Insulation Resistance Calculations of Airfield Lighting Circuits

Joseph Vigilante, PE and Charles Dennie, PE
Presentation Agenda

• Driving Factors
• Cable insulation resistance (IR) background
• FAA IR guideline recommendations
• Formula development
• Airfield lighting circuit calculations
• Presentation summary
• Why calculate circuit IR during design
• Open Q&A
Objective

To initiate a practice of analyzing AFL circuits during design utilizing both load and insulation resistance calculations to provide a minimum obtainable value for construction verification and maintenance practices.
Driving factors

- Circuit load is only half the story
- Disappointing field results
- Specifying a “given” is scary
Insulation resistance background

• IR measured value
• Factor of applied voltage and leakage current
• Understand characteristics of leakage current
Anatomy of insulation current flow

- Capacitance charging currents, $C$
- Absorption current, $AC$
- Conduction current, $CC$
Anatomy of insulation current flow
Types of insulation resistance testing

Short-time/spot reading

- Circuit A: 100 MEGOHMS
- Circuit B: 50 MEGOHMS

VALUES CHARTED

TIME (MONTHS) →

MEGOHMS

0 50 100

TIME →

60 sec

VALUE READ AND RECORDED
Types of insulation resistance testing

Time-resistance method

- **0 TIME**
- **10 Min**
- **MEGOHMS**

**INSULATION PROBABLY OK**

**INSULATION SUSPECT**

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Testing airfield lighting circuits

- AC 150/5340-30G, *Design & Installation Details for Airport Visual Aids* - Chapter 12, Equipment & Material, Section 13, Testing
  - 50MΩ Non-grounded series circuits
  - FAA-C-1391, *Installation & Splicing of Underground Cable*
Resistance values for maintenance

- AC 150/5340-26B, *Maintenance of Airport Visual Aid Facilities*
  - Suggested minimum maintenance values
    - 10,000 ft. or less - **50MΩ**
    - 10,001 ft. – 20,000 ft. - **40MΩ**
    - 20,001+ ft. - **30MΩ**
FAA-C-1391 Installation & Splicing of Underground Cables

• Spot Test – take readings no less than 1 minute after readings stabilized
• Cable IR values reduced to the length
• Circuit IR reduced due to parallel summation
Airfield circuit anatomy

Three circuit components

• L-823 cable connectors
• L-824 series lighting cable
• L-830 isolation transformers
Series circuit insulation resistance

Constant current series lighting circuit

- Combine similar components to reduce circuit
- Parallel summation from conductor to ground

\[
IR = \frac{1}{\frac{1}{R_n} + \frac{1}{R_c} + \frac{1}{R_t}} \quad M\Omega
\]
L-824 airfield cable

AC 150/5345-7E, Specification for L-824 Under ground Electrical Cable for Airport Lighting Circuits

- Table 1, Test #9 > ICEA S-96-659, Section 7.11.2
- Corresponding to IR Constant 50,000 MΩ @ 1000 ft. @ 60°F
Cable expression

The insulation resistance of cable for a given length is expressed by the following formula:

\[ RC = K \times \log \left( \frac{D}{d} \right) \times \left( \frac{1000}{L} \right) \]

Where:
- RC = Insulation resistance in MΩ of cable
- K = Specific IR in MΩ @ 1000ft @ 60° F of insulation
- D = Outer diameter of insulation
- d = Outer diameter of bare copper wire
- L = Length of airfield cable in feet

Value of K for EPR insulation = 50,000 Megohms
Cable expression

**FAA L-824 TYPE B AIRFIELD LIGHTING CABLE**

<table>
<thead>
<tr>
<th>Conductor Size</th>
<th>Stranding</th>
<th>Insulation Thickness (mils mm)</th>
<th>Jacket Thickness (mils mm)</th>
<th>Approximate Cable O.D. (In mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 AWG</td>
<td>7</td>
<td>90 (2.3)</td>
<td>30 (0.76)</td>
<td>0.420 (10.7)</td>
</tr>
<tr>
<td>6 AWG</td>
<td>7</td>
<td>90 (2.3)</td>
<td>30 (0.76)</td>
<td>0.460 (11.7)</td>
</tr>
<tr>
<td>4 AWG</td>
<td>7</td>
<td>90 (2.3)</td>
<td>30 (0.76)</td>
<td>0.505 (12.8)</td>
</tr>
</tbody>
</table>

