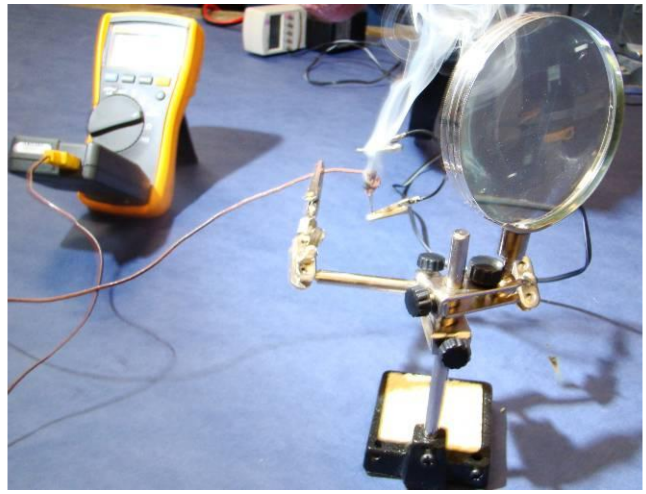

Figure 4: High impedance connection ignition

CLASS 2 AC

Two tests were conducted with Class 2 AC transformer supplies.

Procedure	Test 4
Power Supply	Class 2, 12 VAC, 830mA
Resistance	2- 1Ω resistors in parallel
Measured power	22 W
Result	visible smoke, no flame
Class 2 Effect	fused windings
Resistor Effect	failed
Thermocouple	in contact with resistors
Temperature	340.6°F momentarily

Procedure	Test 5
Power Supply	Class 2, 15 VAC, 140mA
Resistance	3- 1Ω resistors in parallel
Measured power	16 W
Result	visible smoke, no flame
Class 2 Effect	fused windings
Resistor Effect	failed
Thermocouple	in contact with resistors
Temperature	225°F

Although smoke was generated within the transformers, no fire escaped. The windings failed before adequate power could be generated to create heat. The resistors failed before adequate heat could be generated to create flame.

Further tests are warranted to investigate the possible effect of other resistance values, resistances with higher Watt ratings, and other transformer ratings. Clearly from the initial AC test, a Class 2 transformer has adequate energy to create a fire during a high impedance connection.

CLASS 2 DC

Multiple tests were conducted with Class 2 DC power supplies. Multiple failure scenarios were observed. In each test either the resistors failed or the power supply rectifier burned. Temperatures were adequate to ignite combustible materials with adequate exposure time.

Procedure	Test 1
Power Supply	Class 2, 12 VDC, 900mA
Resistance	3- 1Ω resistors in parallel
Measured power	0.18A, 120VAC – 21.6 W
Result	Within 20 seconds of application of power, cellulose material ignited and created visible flame.
Class 2 Effect	none
Resistor Effect	none
Thermocouple	in contact with cellulose
Temperature	533°F after flame-up

The rapid ignition of the cellulose material precluded damage to the power supply and resistors. The power supply was reused on other tests. Multiple small resistors allowed heat dissipation without damage. At the same time, the cellulose could ignite.

Procedure	Test 2
Power Supply	Class 2, 12 VDC, 900mA
Resistance	1Ω resistors
Measured power	na
Result	immediate failure of 1Ω resistor
Class 2 Effect	none
Resistor Effect	failed
Thermocouple	in contact with resistors
Temperature	na

A single resistor could not dissipate the heat, so it failed. That is not to imply that 1 Ohm would not cause flame, if it had greater heat dissipation capability.

Procedure	Test 3
Power Supply	Class 2, 12 VDC, 900mA
Resistance	3- 1Ω resistors in parallel
Measured power	na
Result	visible smoke, no flame
Class 2 Effect	burning of rectifier bridge
Resistor Effect	failed
Thermocouple	in contact with resistors
Temperature	784°F

The temperature obviously was great enough to cause ignition. Our safety system removed power after the power supply ignited. Given the temperature observed, fire from both the power supply and the resistor would have resulted.

