An Investigation of the Use of 16 and 18 AWG Conductors for Power Branch Circuits in Industrial Machinery Applications

for

NFPA79 Small Wire Working Group

by

Underwriters Laboratories Inc.
Northbrook, IL  60062

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BACKGROUND AND SUMMARY

In order to remain competitive in the global marketplace, United States industrial machinery manufacturers on the committee for NFPA79 (Electrical Standard for Industrial Machinery) expressed the need to be able to utilize power circuit conductors which are smaller than 14 AWG, the existing minimum allowed for branch circuits in the United States. This report details the investigation and testing that was conducted to investigate the use of 16 and 18 AWG conductors for power branch circuits. Various fuse type overcurrent protective devices, including commercial fuses and special test fuses (unbrella) were used for the investigation. The testing considered the performance of 16 and 18 AWG conductors under these conditions:

- Short Circuit
- Overload
- Use on various electrical systems

Following the testing, the conductors were subjected to a dielectric withstand test on the insulation. The results of the study are summarized in the table below.
### Summary of Results

<table>
<thead>
<tr>
<th>Test #</th>
<th>Volts</th>
<th>Phase (Amps)</th>
<th>Current (Amps)</th>
<th>Overcurrent Protective Device</th>
<th>Wire Size</th>
<th>Conductor Thermal withstand (Amps$^2$ sec)</th>
<th>Maximum $I^2t$ Let Through (Amps$^2$ sec)</th>
<th>Visual Inspection Observation</th>
<th>Dielectric Testing Results (Pass/Fail)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1A</td>
<td>LV</td>
<td>1</td>
<td>15</td>
<td>Commercial Fuse</td>
<td>16</td>
<td>18,657</td>
<td>N/A</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 1B</td>
<td>LV</td>
<td>1</td>
<td>48</td>
<td>Commercial Fuse</td>
<td>16</td>
<td>18,657</td>
<td>N/A</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 1C</td>
<td>LV</td>
<td>1</td>
<td>15</td>
<td>Commercial Fuse</td>
<td>16</td>
<td>18,657</td>
<td>N/A</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 1D</td>
<td>LV</td>
<td>1</td>
<td>33</td>
<td>Commercial Fuse</td>
<td>16</td>
<td>18,657</td>
<td>N/A</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 1E</td>
<td>LV</td>
<td>1</td>
<td>11</td>
<td>Commercial Fuse</td>
<td>16</td>
<td>18,657</td>
<td>N/A</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 1F</td>
<td>LV</td>
<td>1</td>
<td>48</td>
<td>Commercial Fuse</td>
<td>16</td>
<td>18,657</td>
<td>N/A</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 2A</td>
<td>LV</td>
<td>1</td>
<td>15</td>
<td>Commercial Fuse</td>
<td>18</td>
<td>7,355</td>
<td>N/A</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 2B</td>
<td>LV</td>
<td>1</td>
<td>30</td>
<td>Commercial Fuse</td>
<td>18</td>
<td>7,355</td>
<td>N/A</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 2C</td>
<td>LV</td>
<td>1</td>
<td>15</td>
<td>Commercial Fuse</td>
<td>18</td>
<td>7,355</td>
<td>N/A</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 2D</td>
<td>LV</td>
<td>1</td>
<td>21</td>
<td>Commercial Fuse</td>
<td>18</td>
<td>7,355</td>
<td>N/A</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 2E</td>
<td>LV</td>
<td>1</td>
<td>8</td>
<td>Commercial Fuse</td>
<td>18</td>
<td>7,355</td>
<td>N/A</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 2F</td>
<td>LV</td>
<td>1</td>
<td>34</td>
<td>Commercial Fuse</td>
<td>18</td>
<td>7,355</td>
<td>N/A</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 3A</td>
<td>480</td>
<td>3</td>
<td>5000</td>
<td>Umbrella Fuse</td>
<td>16</td>
<td>18,657</td>
<td>1,690</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 3B</td>
<td>480</td>
<td>3</td>
<td>10,000</td>
<td>Umbrella Fuse</td>
<td>16</td>
<td>18,657</td>
<td>1,980</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 3C</td>
<td>480</td>
<td>3</td>
<td>50,000</td>
<td>Umbrella Fuse</td>
<td>16</td>
<td>18,657</td>
<td>1,420</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 4A</td>
<td>480</td>
<td>3</td>
<td>5000</td>
<td>Umbrella Fuse</td>
<td>18</td>
<td>7,355</td>
<td>1,420</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 4B</td>
<td>480</td>
<td>3</td>
<td>10,000</td>
<td>Umbrella Fuse</td>
<td>18</td>
<td>7,355</td>
<td>1,440</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 4C</td>
<td>480</td>
<td>3</td>
<td>50,000</td>
<td>Umbrella Fuse</td>
<td>18</td>
<td>7,355</td>
<td>1,450</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 5B</td>
<td>480</td>
<td>3</td>
<td>10,000</td>
<td>Umbrella Fuse</td>
<td>18</td>
<td>7,355</td>
<td>7,010</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 5C</td>
<td>480</td>
<td>3</td>
<td>50,000</td>
<td>Umbrella Fuse</td>
<td>18</td>
<td>7,355</td>
<td>5,140</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 6A</td>
<td>480</td>
<td>3</td>
<td>10,000</td>
<td>Umbrella Fuse</td>
<td>16</td>
<td>18,657</td>
<td>820</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 6B</td>
<td>480</td>
<td>3</td>
<td>50,000</td>
<td>Umbrella Fuse</td>
<td>16</td>
<td>18,657</td>
<td>1,230</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 6C</td>
<td>480</td>
<td>3</td>
<td>10,000</td>
<td>Umbrella Fuse</td>
<td>18</td>
<td>7,355</td>
<td>1,000</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 6D</td>
<td>480</td>
<td>3</td>
<td>50,000</td>
<td>Umbrella Fuse</td>
<td>18</td>
<td>7,355</td>
<td>1,280</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 7A</td>
<td>600</td>
<td>3</td>
<td>5000</td>
<td>Umbrella Fuse</td>
<td>18</td>
<td>7,355</td>
<td>8,290</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 7B</td>
<td>600</td>
<td>3</td>
<td>10,000</td>
<td>Umbrella Fuse</td>
<td>18</td>
<td>7,355</td>
<td>10,400</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 7C</td>
<td>600</td>
<td>3</td>
<td>50,000</td>
<td>Umbrella Fuse</td>
<td>18</td>
<td>7,355</td>
<td>6,330</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 8A</td>
<td>480</td>
<td>3</td>
<td>5000</td>
<td>Umbrella Fuse</td>
<td>18</td>
<td>7,355</td>
<td>7,070</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 8B</td>
<td>480</td>
<td>3</td>
<td>10,000</td>
<td>Umbrella Fuse</td>
<td>18</td>
<td>7,355</td>
<td>8,120</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 8C</td>
<td>480</td>
<td>3</td>
<td>50,000</td>
<td>Umbrella Fuse</td>
<td>18</td>
<td>7,355</td>
<td>7,900</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 9B</td>
<td>480</td>
<td>1</td>
<td>10,000</td>
<td>Umbrella Fuse</td>
<td>18</td>
<td>7,355</td>
<td>6,690</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
<tr>
<td>Test 9C</td>
<td>480</td>
<td>1</td>
<td>50,000</td>
<td>Umbrella Fuse</td>
<td>18</td>
<td>7,355</td>
<td>6,130</td>
<td>No Visible Damage</td>
<td>Pass</td>
</tr>
</tbody>
</table>
INTRODUCTION

Industry Need to Utilize Small Conductors

In order to remain competitive within the global marketplace, United States industrial machinery manufacturers on the committee for NFPA79 (Electrical Standard for Industrial Machinery) expressed the need to be able to utilize power circuit conductors that are smaller than 14 AWG, the existing minimum allowed for branch circuits in the United States. Several proposals were written and submitted for NFPA79 adoption. However, a study was requested to confirm the theoretical engineering analysis utilized for the substantiation of the proposals. This Report details the results of that study.

Existing Requirements

The general requirements for the 1999 edition of National Electrical Code® (NEC®) and the 1997 edition of NFPA79 Electrical Standard for Industrial Machinery currently do not allow conductors smaller than 14 AWG to be utilized for power branch circuits. In the NEC®, the requirements are found in sections 210-19 and 310-5. In NFPA79 the requirements are found in subclause 15.3.

Industry Needs

The industrial machinery industry has recognized the need to utilize 16 and 18 AWG conductors for both motor and non-motor loads. Wire sizes of 0.75 mm² and 1 mm² are commonly applied where the load currents are very small in applications based upon IEC 60204-1 (Safety of Machinery – Electrical Equipment of Machines). Wire sizes of 0.75 mm² and 1 mm² have an ampacity similar to 18 AWG and 16 AWG wire respectively.

Engineering Analysis

An engineering-based analysis was completed on the properties of 16 and 18 AWG conductors. This analysis, developed by the NFPA Small Wire Working Group, and designed to cover typical “worst case” overcurrent conditions as might be found in various types of electrical distributions, is included here.
ENGINEERING ANALYSIS
(Developed by the NFPA Small Wire Working Group)

Background
The analysis could best be summarized by the requirements in subclause 8.1.2 of NFPA79 shown here:
(d) Load and circuit component characteristics.
   1) Normal operating current.
   2) Inrush characteristics.
   3) Thermal withstand capability ($I^2t$).
   4) Magnetic withstand capability ($I_p$).

