Performing an arc flash analysis for a new or existing electrical distribution system can be a daunting task. Efforts have been made to limit the required scope of the evaluation, but portions of a system are often overlooked due to faulty assumptions. Overlooked areas may have dangerous incident energy levels. The scope of the evaluation may be reduced to a manageable size, but any assumption must be carefully scrutinized to guarantee an accurate determination of the arc flash hazard. This article discusses a method for generalizing the arc flash calculations for select areas of a power distribution system. A specific application of this general method is then presented.

Background

Defining the Scope of Arc Flash Analysis

The NFPA 70E Standard for Electrical Safety in the Workplace, 2004 edition references the equations from IEEE Standard 1584–2002 as a method for quantifying the incident energy available during an arc flash event. The equations in IEEE Standard 1584–2002 are applicable for a voltage range of 208–15,000 V, three-phase and for a range of bolted fault current magnitudes between 700–106,000 A. In addition, IEEE Standard 1584-2002 states that “equipment below 240 V need not be considered unless it involves at least one 125 kVA or larger low-impedance transformer in its immediate power supply [2].

By H. Wallace Tinsley III, Michael Hodder, & Aidan M. Graham
Equipment locations that are “likely to require examination, adjustment, servicing, or maintenance while energized should be field marked to warn qualified persons of potential electric arc flash hazards” [4]. Typically, such equipment includes switchboards, panelboards, industrial control panels, and motor control centers (MCCs). Other work locations such as bus ducts, splitters, and disconnect switches should be considered if energized parts above 50 V may be exposed by qualified personnel. (Unqualified personnel should never be permitted to access energized equipment.)

**Building a Software Model for Arc Flash Analysis**

A commercial software package is usually the most efficient and most accurate way to calculate the potential incident energy throughout a power system. When constructing a software model for arc flash analysis, it is important to include an accurate fault contribution model (utility sources and rotating machines), a complete impedance model (transformers, cables, and bus ducts), and a complete overcurrent protection model (fuses, relays, and circuit breakers).

For each location within the power system, the worst-case model will be represented by a unique operating configuration. What is often overlooked is that a lower magnitude of fault current typically results in a longer operating time of the upstream overcurrent protection, which may then result in a higher level of incident energy and a greater arc flash hazard. Therefore, the power system included in the software model must be represented as accurately as possible.

**Defining the Problem**

The situation just described presents a logistical challenge when attempting to determine the arc flash hazard for locations downstream of low-voltage distribution equipment such as MCCs, panelboards, and bus ducts. If each of the individual circuits is represented, the software model can become extremely cumbersome and extensive. For example, a model extensive enough to provide meaningful arc flash calculations for a bus duct requires the modeling of each individual bus plug, each section of bus duct between the plugs, and the cables from the duct to the load. Even when current-limiting devices protect these locations, there is no guarantee (without knowledge of fault levels) that these devices will operate in the current-limiting region of the tripping characteristic. Some circuits may be right-ly eliminated from the model, but these circuits cannot be identified until the available fault current has been determined for the distribution location (bus duct, MCC, or panelboard.)

**Accurate Fault Calculations**

Because the arc flash calculations are used to prescribe protective equipment for qualified workers, great care must be taken to ensure that the contribution model is able to represent the worst-case scenario in terms of the arc flash hazard.

The available fault currents calculated throughout a power system are determined by the source contributions and are limited by the system impedances between these contributing sources and the location of a fault event.

The primary source of fault current in a typical short-circuit model is the utility or the primary generation supplying power to a facility. When a facility is powered by a utility source, the available fault current information is often obtained as the maximum available current. IEEE Standard 1584–2002 requires the consideration of “the maximum and the minimum available short-circuit currents” [2].

When constructing a model for the purpose of short-circuit analysis and protective device coordination, the fault contribution model is often based on conservatively high calculations of current magnitudes such as utility design values. For example, the utility contribution may be determined by the maximum let-through current of the largest (kVA) transformer with the lowest impedance that the utility company is permitted to install. This information may provide conservative results for evaluation of interrupting ratings, but it does not provide complete or adequate results for the arc flash calculations.

Other contributing sources in a power system include local generators and motors (rotating machines.) In the arc flash model, these contributions must be considered in the appropriate configurations to represent the maximum and minimum available fault current magnitude for each location in the model system. For example, a total maximum contribution may be represented by the maximum utility (source) contribution and the system motors running at full-load current prior to the simulation of the bolted fault. Similarly, the total minimum contribution may be represented by the minimum utility or generator contribution with the minimum number of motors (rotating loads) in operation. Additionally, rotating machine contributions, unlike the utility contribution, will decay rapidly and may not be present for the entire duration of the arc flash event. The short-circuit contribution of an induction motor should only be considered for the first three to five cycles (0.05–0.0833 s) of the event duration. Should the arc flash event last for a time period greater than 0.05–0.0833 s, the modeling software should be able to take this into consideration.