**Diagram:**
- **CONDUCTOR**
- **JACKET**
- **INSULATION**

OD = 10.7 mm
D = 9.18 mm
d = 4.58 mm
Cable expression

\[ RC = K \times \log \left( \frac{D}{d} \right) \times \left( \frac{1000}{L} \right) \]

\[ RC = 50,000 \times \log \left( \frac{9.18}{4.58} \right) \times \left( \frac{1,000}{L} \right) \]

\[ RC = 15,098,860 / L \text{ M}\Omega \]
FAA minimum IR value

L-823 cable connectors

AC 150/5345-26D, FAA Specification for L-823 Plug and Receptacle, Cable Connectors

- Section 5.1 – Type I Connectors 75,000 MΩ
Connector expression

The insulation resistance of L-823 connector splices is expressed by the following formula:

\[ RN = \frac{Rc}{Nc} \]

*Where:*
- \( RN \) = Insulation resistance in Megohms of all connectors
- \( Rc \) = IR of an individual L-823 connector splice
- \( Nc \) = Quantity of L-823 connector splices
Connector expression

\[ Rc = 75,000 \, M\Omega \]

\[ RN = \frac{75,000}{N_c} \]
FAA minimum IR value

**L-830 isolation transformers**

*AC 150/5345-47C, Specification for Series to Series Isolation Transformers for Airport Lighting Systems*

- Table 3 Insulation Resistance 7,500 MΩ

<table>
<thead>
<tr>
<th>Winding under Test</th>
<th>Voltage Applied (kV DC)</th>
<th>Minimum Insulation Resistance (Megohms)</th>
<th>Maximum Leakage Current (Micro amps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot/Cold Primary for transformers up to 150 W</td>
<td>15.0</td>
<td>7500</td>
<td>2.0</td>
</tr>
<tr>
<td>Hot/Cold Secondary for transformers up to 150 W</td>
<td>5.0</td>
<td>2500</td>
<td>2.0</td>
</tr>
<tr>
<td>Hot/Cold Primary for transformers over 150 W</td>
<td>15.0</td>
<td>3000</td>
<td>5</td>
</tr>
<tr>
<td>Hot/Cold Secondary for transformers over 150 W</td>
<td>5.0</td>
<td>1000</td>
<td>5</td>
</tr>
</tbody>
</table>
The insulation resistance of L-830 isolation transformers is expressed by the following formula:

\[ RT = \frac{Rt}{Nt} \]

*Where:*
- \( RT \) = Insulation resistance in Megohms of all transformers
- \( Rt \) = IR of an individual L-830 isolation transformers
- \( Nt \) = Quantity of L-830 isolation transformers
Isolation transformer expression

\[
R_t = 7,500 \ \text{M}\Omega
\]

\[
RT = \frac{7,500}{N_t}
\]
Root IR formula

\[ \frac{1}{IR} = \frac{1}{RC} + \frac{1}{RN} + \frac{1}{RT} \]

\[ IR = \frac{1}{\frac{L}{15,098,860} + \frac{Nc}{75,000} + \frac{Nt}{7,500}} \quad M\Omega \]
Developing IR calculation formula

\[
\frac{1}{IR_{section\ 1}} = \frac{L}{15,098,860} + \frac{Nc}{75,000} \quad \text{MΩ}^{-1}
\]
Developing IR calculation formula

\[
\frac{1}{IR_{section\ 2}} = \frac{L}{15,098,860} + \frac{N_c}{75,000} + \frac{N_t}{7,500} \quad M\Omega^{-1}
\]
Developing IR calculation formula

\[
\frac{1}{IR_{section\ 3}} = \frac{L}{15,098,860} + \frac{Nc}{75,000} \quad M\Omega^{-1}
\]
Developing IR calculation formula