Normal Operating Current
First normal operating current was considered per NFPA79 8.1.2 (d) (1). The UL standard for
Industrial Control Equipment, UL508, provides ampacities for 16 and 18 AWG conductors. The
information is summarized in Table 1 below as follows:

<table>
<thead>
<tr>
<th>Wire Size</th>
<th>Copper Conductors Insulation Rating</th>
<th>Ampacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 AWG</td>
<td>60°C</td>
<td>10 amps</td>
</tr>
<tr>
<td>18 AWG</td>
<td>60°C</td>
<td>7 amps</td>
</tr>
</tbody>
</table>

Inrush Characteristics
Further engineering analysis explored the nature of the loads that the smaller conductors would supply.
Research of the types of devices to be used for these loads was explored. As stated earlier, the desire
from the NFPA79 committee was to utilize this small wire on motor and non-motor loads. For motor
loads, the analysis included the use of motor starters for overload protection along with a branch
circuit, overcurrent protective device for short-circuit protection. For non-motor loads, the analysis
included the use of only a single branch circuit overcurrent device.

Thermal Withstand Ratings for Insulated Conductors - Various Methods
The next step in the analysis was to explore the withstand capabilities of the small wire, as required in
NFPA79 subclause 8.1.2 (d) (3). Withstand capabilities of insulated cable pertains to the level of
short-circuit current an insulated conductor can handle for a certain amount of time. Insulated
conductors are components of an electrical system and are required to be protected against “excessive
damage” per the NEC® in section 110-10 and NFPA79 subclause 8.1.2.

Research of available literature was conducted on the effects of short-circuit currents on insulated
conductors. The findings of four different methods were analyzed to determine the most appropriate
method to use for this analysis. The four different methods included:

- Insulated Cable Engineers Association Standard P-32-382
- Research conducted by William H. Middendorf
- “Grounding Electrical Systems for Safety,” Eustice Soares
- Onderdonk melting point

1 Information obtained from UL508, August 22, 2000, Section 43 Table 43.2
The Insulated Cable Engineers Association (ICEA) standard P-32-382 provides a standard physics formula for determining the short-circuit withstand of insulated copper conductors. The formula is as follows:

\[
\left(\frac{I}{A}\right)^2 t = 0.0297\log\left(\frac{T_2 + 234}{T_1 + 234}\right)
\]

- \(I\) = Short-circuit Current – Amperes
- \(A\) = Conductor Area – Circular Mil
- \(t\) = Time of Short-circuit - Seconds
- \(T_1\) = Maximum Operating Temperature
- \(T_2\) = Maximum Short-circuit Temperature

This physics formula for determining the heat rise for a specific cross sectional area of copper was used to create a worst case condition for the wire. The formula utilized by ICEA was based upon an adiabatic process where all the heat is contained within the wire. ICEA, using the standard physics formula, determined maximum short-circuit temperatures for conductors with various types of insulation as shown:

- Thermoplastic (150 °C)
- Rubber, paper, varnished cloth (200 °C)
- Crosslinked Polyethylene & Ethylene Propylene Rubber (250 °C)

The temperatures specified above designate the start of insulation damage. Using the most conservative approach, thermoplastic insulation (150 °C) has the lowest short-circuit temperature of the types tested. Inserting 150 °C for \(T_2\) into physics equation 1, would generate \(I^2t\) values as shown in Table 2.

<table>
<thead>
<tr>
<th>Wire Size</th>
<th>Short-circuit Withstand (I^2t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 AWG</td>
<td>47,000 A²s</td>
</tr>
<tr>
<td>12 AWG</td>
<td>120,000 A²s</td>
</tr>
<tr>
<td>10 AWG</td>
<td>303,000 A²s</td>
</tr>
</tbody>
</table>

Studies conducted by William H. Middendorf of the University of Cincinnati explored the effects of short-circuit currents on insulated conductors. The studies were conducted to evaluate the damage levels referenced in the ICEA standard P-32-382. The purpose was to evaluate the accuracy of the ICEA damage levels. As a result, Middendorf derived withstand limits different from the levels achieved by ICEA. The withstand levels derived from this research were based upon the amount of \(I^2t\) that would cause the dielectric strength of the insulation to be half the value of untested wire. As expected, the \(I^2t\) levels required to reduce the dielectric strength of the wire were greater than those for
which there was no insulation damage (ICEA). The \( I^2t \) values resulting from this research are shown in Table 3.

<table>
<thead>
<tr>
<th>Wire Size</th>
<th>Short-circuit Withstand ( I^2t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 AWG</td>
<td>150,000 A²s</td>
</tr>
<tr>
<td>12 AWG</td>
<td>450,000 A²s</td>
</tr>
<tr>
<td>10 AWG</td>
<td>1,100,000 A²s</td>
</tr>
</tbody>
</table>

Eustice Soares wrote, “Grounding Electrical Systems for Safety.” Soares provides another reference level for conductor withstand. Soares states that the validity rating for conductors corresponds to the amount of energy required to cause the copper to become loose under a lug after the conductor has had a chance to cool back down. This “validity” rating is based on raising the copper temperature from 75°C to 250°C. Using physics equation 1, the \( I^2t \) withstand levels of conductors that will become loose under a lug is shown in Table 4 below.

<table>
<thead>
<tr>
<th>Wire Size</th>
<th>Short-circuit Withstand ( I^2t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 AWG</td>
<td>94,000 A²s</td>
</tr>
<tr>
<td>12 AWG</td>
<td>238,000 A²s</td>
</tr>
<tr>
<td>10 AWG</td>
<td>599,000 A²s</td>
</tr>
</tbody>
</table>

The final method, by Onderdonk, provides the withstand level that represents the amount of \( I^2t \) required to cause copper conductors to melt. Onderdonk determined the short-circuit temperature to be 1083°C. Inserting this temperature into physics equation 1, the \( I^2t \) withstand levels for melting of copper is as shown in Table 5.

<table>
<thead>
<tr>
<th>Wire Size</th>
<th>Short-circuit Withstand ( I^2t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 AWG</td>
<td>320,000 A²s</td>
</tr>
<tr>
<td>12 AWG</td>
<td>804,000 A²s</td>
</tr>
<tr>
<td>10 AWG</td>
<td>2,300,000 A²s</td>
</tr>
</tbody>
</table>

In addition to the analysis just discussed, both United States and International standards were researched to explore procedures already utilized in the United States and other parts of the world for short-circuit protection of conductors.

The Institute of Electrical and Electronics Engineers (IEEE) recommends the short circuit protection of insulated conductors, using the ICEA physics formula in equation 1, in standards:
Various machinery standards also recommend the short circuit protection of insulated conductors using a formula similar to the ICEA physics formula in Equation 1, with conversion factors being the difference. These standards also state the insulation damage level for thermoplastic insulation is at 160°C as compared to the 150°C level used by ICEA. The machinery standards that suggest this approach include:

- IEC60204-1 1997 section 13.1 and Annex C section C.4
- SAE HS-1738 2000 section 13.1 and Annex C section C.4

IEC60204-1 is the accepted machinery standard in Europe. SAE HS-1738 is the accepted machinery standard for the United States automotive industry.

The International Electrotechnical Commission (IEC) standard 60364-4-43 1997 requires short-circuit protection of conductors, using a formula equal to physics equation 1 (with conversion factors being the difference), see equation 2.

\[
I^2t = K^2 S^2 \ln \left( \frac{\theta_f + \beta}{\theta_i + \beta} \right)
\]

where:
- \( K \) = conductor material constant
  - 226 for copper
- \( S \) = cross sectional area of conductor, mm\(^2\)
- \( \theta_f \) = final temperature of conductor, °C
- \( \theta_i \) = initial temperature of conductor, °C
- \( \beta \) = reciprocal of temperature coefficient of resistance for conductor material at 0°C, °C
  - 234.5 for copper

\[ K = \frac{1}{S^2} \ln \left( \frac{\theta_f + \beta}{\theta_i + \beta} \right) \]

Equation 2 – IEC Conductor Withstand Formula

The Canadian Electrical Code (CEC), C22.1-98 Safety Standard for Electrical Installations, recommends the ICEA method for determination of conductor protection in Appendix B.

After researching the above methods along with the ANSI, CEC, and International approaches, the safest approach was to analyze the withstand limits using the most conservative method. The physics formula, as promoted by ICEA, was the most conservative, see Table 6, as well as most used, and was therefore used to analyze 16 and 18 AWG insulated conductors.

<table>
<thead>
<tr>
<th>Wire Size</th>
<th>ICEA</th>
<th>Middendorf</th>
<th>Soares</th>
<th>Onderdonk</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>47,000</td>
<td>150,000</td>
<td>94,000</td>
<td>320,000</td>
</tr>
<tr>
<td>12</td>
<td>120,000</td>
<td>450,000</td>
<td>238,000</td>
<td>804,000</td>
</tr>
<tr>
<td>10</td>
<td>303,000</td>
<td>1,100,000</td>
<td>599,000</td>
<td>2,300,000</td>
</tr>
</tbody>
</table>
Determination of the Thermal Withstand Ratings for 16 and 18 AWG conductors

Short-circuit Withstand Ratings
Using physics equation 1 and cross sectional area from NEC®, Table 8, thermal $I^2t$ withstand ratings for 16 and 18 AWG insulated conductors were calculated, see Table 7.

<table>
<thead>
<tr>
<th>Wire Size</th>
<th>Short-circuit Withstand $I^2t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 AWG</td>
<td>7,355 A²s</td>
</tr>
<tr>
<td>16 AWG</td>
<td>18,657 A²s</td>
</tr>
</tbody>
</table>

Physics equation 1 could also be used to calculate the maximum short-circuit current an insulated conductor can withstand for a specified amount of time. This type of analysis was conducted at the NFPA79 committee meetings. See Annex A for details on this analysis.

Medium Range Overcurrent Capabilities
While the withstand temperatures of insulated cables under short-circuit conditions has been thoroughly researched, medium range overcurrent capability research is not as plentiful. This is partially due to the fact that this condition can not really be considered adiabatic, and the dissipation of heat from the conductor into the system varies greatly from installation to installation. Since the formula developed by ICEA, physics Equation 1, assumes an adiabatic condition, this would constitute a “worse case” condition for the conductor, with no heat loss to the system, and was used in this analysis for a conservative approach. The amounts of current that 16 and 18 AWG conductors could handle under overload conditions are summarized in Table 8 and Table 9. This type of analysis was conducted at the NFPA79 committee meetings. See Annex A for details on this analysis.