Procedure	Test 6
Power Supply	Class 2, 9 VDC, 800mA
Resistance	3- 1Ω resistors in parallel
Measured power	52 W
Result	visible smoke, no flame
Class 2 Effect	failure of bridge rectifier
Resistor Effect	failed
Thermocouple	in contact with resistors
Temperature	245°F

Heat and flame can be created with low resistance connections to Class 2 DC power supplies. The flame and temperature is very dependent on the resistance of the connection. The rectifier circuits fail and can generate adequate heat to burn the supply and surrounding materials.

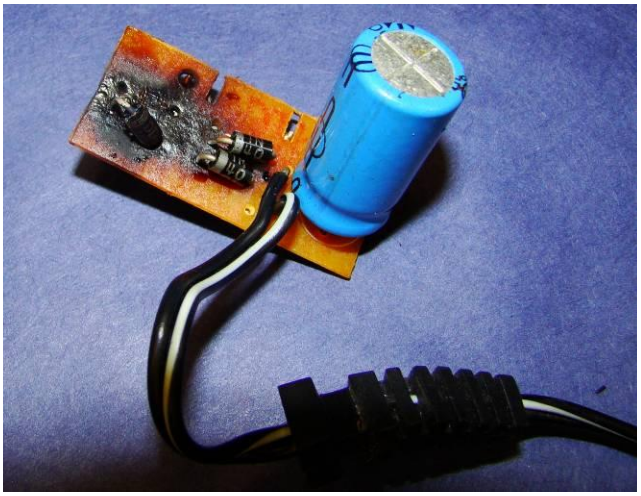

Figure 5: Circuit board failure

ANALYSIS

Multiple observations can be made concerning low energy ignition.

1. Ignition and flame can occur at energy of 11 Watts or lower.

2. AC supplies fail in a winding but do not cause ignition inside the supply.

3. DC supplies fail at the diodes and can cause ignition of the circuit board internal to the supply.

4. Class 2 supplies can provide adequate energy to cause at fire at a high impedance connection.

5. The time to ignition can be very short for lower resistances and longer for other resistances.

REFERENCES

[1] NFPA 921, *Guide for Fire and Explosion Investigations*, National Fire Protection Association, Quincy, MA, 2008.

[2] UL 1310 *UL Standard for Safety Class 2 Power Units*, Underwriters Laboratory, Camas, WA.

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[4] NFPA 70, 2008, *National Electrical Code*, National Fire Protection Association, Quincy, MA.

[5] "NEC Article 725 - Cost Effective Control Wiring," Marcus O. Durham and Clark Lockerd, *IEEE Transactions on Industry Applications*, Vol. 25, No. 5, New York, September/October 1989, pp 901-905.

[6] "NEC Article 725: Requirement or Loophole," Marcus O. Durham and Clark Lockerd, *Institute of Electrical and Electronic Engineers PCIC*, PCIC-88-3, 88CH2661-7, Dallas, September 1988, pp. 15-19.

VITAE

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Curtis is past president of the Oklahoma Chapter of the International Association of Arson Investigators as well as a Life Member and was a board member for seven years. He is a past Adjunct instructor at Tulsa Community College instructing Fire Scene Investigations and is also an instructor for the National Fire Academy in Emmittsburg MD, and. the Mississippi Fire Academy and Council on Law Enforcement Education and Training. He is past instructor at the Tulsa Fire Department and Police Department instructing fire scene investigation. He has received a Medal for Valor as well as Fire Prevention Officer of the year in 1992 and 2000. He is past board member of the Violent Crime Task Force, the Tulsa Metropolitan Crime Commission and is currently a council member of the Oklahoma Arson Advisory Council. Curtis is also past coordinator of the Arrest Arson program and the Community Based Arson Program and was assigned as the Juvenile Fire Setter coordinator for the Tulsa Fire Department.

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