Obtained from a complete contribution model, the three-phase bolted fault current values provide the starting point for accurate arc flash calculations at each system location. Bolted fault current magnitudes are calculated at each bus or node location and represent the sum total of all contributions. In the event of a low-voltage (<1,000 V) arc flash incident, the current flowing into the fault is not equal to the bolted fault current represented by the short-circuit model. This arcing fault current is calculated using IEEE Standard 1584–2002 equations (1) and (2), presented below, and is based on the portion of the calculated bolted fault current that flows through the upstream overcurrent protective device [2].

For applications with system voltages under 1,000 V, solve the equation

\[
l_g\, I_g = K + 0.662\, l_g \, l_{bf} + 0.0966\, V + 0.000526\, G + 0.5588\, V(l_g\, l_{bf}) - 0.00304\, G(l_g\, l_{bf})
\]  

(1)
where

\[ I_a = \log_{10} I_a \]

\[ K = \begin{cases} -0.153 & \text{for open configurations} \\ -0.097 & \text{for box configurations} \end{cases} \]

\[ I_{bf} = \text{bolted fault current for three-phase faults (symmetrical rms) (kA)} \]

\[ V = \text{system voltage (kV)} \]

\[ G = \text{gap between conductors (mm)} \]

For applications with system voltages from 1,000 V up to and including 15,000 V, solve the equation

\[ I_a = 0.00402 + 0.983 I_{bf} \]  \hspace{1cm} (2)

For system voltages greater than 1,000 V, there is no distinction between open and box configurations. Also, for system voltages above 15,000 V, the arcing fault current is considered equal to the bolted fault current.

Table 1 shows that the calculated bolted fault current will be significantly reduced by the impedance of the arc when the system voltage is less than 1,000 V.

IEEE Standard 1584–2002 also requires that the arcing fault magnitude be further reduced to 85% of the calculated value [2]. A corresponding clearing time is selected for both the 85% value and the 100% value. This is done because it is very difficult to accurately predict the arcing current, and a small change in current could result in a significant change in clearing time.

To illustrate this fact, the time-current curve of a typical 480-V, 200-A thermal-magnetic molded-case circuit breaker (MCCB) is shown in Figure 1. Notice the change in breaker clearing time when transitioning from the instantaneous (magnetic) portion of the curve to the long time (thermal) portion of the curve. This “threshold point” is defined as the value of current where the protective device transitions from fast to slow clearing time. For MCCBs or motor circuit protectors (MCPs), the threshold point is where instantaneous tripping may not occur. For current-limiting fuses (CLFs), the threshold point is the minimum current that will cause current-limiting action.

As illustrated in Figure 1, when the fault current is reduced to a value just below this threshold point, the maximum clearing time is increased from roughly 0.021 to 2.1 s. One can easily see that decreasing the fault current will typically increase the clearing time of the upstream protective device, which often results in higher calculated incident energy values. This makes accurate fault current calculations essential when performing an arc flash hazard analysis.

### TABLE 1. SAMPLE OF BOLTED VERSUS ARCING FAULT CURRENTS, BY VOLTAGE LEVEL.

<table>
<thead>
<tr>
<th>Voltage (kV)</th>
<th>Bolted Fault Current (kA)</th>
<th>Arcing Fault Current* (kA)</th>
<th>% of Bolted Fault Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.208</td>
<td>10.00</td>
<td>4.35</td>
<td>43%</td>
</tr>
<tr>
<td></td>
<td>20.00</td>
<td>7.08</td>
<td>35%</td>
</tr>
<tr>
<td></td>
<td>30.00</td>
<td>9.41</td>
<td>31%</td>
</tr>
<tr>
<td></td>
<td>40.00</td>
<td>11.51</td>
<td>29%</td>
</tr>
<tr>
<td></td>
<td>50.00</td>
<td>13.47</td>
<td>27%</td>
</tr>
<tr>
<td>0.480</td>
<td>10.00</td>
<td>6.56</td>
<td>66%</td>
</tr>
<tr>
<td></td>
<td>20.00</td>
<td>11.85</td>
<td>59%</td>
</tr>
<tr>
<td></td>
<td>30.00</td>
<td>16.76</td>
<td>56%</td>
</tr>
<tr>
<td></td>
<td>40.00</td>
<td>21.43</td>
<td>54%</td>
</tr>
<tr>
<td></td>
<td>50.00</td>
<td>25.93</td>
<td>52%</td>
</tr>
<tr>
<td>0.600</td>
<td>10.00</td>
<td>7.86</td>
<td>79%</td>
</tr>
<tr>
<td></td>
<td>20.00</td>
<td>14.88</td>
<td>74%</td>
</tr>
<tr>
<td></td>
<td>30.00</td>
<td>21.62</td>
<td>72%</td>
</tr>
<tr>
<td></td>
<td>40.00</td>
<td>28.19</td>
<td>70%</td>
</tr>
<tr>
<td></td>
<td>50.00</td>
<td>34.62</td>
<td>69%</td>
</tr>
</tbody>
</table>
| \( \geq 1.00 \)
up to 15.00  | 10.00                    | 9.71                      | 97%                      |
| 15.00       | 20.00                    | 19.18                     | 96%                      |
|             | 30.00                    | 28.58                     | 95%                      |
|             | 40.00                    | 37.92                     | 95%                      |
|             | 50.00                    | 47.22                     | 94%                      |