<table>
<thead>
<tr>
<th>Duration of Overcurrent (seconds)</th>
<th>Withstand Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>137</td>
</tr>
<tr>
<td>5</td>
<td>61</td>
</tr>
<tr>
<td>10</td>
<td>43</td>
</tr>
</tbody>
</table>

* Data based upon formula in ICEA Publication P-32-382, See Equation 1

<table>
<thead>
<tr>
<th>Duration of Overcurrent (seconds)</th>
<th>Withstand Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>86</td>
</tr>
<tr>
<td>5</td>
<td>38</td>
</tr>
<tr>
<td>10</td>
<td>27</td>
</tr>
</tbody>
</table>

* Data based upon formula in ICEA Publication P-32-382, See Equation 1
Magnetic Withstand for Insulated Conductors

Another step in the analysis is to analyze the magnetic withstand capabilities of the small wire, as required in NFPA79 subclause 8.1.2 (d) (4). The proper analysis of the magnetic withstand limits is best conducted via testing. This analysis is currently conducted in product testing via assurance that the conductor cannot pull out of any termination as a result of testing. For this investigation, the magnetic withstand capabilities will be addressed by testing.

Selection of Overcurrent Protective Devices

The major properties, current carrying capacity and short-circuit withstand required for proper application of insulated conductors have been determined. Now proper overcurrent protection needs to be determined.

Using the properties that have been documented, overcurrent protective devices that will carry the rated current and protect the insulated conductor against overcurrents must be chosen.

Short-circuit Protection

The overcurrent protective devices will need to limit the energy let-through, of short-circuit currents, to a level below the short-circuit thermal withstand of the 16 and 18 AWG conductors as specified in Table 7. Knowing this, various overcurrent protective devices can be explored.

UL/CSA/ANCE 248 Current Limiting Fuses

Originally current limiting devices were chosen by the NFPA79 adhoc committee in order to easily cover the variety of fault current conditions that exist upon which the machine may be applied. Listed current limiting fuses are classified by umbrella limits published in the UL/CSA/ANCE 248 series of standards. The umbrella limits provide maximum permissible let through values for instantaneous peak current and \( I^2t \) for a specific class of fuse and ampere rating. In order for a current limiting fuse to achieve listing, the let through values of the fuse must be less than the umbrella limits required for that class and ampere rating of fuse. The umbrella limits governing current limiting fuses provide a sound way of performing engineering analysis. In addition to the UL/CSA/ANCE 248 series of standards, the UL White book, *General Information for Electrical Equipment Directory*, provides the umbrella limits for the various classes of current limiting fuses. Upon examination of the White book, the \( I^2t \) and peak let through currents of various current limiting branch circuit fuses were evaluated. Initially, Class CC fuses, 20 amps and below, were found to protect both the 16 and 18 AWG wire according to limits set forth. See Table 10. Class CC fuses 20 amps and below were used in the analysis that was conducted at the NFPA79 committee meetings. See Annex A for details on this analysis.

<table>
<thead>
<tr>
<th>Current Rating</th>
<th>Between Threshold and 50KA</th>
<th>At 100 KA</th>
<th>At 200KA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ip (A) ( I^2t ) (A^2s)</td>
<td>Ip (A) ( I^2t ) (A^2s)</td>
<td>Ip (A) ( I^2t ) (A^2s)</td>
</tr>
<tr>
<td>15</td>
<td>3,000 2,000</td>
<td>3,000 2,000</td>
<td>4,000 3,000</td>
</tr>
<tr>
<td>20</td>
<td>3,000 2,000</td>
<td>4,000 3,000</td>
<td>5,000 3,000</td>
</tr>
</tbody>
</table>

Further research of current limiting fuses using the umbrella limits, expanded the list of potential devices to include Class J, T, and CC fuses up to 30 amps. A review of the umbrella limits for the Class J, T, and CC 30 amp fuses showed that the maximum permissible \( I^2t \) limits for these fuses are less than the wire limits shown in Table 7. See Table 11 below:
### Table 11

<table>
<thead>
<tr>
<th>UL Class of Fuse</th>
<th>Current Rating</th>
<th>Between Threshold and 50KA</th>
<th>At 100 KA</th>
<th>At 200KA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ip (A)</td>
<td>I²t (A²s)</td>
<td>Ip (A)</td>
</tr>
<tr>
<td>Class CC</td>
<td>30</td>
<td>6,000</td>
<td>7,000</td>
<td>7,500</td>
</tr>
<tr>
<td>Class J</td>
<td>30</td>
<td>6,000</td>
<td>7,000</td>
<td>7,500</td>
</tr>
<tr>
<td>Class T (600V)</td>
<td>30</td>
<td>6,000</td>
<td>7,000</td>
<td>7,500</td>
</tr>
</tbody>
</table>

### Overload Protection

The overcurrent protective device needs to interrupt low level overloads prior to thermal damage of the conductor insulation. Two major types of branch circuit loads were included in this analysis, motor loads and non-motor loads. For motor loads, an overload relay as part of a motor starter, is used for this purpose. This motor starter is used in conjunction with a branch-circuit short-circuit protective device as it would be applied in the field.

The standard used to investigate overload relays and motor starters is UL508. Overload relays can be classified according to their tripping time at 600 percent of their current rating. The classification is outlined in Table 12.

### Table 12

<table>
<thead>
<tr>
<th>Class Designation for Overload Relays per UL508*</th>
<th>Tripping Time @ 600% (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 10</td>
<td>10</td>
</tr>
<tr>
<td>Class 20</td>
<td>20</td>
</tr>
<tr>
<td>Class 30</td>
<td>30</td>
</tr>
</tbody>
</table>

* Data based upon UL Standard 508 Table 146.1

For non-motor loads a single branch circuit overcurrent protective is used. This device must be capable of interrupting both short-circuit and overload currents. Current limiting fuses tested to UL/CSA/ANCE 248 undergo low level testing as outlined in Table 13.

### Table 13

<table>
<thead>
<tr>
<th>UL248 Test Points*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Level (% Rated Current)</td>
</tr>
<tr>
<td>135</td>
</tr>
<tr>
<td>200</td>
</tr>
</tbody>
</table>

* For fuses 30 amps and less

The data shown in Tables 12-13 provide reference levels for opening times of overcurrent protective devices under overload conditions. These levels are used to evaluate the performance of the various overcurrent protective devices compared to the withstand of 16 and 18 AWG conductors. This type of analysis was conducted at the NFPA79 committee meetings, See Annex A for details on this analysis.
Testing

The next step in the process evaluates the suitability of 16 and 18 AWG insulated conductors for power branch circuits with actual testing. Testing was designed to cover a broad range of overcurrents, overload and short-circuit, in order to analyze the suitability of 16 and 18 AWG conductors for power branch-circuit application. The plan for investigation, test data and results, and analysis of the results are contained in the remainder of this report.
PLAN OF INVESTIGATION

General Considerations
In order to provide data to support the Engineering Analysis provided by the NFPA Small Wire Working Group, a test program was developed by the Working Group with three major principles:

1. Create tests using conservative approaches simulating worst case conditions
   - “Bus bar” testing from UL489
   - Umbrella fuses for short circuit testing
   - 1’, 4’, and 100’ lengths of wire
2. Create tests to cover various types of electrical systems and grounding schemes
   - Full voltage, high current testing on each pole
3. Check validity of wire insulation via dielectric testing
   - Per UL83, *Thermoplastic Insulated Wire and Cable*, section 27

Test setups hinged around these three major principles and were used in the plan for investigation. UL standards 508, 489, and 248 were used as the base documents for the testing. The actual test configurations deviated from these test configurations only to create worst case conditions, and account for real application scenarios for industrial machinery.

The test program explored the suitability of 16 and 18 AWG insulated conductors for use on power branch circuits. The test program was divided into two major categories: Verification of Overload Protection of Conductor and Verification of Short-circuit Protection of Conductor. Following the testing the conductor was tested for insulation damage via dielectric testing outlined in UL83, section 27.

**Verification of Short-circuit Protection of Conductor**
Testing was performed to investigate the short-circuit protection of 16 and 18 AWG cable. Development of the test setups was based upon creating tests that would cover the majority of the applications for which the wire would be installed. A conservative approach using “worst case” test situations was used for this development.

The first step was to determine the test configuration for the short-circuit testing. In order to cover the variety of installations that could exist, it was determined that, initially, 1 foot and 100 foot lengths of conductor would be used in the testing, see Figures 1 and 2.

![Image 1](image1.png)  
Figure 1 – 1 foot Test Setup

![Image 2](image2.png)  
Figure 2 – 100 foot Test Setup
The 1 foot length would investigate the thermal and magnetic withstands of short runs of conductor inside a cabinet. The 100 foot test setup investigated the thermal and magnetic withstands of long runs of conductor.

A conditional test with 4' of conductor was also used on the high fault level testing for the devices that passed the 1 foot test. The 4' length would provide an additional check on the magnetic withstand of the conductor.

Bolted fault conditions were used to coincide with existing testing configurations employed by UL in standards UL/CSA/ANCE 248, UL489, and UL508 and to give to a worst case short-circuit condition. The fault was created directly at the end of the run of the conductor, see Figures 1, 2, and 3. Connection to the test lab terminals followed the "bus bar" high fault circuit test configurations in UL 489. The "bus bar" test conditions in UL489 require 4' of #1 conductor feeding the line lugs of the OCP device and 10" of rated wire in the load side. One foot of rated wire was used instead of 10" for simplicity. For all the short-circuit testing using fuses, umbrella fuses were used. This follows the existing requirements in standards UL/CSA/ANCE248, UL489, and UL508 and creates a worst case situation, since any listed commercially available fuse will perform better than the umbrella fuses. See Annex B for data on umbrella fuses used in the test program. Note in Annex B that there is not an upper limit on the instantaneous peak current and $I^2t$ let through when selecting umbrella fuses. In this testing, for example, the $I^2t$ was more than double the umbrella limit.