Section 1

L-823 Connector

Insulation Resistance to Earth

Section 2

L-830 Isolation Transformer

Section 3

L-824 Series Lighting Cable

Earth Ground

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Developing IR calculation formula

\[ IR_{total} = \frac{1}{IR_{section\ 1}} + \frac{1}{IR_{section\ 2}} + \frac{1}{IR_{section\ 3}} \quad M\Omega \]
Sample calculation

**Section 1:**
- Cable = 4,000 feet
- Connectors = 4
- Isolation XFMRs = 0

**Section 2:**
- Cable = 37,500 feet
- Connectors = 400
- Isolation XFMRs = 185

**Section 3:**
- Cable = 10,500 feet
- Connectors = 14
- Isolation XFMRs = 0

**Load Calc:**
- Cable = 52,000 feet
- Fixtures = 140
- **Circuit Load = 9.34kW**
Sample calculation - section one

\[
\frac{1}{IR_{section\ 1}} = \frac{4000}{15,098,860} + \frac{4}{75,000}
\]

\[IRs1 = 3,142 \ \text{M} \Omega\]
Sample calculation – section two

\[
\frac{1}{IR_{section \ 2}} = \frac{37,500}{15,098,860} + \frac{400}{75,000} + \frac{185}{7,500}
\]

\[
IR_{s2} = 30.8 \text{ M}\Omega
\]
Sample calculation – section three

\[
\frac{1}{IR_{\text{section} \ 3}} = \frac{10,500}{15,098,860} + \frac{14}{75,000}
\]

\[IR_{s3} = 1,134 \ \text{M}\Omega\]
Calculation example

\[
\begin{align*}
\frac{1}{IR_{section\ 1}} &= \frac{4000}{15,098,860} + \frac{4}{75,000} = .00031825\ M\Omega^{-1} \\
\frac{1}{IR_{section\ 2}} &= \frac{37,500}{15,098,860} + \frac{400}{75,000} + \frac{185}{7,500} = .032408\ M\Omega^{-1} \\
\frac{1}{IR_{section\ 3}} &= \frac{10,500}{15,098,860} + \frac{14}{75,000} = .0008828\ M\Omega^{-1}
\end{align*}
\]

\textit{IR total} = 29.7 M\Omega

AC 150/5340-30G : 50 M\Omega  \\
AC 150/5340-26B : 30 M\Omega  \\
Circuit design should be evaluated
Modified circuit

Section 1:
Cable = 6,000 feet
Connectors = 6
Isolation XFMRs = 0

Section 2:
Cable = 9000 feet
Connectors = 120
Isolation XFMRs = 52

Section 3:
Cable = 9,500 feet
Connectors = 14
Isolation XFMRs = 0

Load Calc:
Cable = 24,500 feet
Fixtures = 52
Circuit Load = 3.03kW

\[
IR = \frac{1}{\left( \frac{1}{2,095} + \frac{1}{110} + \frac{1}{1,226} \right)} \\
IR = 95.9 \, \text{M}\Omega
\]
Presentation summary

- High initial field value – not necessarily indicate good circuit
- Standards provide recommended values - reductions are allowed
- Utilize parallel summation to calculate IR
- Check & verify transformer sizes and cable types for IR values
- Minimum allowable component values – higher factory test values
- Establish field test baseline and track results
Why calculate circuit IR during design?

- Mathematical model – eliminate unknown variables
- Good engineering practice – circuit load and insulation resistance calculations
- Establish the design baseline – expected results
- Helps understand the dynamics of the circuit & environment which it lives in
Open Q & A

Joe Vigilante, PE
jvigilante@burns-group.com / 215-979-7700, ext 7732

Chuck Dennie, PE, LC
cdennie@burns-group.com / 215-979-7700, ext 7762