*Arcing fault current was calculated based on the equations given in IEEE Standard 1584-2004a. For the low-voltage calculations, a box configuration was assumed with a gap between conductors of 25 mm; the system is considered solidly grounded.

Instantaneous pickup point of a typical 200-A MCCB.
A similar characteristic is illustrated for a typical 480-V, 200-A class J fuse in Figure 2. As the fault current is reduced below the threshold point of the fuse, the maximum clearing time increases to a value above 0.01 s.

As illustrated in Figure 2, the clearing time and resulting incident energy are highly dependent on the calculated arcing fault current. Therefore, the power system engineer must evaluate not only the major equipment locations (switchgear, switchboards, panelboards, and MCCs), but all locations downstream where energized work may be performed; this often leads to a very extensive computer model. To decrease the size of the required model (and the associated amount of data collection), some creative generalizations can be made without reducing the accuracy of the resulting calculations.

**Demonstration of the Problem**

**Old Paradigm for Assumptions**

Before considering the applicable generalizations and assumptions, it is instructive to consider the paradigm that is historically associated with a short-circuit analysis and a protective device coordination study. This traditional approach is no longer valid when performing an arc flash analysis.

The arc flash calculations are based on several constant values defined by the physical parameters of the equipment location for which an analysis is performed. The two most important system variables, however, will change according to the system configuration, as represented in the software model. These two variables are the calculated fault current magnitude and the clearing time of the protective device responsible for the isolation of the fault location. When an arc flash incident occurs, the magnitude of the fault current flowing through the arc will determine the clearing time of the overcurrent protection.

Prior to beginning an arc flash analysis, accurate system data must be gathered for incorporation into the software model. When building a short-circuit model for evaluation of equipment interrupting and withstand ratings, assumptions are easily accepted to determine the worst-case scenario. For example, if the length of a conductor is unknown, a conservatively short assumption will yield the highest fault current duty calculation for the device to be evaluated. For arc flash analysis, however, the greatest fault current magnitude may provide the worst-case calculation, or it may result in a dangerously erroneous result because the high magnitude of fault current will lead to the conclusion that a rapid clearing time of the upstream overcurrent protection will occur.

For coordination purposes, the overcurrent protection model may only include the larger adjustable devices associated with a given system location, since most devices 200 A or less have fixed trip curves. However, for the arc flash model, every overcurrent protective device responsible for the reduction of the arc flash hazard—adjustable or not—must be accurately modeled in the system.

**Goals of Arc Flash Analysis**

When performing an arc flash hazard analysis, it is important to consider several goals of the study as well as results. The primary goal is to determine the hazard risk category (HRC) associated with all locations in the distribution system where energized work may be performed. The HRC is required to define the personal protective equipment (PPE) that should be worn when working on or near energized electrical equipment. An arc flash hazard is quantified according to the incident energy (cal/cm²) calculated at a specific working distance for each system location. As summarized in Table 2, NFPA 70E-2004 Table

<table>
<thead>
<tr>
<th>Hazard Risk Category (HRC)</th>
<th>Incident Energy from (cal/cm²)</th>
<th>Incident Energy to (cal/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>&gt;0</td>
<td>&lt;2</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>&lt;4</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>&lt;8</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>&lt;25</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>&lt;40</td>
</tr>
</tbody>
</table>

Current-limiting point of a typical 200-A class J fuse.
130.7(C)(11) defines five HRCs, which correspond to ranges of calculated energy (cal/cm²) [1]. Each of these HRCs is associated with specific requirements for PPE.

The second goal of an arc flash analysis is to determine the ideal settings and current ratings for the overcurrent protective devices in the system. The operating times of the phase overcurrent protective devices are based on arcing current flow and are used to determine the HRC for each location analyzed.