A wide variety of short-circuit current levels were used to cover the variance in installations and fault levels in the industry. The following short-circuit current levels were used in the testing:

- 50,000 amps
- 10,000 amps
- 5,000 amps

The 50kA level was chosen based upon UL/CSA/ANCE 248 fuse testing and the work conducted by the NFPA79 Committee. See annex A. Since the $I^2t$ umbrella limit of Class CC, J, and T fuses are the same at 50, 100, and 200kA, the 50kA level was determined to represent the high short-circuit current testing level. The 50kA test was conducted on all of the branch-circuit short-circuit devices tested with varying power factors. The 10kA level is a common test level used in various UL standards for low level short-
circuit current testing. All of the branch-circuit, short-circuit devices were tested at this level. The 5kA test level was selected to cover the lower end of the short-circuit current spectrum. This testing was limited to the stand alone branch-circuit, short circuit devices and the 1' test configuration.

The 1, 4, and 100 foot tests were performed at 480V, 3 phase with varying power factors. Conditional tests at a full 600V were performed on the branch-circuit, short-circuit devices that passed all the 480V testing, see Figure 1 for setup. This test sequence was conducted for the 5, 10, and 50kA tests.

Additional test configurations were utilized to investigate various commonly used grounding schemes. The test configurations were used to verify the suitability of the conductors where the maximum possible $I^2t$, instantaneous peak current, and voltage would be imposed on the conductor pertaining to the various systems. The four main types of systems investigated were:

**Solidly grounded WYE**

![Solidly grounded WYE](image)

**Corner grounded Delta**

![Corner grounded Delta](image)

**Resistance grounded WYE**

![Resistance grounded WYE](image)

**Ungrounded systems**

![Ungrounded systems](image)

The three phase bolted fault test configuration described previously covered the solidly grounded wye system. Additional test configurations were used to investigate the remainder of the systems. A fault was created across one pole of the branch-circuit, short-circuit devices using line to line voltage. This would simulate a situation that could exist in these grounding schemes where single or multiple line to ground faults could impose line to line voltage across one pole of the device. The test setup is shown in Figure 4.
The 50kA and 10kA fault levels were used for this test configuration. Only the stand alone branch-circuit, short-circuit devices were investigated.

**Verification of Overload Protection of Conductor**

At the end of the short circuit testing, the devices that passed were subjected to overload testing. In order to investigate overload protection of 16 and 18 AWG conductors, testing was performed to explore overcurrent protection for two different types of loads: motor loads and non-motor loads.

**Motor Loads**

In order to investigate motor branch circuits, motor starters were used in conjunction with branch-circuit short-circuit protective devices that they were listed with. Both class 10 and class 20 overload relays were used in the test program. Class 20 overload relays are more popular, but as shown below, the use of class 10 overloads could lead to a larger permissible load current. See Annex A for details on this analysis. As a result of the work conducted by the NFPA79 adhoc committee, limitations were placed on the load current for 16 and 18 AWG conductors depending on the class overload relay used. These current levels are shown in Table 15.

**Table 15**

<table>
<thead>
<tr>
<th>Overload Relay Class</th>
<th>16 AWG Maximum Full Load Ampacity</th>
<th>18 AWG Maximum Full Load Ampacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td>5.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Two current levels were investigated on each test setup:

- 15 Amps
- 600% Maximum Full Load Ampacity
The first level was selected to link the overload testing with a common branch circuit current level recognized in the industry. The second level was selected to link up with UL508 testing for the overload relays and to simulate a locked rotor condition on a motor. The overload relay was sized according to the maximum permissible load current during the overload testing. Opening time was recorded for each test. Visual inspection and dielectric testing of the wire was conducted.

Non-Motor Loads
Testing in this area consisted of a single branch circuit overcurrent protective device sized per the ampacity of the conductor. As a result of the work conducted by the NFPA79 committee, limitations were placed on the load current for 16 and 18 AWG conductors, See Annex A for details on this analysis. These current levels are shown in Table 16. Note that these values are 80% of the ampacities shown in Table 1.

<table>
<thead>
<tr>
<th>Maximum Full Load Ampacity</th>
<th>16 AWG</th>
<th>18 AWG</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>5.6</td>
<td></td>
</tr>
</tbody>
</table>

Two current levels were investigated on each test setup:
- 135% Overcurrent Protective Device Rating
- 600% of Maximum Full Load Ampacity

The first level was selected based upon a common overload test level conducted on branch circuit overcurrent protective devices. The second was selected to simulate a higher level overload condition that might exist.

Inspection of Wire
In order to verify if a conductor passes the overload and short-circuit testing, a two step investigation was used. The first step is a common practice in testing today. Immediately following the tests, a visual inspection was performed on the conductor and observations were noted.

Acceptability of Results
Visual damage to the insulated wire including insulation damage, wire pulled out of terminal, or vaporization of the wire would result in a failure for the test. If a failure of the visual test resulted, the dielectric test was not conducted.

Insulation Dielectric Withstand Tests
The second step in the wire acceptance testing was a dielectric withstand test. It was determined that the dielectric withstand test in UL83, *Thermoplastic Insulated Wire and Cable*, section 27 would be used.

Perform Dielectric Voltage-Withstand Test as specified in UL83 section 27,
- Immerse as much of the insulation of the wire as possible in room temperature tap water for a period of not less than 6 hours.
- With wire still immersed in the tap water, attach one lead of a dielectric voltage tester to the bare ends of the wire. Attach the other lead to a conducting material that is immersed in the water.
- Apply 2000V to the wire under test for 60 seconds.
Acceptability of Results
The wire shall be able to withstand the applied voltage without breakdown for the said amount of time.

See Annex C for a flow chart representation of the testing sequence used in this investigation.
TEST DATA, OBSERVATIONS, AND RESULTS

Data, observations, and results obtained from the testing in this study are outlined in this section. Results from each test are outlined in three main sections:

Test Data Sheet
This section provides information relating to the setup of the test, a description of the test, test circuit parameters, and test results.

Test Observations
This section provides a frame by frame view from the NTSC VHS video that was taken during the testing. The frames shown are the six frames surrounding the test.

Assessment of Results
This section links the results of the testing to the analysis that was conducted on withstand ratings of conductors prior to the testing. The data accumulated during the testing was compared to the withstands shown in Table 16.

<table>
<thead>
<tr>
<th>Wire Size</th>
<th>Short-circuit Withstand I$^t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 AWG</td>
<td>7,355 A$^2$s</td>
</tr>
<tr>
<td>16 AWG</td>
<td>18,657 A$^2$s</td>
</tr>
</tbody>
</table>

Table 16

ICEA I$^t$ Withstand Limits Copper Conductor, Thermoplastic Insulation
TEST #: 1A

Purpose: Verification of Overload Protection - Class 10 Overload Relay

Description: 16 AWG type MTW wire
   Class 10 overload relay set at 8 Amps
   Protective device is a 20 Amp Class CC fuse

Test Parameters

| Current: 15 A |

Test DATA:

- Relay opened in 5 seconds
- Fuse did not open

Results:

- Visual: No Visible Damage
- Dielectric: Passed
Assessment of Results

Test 1A:

Overload relay opened in 5 seconds.

Fuse did not open. There was no visible damage to the conductor. The conductor passed the dielectric test.
**TEST #:** 1B

**Purpose:** Verification of Overload Protection - Class 10 Overload Relay

**Description:**
- 16 AWG type MTW wire
- Class 10 overload relay set at 8 Amps
- Protective device is a 20 Amp Class CC fuse

**Current:** 48 A (600%)

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current: 48 A (600%)</td>
<td>Relay opened in 2 seconds</td>
</tr>
<tr>
<td></td>
<td>Fuse did not open</td>
</tr>
</tbody>
</table>

**Results:**
- Visual: No Visible Damage
- Dielectric: Passed
Assessment of Results

Test 1B:

Overload relay opened in 2 seconds.

Fuse did not open. There was no visible damage to the conductor. The conductor passed the dielectric test.
TEST #: 1C

Purpose: Verification of Overload Protection - Class 20 Overload Relay

Description: 16 AWG type MTW wire
Class 20 overload relay set at 8 Amps
Protective device is a 20 Amp Class CC fuse

Test Parameters

<table>
<thead>
<tr>
<th>Current: 15 A</th>
</tr>
</thead>
</table>

TEST DATA:
Relay opened in 4.9 seconds
Fuse did not open

Results:
Visual: No Visible Damage
Dielectric: Passed
Assessment of Results

Test 1C:
Overload relay opened in 4.9 seconds.

Fuse did not open. There was no visible damage to the conductor. The conductor passed the dielectric test.
TEST #: 1D

Purpose: Verification of Overload Protection - Class 20 Overload Relay

Description: 16 AWG type MTW wire
Class 20 overload relay set at 8 Amps
Protective device is a 20 Amp Class CC fuse

Test Parameters

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
</tr>
</thead>
</table>
| Current: 33 A (600%) | Relay opened in 3.13 seconds
Fuse did not open |

Results:
Visual: No Visible Damage
Dielectric: Passed
Test ID:

Overload relay opened in 3.13 seconds.

Fuse did not open. There was no visible damage to the conductor. The conductor passed the dielectric test.
**TEST #:** 1E  

**Purpose:** Verification of Overload Protection - Fuse Only

**Description:** 16 AWG type MTW wire  
Protective device is a 10 Amp Class CC fuse

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current:</strong> 13.51 A (135%)</td>
<td>Fuse cleared in 5 min. 48 sec.</td>
</tr>
</tbody>
</table>

**Results:**  
Visual: No Visible Damage  
Dielectric: Passed
Test 1E:
Fuse opened in 5 minutes 48 seconds. There was no visible damage to the conductor. The conductor passed the dielectric test.
**TEST #:** 1F  

**Purpose:** Verification of Overload Protection - Fuse Only

**Description:** 16 AWG type MTW wire  
Protective device is a 10 Amp Class CC fuse

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current: 48 A (600%)</td>
<td>Fuse cleared in 4.6 seconds</td>
</tr>
</tbody>
</table>

**Results:**  
Visual: No Visible Damage  
Dielectric: Passed
Test 1F:

Fuse opened in 4.6 seconds. There was no visible damage to the conductor. The conductor passed the dielectric test.
TEST #: 2A

Purpose: Verification of Overload Protection - Class 10 Overload Relay

Description: 18 AWG type MTW wire
Class 10 overload relay set at 6 Amps
Protective device is a 15 Amp Class CC fuse

Test Parameters

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current: 15 A</td>
<td>Relay opened in 6 seconds</td>
</tr>
<tr>
<td></td>
<td>Fuse did not open</td>
</tr>
</tbody>
</table>

Results:
Visual: No Visible Damage
Dielectric: Passed
Test 2A:

Overload relay opened in 6 seconds.

Fuse did not open. There was no visible damage to the conductor. The conductor passed the dielectric test.
### TEST #:

| 2B |

### Purpose:

Verification of Overload Protection - Class 10 Overload Relay

### Description:

- 18 AWG type MTW wire
- Class 10 overload relay set at 6 Amps
- Protective device is a 15 Amp Class CC fuse

### Test Parameters

| Current: 30 A (600%) |

### TEST DATA:

| Relay opened in 3 seconds |
| Fuse did not open |

### Results:

- **Visual:** No Visible Damage
- **Dielectric:** Passed
Test 2B:
Overload relay opened in 3 seconds.

Fuse did not open. There was no visible damage to the conductor. The conductor passed the dielectric test.
TEST #: 2C

Purpose: Verification of Overload Protection - Class 20 Overload Relay

Description: 18 AWG type MTW wire
Class 20 overload relay set at 6 Amps
Protective device is a 15 Amp Class CC fuse

Test Parameters

| Current | 15 A |

TEST DATA:
Relay opened in 5.8 seconds
Fuse did not open

Results:
Visual: No Visible Damage
Dielectric: Passed
Test 2C:

Overload relay opened in 5.8 seconds.

Fuse did not open. There was no visible damage to the conductor. The conductor passed the dielectric test.
### TEST #:

<table>
<thead>
<tr>
<th>TEST DATA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relay opened in 3.8 seconds</td>
</tr>
<tr>
<td>Fuse did not open</td>
</tr>
</tbody>
</table>

### Test Parameters

<table>
<thead>
<tr>
<th>Current: 20.96 A (600%)</th>
</tr>
</thead>
</table>

### Results:

- **Visual:** No Visible Damage
- **Dielectric:** Passed
Test 2D:

Overload relay opened in 3.8 seconds.

Fuse did not open. There was no visible damage to the conductor. The conductor passed the dielectric test.
TEST #: 2E

Purpose: Verification of Overload Protection - Fuse Only

Description: 18 AWG type MTW wire
Protective device is a 7 Amp Class CC fuse

Test Parameters

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current: 9.51 A (135%)</td>
<td>Fuse cleared in 35 seconds</td>
</tr>
</tbody>
</table>

Results:

Visual: No Visible Damage
Dielectric: Passed
Test 2E:
  Fuse opened in 6 minutes 35 seconds. There was no visible damage to the conductor. The conductor passed the dielectric test.
TEST #: 2F

Purpose: Verification of Overload Protection - Fuse Only

Description: 18 AWG type MTW wire
Protective device is a 7 Amp Class CC fuse

![Diagram with 18 AWG wire]

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current: 34 A (600%)</td>
<td>Fuse cleared in 5.4 seconds</td>
</tr>
</tbody>
</table>

Results:

Visual: No Visible Damage
Dielectric: Passed
Test 2F:

Fuse opened in 5.4 seconds. There was no visible damage to the conductor. The conductor passed the dielectric test.
**Purpose:** Verification of Short-Circuit Protection - Low Level

**Description:** 1 foot of 16 AWG type MTW wire per phase
3 phase bolted fault on line side of motor starter.
Protective device is a 20 amp Class CC umbrella fuse.

---

**Test Parameters**

<table>
<thead>
<tr>
<th>Voltage</th>
<th>482 Vac</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>5.2 KA</td>
<td></td>
</tr>
<tr>
<td>pf</td>
<td>72 %</td>
<td></td>
</tr>
</tbody>
</table>

**TEST DATA:**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Clearing $I_2t \times 10^3$</th>
<th>$I_p \times 10^3$</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.03</td>
<td>0.98</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>B</td>
<td>1.53</td>
<td>1.69</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>C</td>
<td>0.81</td>
<td>0.91</td>
<td>Fuse Opened</td>
</tr>
</tbody>
</table>

**Results:**

- **Visual:** No Visual Damage on any Phase
- **Dielectric:** Passed
Test #: 3A

Test 3A:

Maximum Clearing $I^2t$ = 1,530 A$^2$s
Maximum Peak Current $I_p$ = 1,690 Amps

Maximum clearing $I^2t$ let through during this test was below the calculated withstand level. There was no visual damage to any of the conductors. Video footage showed little activity, with minor movement of the conductors. All the conductors passed the dielectric test.
Purpose: Verification of Short-Circuit Protection - Medium Level

Description: 1 foot of 16 AWG type MTW wire per phase
3 phase bolted fault on line side of motor starter.
Protective device is a 20 amp Class CC umbrella fuse.

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage: 484 Vac</td>
<td>Phase Clearing $12t \times 10^3$</td>
</tr>
<tr>
<td>Current: 10.9 KA</td>
<td>A</td>
</tr>
<tr>
<td>pf: 76 %</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>

Results:
Visual: No Visual Damage on any Phase
Dielectric: Passed
Test #: 3B

Test 3B:

Maximum Clearing $I^2t = 1,980 \text{ A}^2\text{s}$

Maximum Peak Current $I_p = 2,310 \text{ Amps}$

Maximum clearing $I^2t$ let through during this test was below the calculated withstand level. There was no visual damage to any of the conductors. Video footage showed little activity, with minor movement of the conductors. All the conductors passed the dielectric test.
TEST #: 3C

Purpose: Verification of Short-Circuit Protection - High Level

Description: 1 foot of 16 AWG MTW wire per phase
3 phase bolted fault on line side of motor starter.
Protective device is a 20 amp Class CC umbrella fuse.

Test Parameters

| Voltage: 482 Vac | Current: 53.6 KA | pf: 13.5 % |

TEST DATA:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Clearing $I_2t \times 10^3$</th>
<th>$I_p \times 10^3$</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.77</td>
<td>2.28</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>B</td>
<td>1.42</td>
<td>3.15</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>C</td>
<td>0.24</td>
<td>1.14</td>
<td>Fuse Did Not Open</td>
</tr>
</tbody>
</table>

Results:

Visual: No Visual Damage on any Phase
Dielectric: Passed
Test #: 3C

Assessment of Results

Test 3C:

Maximum Clearing $I^2t$ = 1,420 $A^2$s  
Maximum Peak Current $I_p$ = 3,150 Amps

Maximum clearing $I^2t$ let through during this test was below the calculated withstand level. There was no visual damage to any of the conductors. Video footage showed little activity, with minor movement of the conductors. All the conductors passed the dielectric test.
Purpose: Verification of Short-Circuit Protection - Low Level

Description: 1 foot of 18 AWG type MTW wire per phase
3 phase bolted fault on line side of motor starter.
Protective device is a 20 amp Class CC umbrella fuse.

Test Parameters

| Voltage: 482 Vac | Current: 5.2 KA | pf: 72 % |

<table>
<thead>
<tr>
<th>Phase</th>
<th>Clearing I2t x 10³</th>
<th>Ip x 10³</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.77</td>
<td>0.83</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>B</td>
<td>1.42</td>
<td>1.65</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>C</td>
<td>0.6</td>
<td>0.83</td>
<td>Fuse Did Not Open</td>
</tr>
</tbody>
</table>

Results:
Visual: No Visual Damage on any Phase
Dielectric: Passed
Test #: 4A

Test 4A:

Maximum Clearing $I^2t = 1,420 \text{ A}^2 \text{s}$

Maximum Peak Current $I_p = 1,650 \text{ Amps}$

Maximum clearing $I^2t$ let through during this test was below the calculated withstand level. There was no visual damage to any of the conductors. Video footage showed little activity, with minor movement of the conductors. All the conductors passed the dielectric test.
TEST #: 4B

Purpose: Verification of Short-Circuit Protection - Medium Level

Description: 1 foot of 18 AWG type MTW wire per phase
3 phase bolted fault on line side of motor starter.
Protective device is a 20 amp Class CC umbrella fuse.

![Diagram of setup with 1 AWG, 4' and 18 AWG, 1' wires connected to motor starter with short created here]

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage: 484 Vac</td>
<td>Phase</td>
<td>Clearing I2t x 10^3</td>
</tr>
<tr>
<td>Current: 10.9 KA</td>
<td>A</td>
<td>0.384</td>
</tr>
<tr>
<td>pf: 76 %</td>
<td>B</td>
<td>1.44</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>0.536</td>
</tr>
</tbody>
</table>

Results:
Visual: No Visual Damage on any Phase
Dielectric: Passed
Test #: 4B

Test 4B:

\[
\begin{align*}
\text{Maximum Clearing } I^2t &= 1,440 \text{ A}^2\text{s} \\
\text{Maximum Peak Current } I_p &= 2,070 \text{ Amps}
\end{align*}
\]

Maximum clearing \( I^2t \) passed through during this test was below the calculated withstand level. There was no visual damage to any of the conductors. Video footage showed little activity, with minor movement of the conductors. All the conductors passed the dielectric test.
TEST #: 4C

Purpose: Verification of Short-Circuit Protection - High Level

Description: 1 foot of 18 AWG type MTW wire per phase
3 phase bolted fault on line side of motor starter.
Protective device is a 20 amp Class CC umbrella fuse.

1 AWG, 4’

18 AWG, 1’

Motor Starter

Short Created Here

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage: 482 VAC</td>
<td>Phase</td>
</tr>
<tr>
<td>Current: 53.6 KA</td>
<td>A</td>
</tr>
<tr>
<td>pf: 13.5 %</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>

Results:
Visual: No Visual Damage on any Phase
Dielectric: Passed
Test #: 4C

Test 4C:

Maximum Clearing $I^2t = 1,450 \text{ A}^2\text{s}$
Maximum Peak Current $I_p = 3,300 \text{ Amps}$

Maximum clearing $I^2t$ let through during this test was below the calculated withstand level. There was no visual damage to any of the conductors. Video footage showed little activity, with minor movement of the conductors. All the conductors passed the dielectric test.
**TEST #:** 5B

**Purpose:** Verification of Short-Circuit Protection - Medium Level

**Description:** 4 feet of 18 AWG type MTW wire per phase  
3 phase bolted fault on line side of motor starter.  
Protective device is a 30 amp Class CC, J, and T umbrella fuse.

---

**Test Parameters**

| Voltage: 484 Vac | Current: 10.9 KA | pf: 76 % |

<table>
<thead>
<tr>
<th>TEST DATA:</th>
<th>Phase</th>
<th>Clearing I₂t x 10³</th>
<th>Ip x 10³</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5.17</td>
<td>2.15</td>
<td></td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>B</td>
<td>7.01</td>
<td>3.54</td>
<td></td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>C</td>
<td>4.52</td>
<td>2.15</td>
<td></td>
<td>Fuse Opened</td>
</tr>
</tbody>
</table>

**Results:**

- **Visual:** No Visual Damage on any Phase  
- **Dielectric:** Passed
Test #: 5B

Test 5B:

Maximum Clearing $I^2t$ = 7,010 A$^2$s
Maximum Peak Current $I_p$ = 3,540 Amps

Maximum clearing $I^2t$ lett through during this test was below the calculated withstand level. Video footage showed little activity, with minor movement of the conductors. All conductors passed the dielectric test.
TEST #: 5C

**Purpose:** Verification of Short-Circuit Protection - High Level

**Description:** 4 feet of 18 AWG type MTW wire per phase
3 phase bolted fault on line side of motor starter.
Protective device is a 30 amp Class CC, J, and T umbrella fuse

---

**Test Parameters**

<table>
<thead>
<tr>
<th>Test Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>484 Vac</td>
</tr>
<tr>
<td>Current</td>
<td>53.6 KA</td>
</tr>
<tr>
<td>pf:</td>
<td>13.5 %</td>
</tr>
</tbody>
</table>

**TEST DATA:**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Clearing I2t x 10^3</th>
<th>Ip x 10^3</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4.75</td>
<td>4.41</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>B</td>
<td>5.14</td>
<td>4.65</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>C</td>
<td>1.17</td>
<td>0.86</td>
<td>Fuse Did Not Open</td>
</tr>
</tbody>
</table>

**Results:**

Visual: No Visual Damage on any Phase
Dielectric: Passed
Test #: 5C

Test 5C:

Maximum Clearing $I^2t = 5,140 \text{ A}^2\text{s}$

Maximum Peak Current $I_p = 4,650 \text{ Amps}$

Maximum clearing $I^2t$ let through during this test was below the calculated withstand level. Video footage showed little activity, with minor movement of the conductors. All conductors passed the dielectric test.
**TEST #:** 6B

**Purpose:** Verification of Short-Circuit Protection - Medium Level

**Description:** 100 feet of 16 AWG type MTW wire per phase 
3 phase bolted fault on load side of motor starter. 
Protective device is a 20 amp Class CC umbrella fuse.

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage: 484 Vac</td>
<td>Phase</td>
</tr>
<tr>
<td>Current: 10.9 KA</td>
<td>A</td>
</tr>
<tr>
<td>pf: 76 %</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>

**Results:**
- Visual: No Visual Damage on any Phase
- Dielectric: Passed
Test 6B:

Maximum Clearing $I^2t$ = 820 A$^2$s
Maximum Peak Current $I_p$ = 960 Amps

Maximum clearing $I^2t$ let through during this test was below the calculated withstand level. Video footage showed little activity, with minor movement of the conductors. All conductors passed the dielectric test.
**TEST #:** 6C

**Purpose:** Verification of Short-Circuit Protection - High Level

**Description:** 100 feet of 16 AWG type MTW wire per phase
3 phase bolted fault on load side of motor starter.
Protective device is a 20 amp Class CC umbrella fuse.

**Voltage:** 484 Vac
**Current:** 53.6 KA
**pf:** 13.5 %

**TEST DATA:**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Clearing $I_2t \times 10^3$</th>
<th>$I_p \times 10^3$</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.23</td>
<td>0.7</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>B</td>
<td>0.65</td>
<td>0.92</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>C</td>
<td>0.62</td>
<td>0.43</td>
<td>Fuse Did Not Open</td>
</tr>
</tbody>
</table>

**Results:**

Visual: No Visual Damage on any Phase
Dielectric: Passed
Test #: 6C

Test 6C:

Maximum Clearing $I^2t$ = 1,230 $A^2s$
Maximum Peak Current $I_p$ = 920 Amps

Maximum clearing $I^2t$ let through during this test was below the calculated withstand level. Video footage showed little activity, with minor movement of the conductors. All conductors passed the dielectric test.
TEST #: 6E

Purpose: Verification of Short-Circuit Protection - Medium Level

Description: 100 feet of 18 AWG type MTW wire per phase
3 phase bolted fault on load side of motor starter.
Protective device is a 20 amp Class CC umbrella fuse.

Test Parameters

<table>
<thead>
<tr>
<th>Voltage: 484 Vac</th>
<th>Phase</th>
<th>Clearing I2t x 10^3</th>
<th>Ip x 10^3</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current: 10.9 KA</td>
<td>A</td>
<td>1</td>
<td>0.55</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>pf: 76 %</td>
<td>B</td>
<td>0.7</td>
<td>0.6</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>0.51</td>
<td>0.45</td>
<td>Fuse Did Not Open</td>
</tr>
</tbody>
</table>

Results:
- Visual: No Visual Damage on any Phase
- Dielectric: Passed
Test #: 6E

Test 6E:

Maximum Clearing $I^2t$ = 1,000 A^{2}s
Maximum Peak Current $I_p$ = 600 Amps

Maximum clearing $I^2t$ let through during this test was below the calculated withstand level. Video footage showed little activity, with minor movement of the conductors. All conductors passed the dielectric test.
TEST #: 6F

Purpose: Verification of Short-Circuit Protection - High Level

Description: 100 feet of 18 AWG type MTW wire per phase
3 phase bolted fault on load side of motor starter.
Protective device is a 20 amp Class CC umbrella fuse.

Test Parameters

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage:  484 Vac</td>
<td>Phase</td>
</tr>
<tr>
<td>Current:  53.6 KA</td>
<td>A</td>
</tr>
<tr>
<td>pf:  13.5 %</td>
<td>B</td>
</tr>
</tbody>
</table>

Results:
Visual: No Visual Damage on any Phase
Dielectric: Passed
Test #: 6F

Test 6F:

Maximum Clearing $I^2t = 1,280 \text{ A}^2\text{s}$
Maximum Peak Current $I_p = 610 \text{ Amps}$

Maximum clearing $I^2t$ let through during this test was below the calculated withstand level. Video footage showed little activity, with minor movement of the conductors. All conductors passed the dielectric test.
Purpose: Verification of Short-Circuit Protection – Low Level

Description: 1 foot of 18 AWG type MTW wire per phase
3 phase bolted fault on line side of motor starter.
Protective device is a 30 amp Class CC, J, and T umbrella fuse.

Voltage: 630 Vac
Current: 5 KA
pf: 76%

Test Parameters | TEST DATA:
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase</td>
<td>Clearing I²t x 10³</td>
<td>Ip x 10³</td>
</tr>
<tr>
<td>A</td>
<td>6.73</td>
<td>1.76</td>
</tr>
<tr>
<td>B</td>
<td>8.29</td>
<td>1.45</td>
</tr>
<tr>
<td>C</td>
<td>4.67</td>
<td>2.97</td>
</tr>
</tbody>
</table>

Results:
Visual: No Visual Damage on any Phase
Dielectric: Passed
Test #: 7A

Maximum Clearing $I_t^2 = 8,290 \ A^2s$
Maximum Peak Current $I_p = 2,970 \ Amps$

Maximum clearing $I_t^2$ let through during this test was above the calculated withstand level. There was no visible damage to any of the conductors. Video footage showed little activity, with minor movement of the conductors. All the conductors passed the dielectric test.
TEST #: 7B

Purpose: Verification of Short-Circuit Protection - Medium Level

Description: 1 foot of 18 AWG type MTW wire per phase
3 phase bolted fault on line side of motor starter.
Protective device is a 30 amp Class CC, J, and T umbrella fuse.

Test Parameters

| Voltage: 604 Vac | Current: 10.7 KA | pf: 71 % |

### TEST DATA:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Clearing (I_2t) x 10^3</th>
<th>(I_p) x 10^3</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.88</td>
<td>1.55</td>
<td>Fuse Did Not Open</td>
</tr>
<tr>
<td>B</td>
<td>10.4</td>
<td>3.86</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>C</td>
<td>3.35</td>
<td>2.42</td>
<td>Fuse Opened</td>
</tr>
</tbody>
</table>

**Results:**

Visual: No Visual Damage on any Phase
Dielectric: Passed
Test #: 7B

Test 7B:

\[
\begin{align*}
\text{Maximum Clearing } I^2t &= 10,400 \text{ A}^2\text{s} \\
\text{Maximum Peak Current } I_p &= 3,860 \text{ Amps}
\end{align*}
\]

Maximum clearing \(I^2t\) let through during this test was above the calculated withstand level. There was no visible damage to any of the conductors. Video footage showed little activity, with minor movement of the conductors. All the conductors passed the dielectric test.
**TEST #:** 7C

**Purpose:** Verification of Short-Circuit Protection - High Level

**Description:** 1 foot of 18 AWG type MTW wire per phase
3 phase bolted fault on line side of motor starter.
Protective device is a 30 amp Class CC, J, and T umbrella fuse.

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage: 608 Vac Current: 52.7 KA pf: 8.5 %</td>
<td>Phase Clearing I2t x 10^3</td>
<td>Ip x 10^3</td>
<td>Comments</td>
</tr>
<tr>
<td>A</td>
<td>6.22</td>
<td>5.23</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>B</td>
<td>0.19</td>
<td>0.66</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>C</td>
<td>6.33</td>
<td>5.18</td>
<td>Fuse Did Not Open</td>
</tr>
</tbody>
</table>

**Results:**
Visual: No Visual Damage on any Phase
Dielectric: Passed
Test #: 7C

Test 7C:

Maximum Clearing $I^2t$ = 6,330 A$^2$s
Maximum Peak Current $I_p$ = 5,230 Amps

Maximum clearing $I^2t$ let through during this test was below the calculated withstand level. There was no visible damage to any of the conductors. Video footage showed little activity, with minor movement of the conductors. All the conductors passed the dielectric test.
TEST #: 8A

Purpose: Verification of Short-Circuit Protection – Low Level

Description: 1 foot of 18 AWG type MTW wire per phase 3 phase bolted fault on line side of motor starter. Protective device is a 30 amp Class CC, J, and T umbrella fuse.

Voltage: 482 Vac
Current: 5.2 KA
pf: 72 %

TEST DATA:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Clearing I2t x 10^3</th>
<th>Ip x 10^3</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6.06</td>
<td>1.81</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>B</td>
<td>7.07</td>
<td>2.91</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>C</td>
<td>4.76</td>
<td>1.83</td>
<td>Fuse Opened</td>
</tr>
</tbody>
</table>

Results:
Visual: No Visual Damage on any Phase
Dielectric: Passed
Test #: 8A

Test 8A:

Maximum Clearing $I^2t = 7,070 \, \text{A}^2\text{s}$
Maximum Peak Current $I_p = 2,910 \, \text{Amps}$

Maximum clearing $I^2t$ let through during this test was below the calculated withstand level. There was no visible damage to any of the conductors. Video footage showed little activity, with minor movement of the conductors. All the conductors passed the dielectric test.
TEST #: 8B

Purpose: Verification of Short-Circuit Protection - Medium Level

Description: 1 foot of 18 AWG type MTW wire per phase
3 phase bolted fault on line side of motor starter.
Protective device is a 30 amp Class CC, J, and T umbrella fuse.

![Diagram of test setup]

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage: 484 Vac</td>
<td>Phase</td>
</tr>
<tr>
<td>Current: 10.9 KA</td>
<td>A</td>
</tr>
<tr>
<td>pf: 76 %</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>

Results:
Visual: No Visual Damage on any Phase
Dielectric: Passed
Test #: 8B

Test 8B:

Maximum Clearing $I^2t = 8,120 \text{ A}^2\text{s}$

Maximum Peak Current $I_p = 3,740 \text{ Amps}$

Maximum clearing $I^2t$ let through during this test was above the calculated withstand level. There was no visible damage to any of the conductors. Video footage showed little activity, with minor movement of the conductors. All the conductors passed the dielectric test.
### TEST #:
8C

**Purpose:** Verification of Short-Circuit Protection - High Level

**Description:**
1 foot of 18 AWG type MTW wire per phase
3 phase bolted fault on line side of motor starter.
Protective device is a 30 amp Class CC, J, and T umbrella fuse.

#### Test Parameters

<table>
<thead>
<tr>
<th>Voltage: 482 Vac</th>
<th>Current: 53.6 KA</th>
<th>pf: 13.5 %</th>
</tr>
</thead>
</table>

#### TEST DATA:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Clearing (I_2t) x 10³</th>
<th>(I_p) x 10³</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4.21</td>
<td>3.75</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>B</td>
<td>7.9</td>
<td>5.63</td>
<td>Fuse Opened</td>
</tr>
<tr>
<td>C</td>
<td>2.3</td>
<td>2.52</td>
<td>Fuse Did Not Open</td>
</tr>
</tbody>
</table>

#### Results:

**Visual:** No Visual Damage on any Phase
**Dielectric:** Passed
Test #: 8C

Test 8C:

Maximum Clearing $I^2t$ = 7,900 $A^2s$
Maximum Peak Current $I_p$ = 5,630 Amps

Maximum clearing $I^2t$ let through during this test was above the calculated withstand level. There was no visible damage to any of the conductors. Video footage showed little activity, with minor movement of the conductors. All the conductors passed the dielectric test.
TEST #: 9B

Purpose: Verification of Short-Circuit Protection - Medium Level for Various Grounding Schemes

Description: 10 inches of 18 AWG type MTW 1 phase bolted fault on line side of motor starter. Protective device is a 30 amp Class CC, J, and T umbrella fuse.

Test Parameters

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage: 484 Vac</td>
<td>Phase</td>
</tr>
<tr>
<td>Current: 10.9 KA</td>
<td>A</td>
</tr>
<tr>
<td>pf: 76 %</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>

Results:

Visual: No Visual Damage
Dielectric: Passed
Test #: 9B

Test 9B:

Maximum Clearing $I^2t = 6,690 \text{ A}^2\text{s}$
Maximum Peak Current $I_p = 2,830 \text{ Amps}$

Maximum clearing $I^2t$ let through during this test was below the calculated withstand level. Video footage showed little activity, with minor movement of the conductor. The conductor passed the dielectric test.
TEST #: 9C

Purpose: Verification of Short-Circuit Protection - High Level for Various Grounding Schemes

Description: 10 inches of 18 AWG type MTW
1 phase bolted fault on line side of motor starter.
Protective device is a 30 amp Class CC, J, and T umbrella fuse.

<table>
<thead>
<tr>
<th>Test Parameters</th>
<th>TEST DATA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage: 484 Vac</td>
<td>Phase</td>
</tr>
<tr>
<td>Current: 53.6 KA</td>
<td>A</td>
</tr>
<tr>
<td>pf: 13.5 %</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>

Results:
Visual: No Visual Damage
Dielectric: Passed
Test #: 9C

Test 9C:

Maximum Clearing $I^2t = 6,130 \text{ A}^2\text{s}$

Maximum Peak Current $I_p = 3,810 \text{ Amps}$

Maximum clearing $I^2t$ let through during this test was below the calculated withstand level. Video footage showed little activity, with minor movement of the conductor. The conductor passed the dielectric test.
REPORT BY:

GEORGE R. GOLDING
Senior Project Engineer
Conformity Assessment Services

REVIEWED BY:

DAVID A. DINI
Senior Research Engineer
Research Department
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NFPA, Quincy, MA


ANNEX A

The following outlines the work and recommendations conducted by the NFPA79 committee.

The new exceptions in NFPA79, prior to the ROP meetings, would read:

13.6 Conductor sizing.

Conductors shall not be smaller than:

13.6.1 Power circuits  No. 14

Exception 1: No. 16 shall be permitted where applied as follows:
   a) For non-motor power circuits of 8 amperes or less where protected in accordance with
      Clause 7 and with Class CC fuses rated at not more than 10 amperes, or
   b) For motor loads with a full load ampacity of 8 amperes or less, where protected with
      Class CC fuses at not more than 250% of full load ampacity, and Class 10 overload
      protection per UL 508, or
   c) For motor loads with a full load ampacity of 5.5 amperes or less, where protected with
      Class CC fuses at not more than 250% of full load ampacity, and Class 20 overload
      protection per UL 508, and
   d) Where part of a jacketed multiconductor cable assembly or flexible cord, or as individual
      conductors when used in a cabinet or enclosure.

Exception 2: No. 18 shall be permitted where applied as follows:
   a) For non-motor power circuits of 5.6 amperes or less where protected in accordance with
      Clause 7 and with Class CC fuses rated at not more than 7 amperes, or
   b) For motor loads with a full load ampacity of 5 amperes or less, where protected with
      Class CC fuses at not more than 250% of full load ampacity, and Class 10 overload
      protection per UL 508, or
   c) For motor loads with a full load ampacity of 3.5 amperes or less, where protected with
      Class CC fuses at not more than 250% of full load ampacity, and Class 20 overload
      protection per UL 508, and
   d) Where part of a jacketed multiconductor cable assembly or flexible cord, or as individual
      conductors in a cabinet or enclosure.

Substantiation: The present parts of NFPA 79-1997 15.3 were re-identified to match the
numbering sequence.

These proposed new exceptions permit the use of 16/18 AWG conductors, and factory assembled
16/18 AWG multi-conductor cables, in small motor branch circuit applications. This exception
will also allow a common, desirable, practice unutilized on small horsepower, multi-motor machinery.

Wire sizes of 0.75 mm$^2$ and 1 mm$^2$ are commonly applied where the load currents are very small in applications based upon the IEC 60204-1. Wire sizes of 0.75 mm$^2$ and 1 mm$^2$ have an ampacity similar to 18 AWG and 16 AWG wire respectively.

Conservative based calculations were evaluated relative to short circuit and overload concerns. After considering many variables, it was determined that a similar use of 18 AWG and 16 AWG wire would constitute a reasonable approach and give application guidance to a present practices under the detailed requirements as proposed in 13.6.1 Exceptions 1 and 2.

In order to limit exposure to physical damage the use of these conductors would be limited to multiconductor cables, and to individual conductors when used in a cabinet or enclosure.

The following information is provided to detail the evaluation process.

<table>
<thead>
<tr>
<th>16 AWG Data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time</strong></td>
</tr>
<tr>
<td>.004</td>
</tr>
<tr>
<td>.008</td>
</tr>
<tr>
<td>.0167</td>
</tr>
<tr>
<td>0.1</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>30</td>
</tr>
</tbody>
</table>

$^1$ Data based upon ICEA (Insulated Cable Engineers Association) insulation Damage Formulas

<table>
<thead>
<tr>
<th>UL508 Test Points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Class</strong></td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
</tbody>
</table>

$^2$ Value shown in table is based upon 6 X the limited current specified in the proposed 13.6.1

<table>
<thead>
<tr>
<th>UL 248 Test Point @ 50KA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time (sec)</strong></td>
</tr>
<tr>
<td>.004</td>
</tr>
</tbody>
</table>

$^3$ Current Level Extrapolated from UL T$^2$ limit by dividing out time (.004)
### 18 AWG Data

<table>
<thead>
<tr>
<th>Time</th>
<th>Area (CM)</th>
<th>Isc (Amps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.004</td>
<td>1620</td>
<td>1356</td>
</tr>
<tr>
<td>.008</td>
<td>1620</td>
<td>959</td>
</tr>
<tr>
<td>.0167</td>
<td>1620</td>
<td>664</td>
</tr>
<tr>
<td>0.1</td>
<td>1620</td>
<td>271</td>
</tr>
<tr>
<td>1</td>
<td>1620</td>
<td>86</td>
</tr>
<tr>
<td>5</td>
<td>1620</td>
<td>38</td>
</tr>
<tr>
<td>10</td>
<td>1620</td>
<td>27</td>
</tr>
<tr>
<td>20</td>
<td>1620</td>
<td>19</td>
</tr>
<tr>
<td>30</td>
<td>1620</td>
<td>16</td>
</tr>
</tbody>
</table>

*a* Data based upon ICEA (Insulated Cable Engineers Association) insulation Damage Damage Formulas

### UL508 Test Points

<table>
<thead>
<tr>
<th>Class</th>
<th>Current @ 600%</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>20</td>
<td>21</td>
</tr>
</tbody>
</table>

*b* Value shown in table is based upon 6 X the limited current specified in the proposed 13.6.1

### UL 248 Test Point @ 50KA

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>Max Current Allowed (Amps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.004</td>
<td>707 *</td>
</tr>
</tbody>
</table>

*c* Current Level Extrapolated from UL I*t* limit by dividing out time (.004)

The Insulated Cable Engineers Association (ICEA) tables for insulation damage was used to create the worst case condition for the wire. The formula as developed by ICEA is based upon an adiabatic process where all the heat will be contained within the wire (conductor). This does not take into account the heat bleed off into the terminations and components. As a result, a damage curve was generated for thermoplastic insulation at 150 deg. C. This was the worst case of the three main types evaluated by ICEA which include:

- thermoplastic (150 deg. C)
- rubber, paper, varnished cloth (200 deg. C)
- crosslinked polyethylene & ethylene propylene rubber (250 deg. C)

This damage curve then supplied the worst possible condition to which the wire (conductor) would be subjected.

After laying the groundwork for wire damage, various overcurrent protective devices were reviewed.

Current limiting devices were decided upon in order to cover the variety of fault current conditions that could apply to a machine. Upon examination of Underwriters Laboratories (UL) “General Information for Electrical Equipment” (White Book), let-through I^2*T of various current
limiting branch circuit fuses were considered. Selecting Class CC fuses and protecting 16 and 18 AWG wire according to UL limits allowed a maximum let-through current to be determined.

Next, motor controller characteristics were explored. Based upon the information provided in UL508, test points were plotted on the time current curve to evaluate the performance of the overload device under long term heating conditions. (Note: Under these conditions there is a high probability the heat will be dissipated from the conductor into the terminals and associated components).

Guidelines were selected for proper fuse sizing and maximum full load current rating of motors based upon the above data. The criteria for determining the maximum full load current rating was (1) the maximum current value the conductor could handle for the set amount of time (10 sec for class 10, etc.), (2) add 10% for a conservative heat bleed off factor, and (3) divide by 6 per the requirements of UL 508. This then derived the FLC value.
Following the NFPA79 ROP meetings the wording of this section was revised to read:

13.6 Conductor sizing.

Conductors shall not be smaller than:

13.6.1 Power circuits  No. 14

Exception 1: No. 16 shall be permitted where applied as follows:

a) For non-motor power circuits of 8 amperes or less where protected in accordance with Clause 7 and with branch circuit rated circuit breakers listed for use with No.16 wire or Class CC,J, or T fuses rated at not more than 10 amperes, or

b) For motor loads with a full load ampacity of 8 amperes or less, where protected in accordance with Clause 7 and with branch circuit rated circuit breakers listed for use with No.16 wire or Class CC,J, or T fuses, and Class 10 overload protection per UL 508, or

c) For motor loads with a full load ampacity of 5.5 amperes or less where protected in accordance with Clause 7 and with branch circuit rated circuit breakers listed for use
with No.16 wire or Class CC, J, or T fuses, and Class 20 overload protection per UL 508, and

d) Where part of a jacketed multiconductor cable assembly or flexible cord, or as individual conductors when used in a cabinet or enclosure.

Exception 2: No. 18 shall be permitted where applied as follows:

a) For non-motor power circuits of 5.6 amperes or where protected in accordance with Clause 7 and with branch circuit rated circuit breakers listed for use with No.18 wire or Class CC, J, or T fuses rated at not more than 7 amperes, or

b) For motor loads with a full load ampacity of 5 amperes or less, where protected in accordance with Clause 7 and with branch circuit rated circuit breakers listed for use with No.18 wire or Class CC, J, or T fuses, and Class 10 overload protection per UL 508, or

c) For motor loads with a full load ampacity of 3.5 amperes or less, where protected in accordance with Clause 7 and with branch circuit rated circuit breakers listed for use with No.18 wire or Class CC, J, or T fuses, and Class 20 overload protection per UL 508, and

d) Where part of a jacketed multiconductor cable assembly or flexible cord, or as individual conductors in a cabinet or enclosure
The following table shows the data for the umbrella fuses used in this testing:

<table>
<thead>
<tr>
<th>Fuse Type</th>
<th>Test Current (Amps x 10³)</th>
<th>Power Factor</th>
<th>UL/CSA/ANCE 248 Clearing I²t (A²sec x 10³)</th>
<th>UL/CSA/ANCE 248 Ip Umbrella Limit (Amps x 10³)</th>
<th>Peak Let Through (Ip) (Amps x 10³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20A Umbrella #1</td>
<td>52</td>
<td>.15</td>
<td>2</td>
<td>3.47</td>
<td>3</td>
</tr>
<tr>
<td>20A Umbrella #2</td>
<td>52</td>
<td>.15</td>
<td>2</td>
<td>4.17</td>
<td>3</td>
</tr>
<tr>
<td>20A Umbrella #3</td>
<td>52</td>
<td>.15</td>
<td>2</td>
<td>4.36</td>
<td>3</td>
</tr>
<tr>
<td>30A Umbrella #1</td>
<td>52</td>
<td>.15</td>
<td>7</td>
<td>13.6</td>
<td>6</td>
</tr>
<tr>
<td>30A Umbrella #2</td>
<td>52</td>
<td>.15</td>
<td>7</td>
<td>14.4</td>
<td>6</td>
</tr>
<tr>
<td>30A Umbrella #3</td>
<td>52</td>
<td>.15</td>
<td>7</td>
<td>14.4</td>
<td>6</td>
</tr>
</tbody>
</table>
1 foot, 480V, 3φ, 10kA Test

- Pass: Save wire for dielectric withstand test
- Fail: 4 foot, 480V, 3φ, 10kA Test
  - Pass: Save wire for dielectric withstand test
  - Fail: 1 foot, 600V, 3φ, 10kA Test
    - Pass: Save wire for dielectric withstand test
    - Fail: 100 foot, 480V, 3φ, 10kA Test
      - Pass: Save wire for dielectric withstand test
      - Fail: 1 foot, 480V, 1φ, Single Pole Test
        - Pass: Save wire for dielectric withstand test
        - Fail: 100 foot, 480V, 3φ, 10kA Test
          - Pass: Save wire for dielectric withstand test
          - Fail: 1 foot, 480V, 1φ, Single Pole Test
            - Pass: Save wire for dielectric withstand test
            - Fail: Go To 5kA Testing
5 kA Testing Sequence

Pass
Save wire for dielectric withstand test

1 foot, 480V, 3φ, 5kA Test

Fail

Save wire for dielectric withstand test

1 foot, 600V, 3φ, 5kA Test

Pass

Fail

END

Overload Testing
Overload Test Sequence

Overload Test

Motor
- Test Current 15A, 1φ
  - Pass: Save wire for dielectric withstand test
  - Fail: Test Current 600%, 1φ
    - Pass: Conduct Dielectric Withstand Testing on wires that passed
    - Fail: Save wire for dielectric withstand test

Non-motor
- Test Current 15A, 1φ
  - Pass: Save wire for dielectric withstand test
  - Fail: Test Current 600%, 1φ
    - Pass: Save wire for dielectric withstand test
    - Fail: Save wire for dielectric withstand test
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