When performing an arc flash hazard analysis, the settings of these overcurrent devices define the magnitude of the downstream hazards. For the maximum reduction of the arc flash hazard, all devices should be configured to provide the most rapid clearing time. This, of course, eliminates the coordination interval required for selective fault clearing, and such a configuration should not be recommended. Considering all of the factors involved, the power systems engineer is required to determine overcurrent protective device settings that provide overcurrent coordination and equipment protection as well as the lowest possible incident energy at all work locations.

Upon the determination of the optimum settings for the overcurrent protection and analysis of the resulting arc flash hazard at each location, the power systems engineer is able to investigate possible solutions to reduce the arc flash hazards. These solutions may include the recommendation of additional or replacement overcurrent protective devices, the implementation of procedures to provide safer access to energized equipment, and/or the installation of solutions that either increase worker distance or decrease protective device clearing time.

Upon the completion of an arc flash analysis, the results of the calculations must be clearly presented. Warning labels, applied to the outside of equipment enclosures, are often considered to be the most effective means of displaying the results of the arc flash analysis for qualified persons. Article 110.16 of the National Electric Code (NEC) 2005 requires industrial and commercial electrical equipment to “be field marked to warn qualified persons of potential electric arc flash hazards” [4]. Specific quantities, ranges, boundaries, and HRCs are not expressly required by the NEC. Many facilities have found that presenting the arc flash hazard warning and listing the HRC on a prominently displayed label enables qualified persons to easily determine the appropriate PPE requirements.

**Current-Limiting Devices and the Arc Hazard**

Current-limiting devices are very important for equipment protection when they operate to prevent equipment damage under a high magnitude fault condition.

Current-limiting protective devices (fuses or circuit breakers) are often recommended as a means of reducing the arc flash hazard. However, care should be taken when such devices are considered as solutions to a hazardous situation. If the arcing fault current magnitude will always be great enough to cause operation in the current-limiting range, then rapid clearing will dramatically reduce the potential exposure to a dangerous amount of incident energy. If, however, under any circumstances, the arcing fault current is not high enough to drive the overcurrent device into the current-limiting range, such devices should not be recommended as a solution to an arc flash hazard. When a fast clearing time is determined on the basis of a calculated arcing fault current magnitude at the physical location of a current-limiting device, it is a common mistake to assume that the device will operate just as quickly when a fault occurs at a protected location further downstream. Instead, the fault current flowing through the current-limiting device will be significantly reduced by the impedance of the cable (often very small in comparison with the ampacity of the equipment bus) supplying individual loads or smaller pieces of distribution equipment. To accurately determine the incident energy and corresponding HRC for the downstream locations, the impedance of the feeder circuit must be considered.

**Solution to the Problem**

To reduce the overall scope of the arc flash hazard analysis, one must limit the required number of calculations. Below is a description of a generalization method developed by the authors to reduce the effort required to provide a comprehensive analysis at a specific location. Similar methods may be applied at other industrial or commercial locations.

**Making Accurate Generalizations**

Using accurate generalizations, an arc flash study can include all equipment locations that are likely to require examination, adjustment, servicing, or maintenance while energized. Using the following steps, this analysis can be performed without the need to model every location:

- **Step 1.** Conduct a detailed analysis from the utility feeder connections down to MCCs, bus ducts, splitters, or panels (600 V or less) fed by overcurrent devices (fuse or trip rating) that are sized at 200 A or larger. Future enhancements of the generalization method may allow an increase above 200 A. Detailed analysis can be accomplished using a commercial software package to develop a model that provides the following for each location studied:
■ bolted fault magnitude and X/R ratio
■ arcing fault magnitude
■ protective device clearing time and duration of the arc flash
■ flash protection boundary
■ incident energy calculated at a working distance (cal/cm²)
■ HRC based on NFPA 70E-2004, Table 130.7(C)(11), (see Table 2) [1].

**Step 2.** Extend the analysis to locations fed from MCCs, bus ducts, splitters, or panels. This can be accomplished by

- using the results from Step 1 in a spreadsheet to calculate the maximum cable length for each feeder size from MCCs, bus ducts, splitters, or panels,
- conducting a site survey to find all feeders that are longer than the maximum cable length in the spreadsheet,
- collecting data for the feeders that exceed the maximum length (including protective device and conductor data), and
- adding these feeders and locations to the model developed in Step 1.

The spreadsheet calculates a conductor size based on the feeder trip or fuse amp rating, which is converted to a conductor size based on

- 80% rated protective equipment (molded case breaker or fuse) 
- copper conductor, 75°C insulation in magnetic conduit.

From the conductor size, the spreadsheet calculates the maximum circuit length, which equates to an impedance. The impedance is used to calculate a fault level at the end of the feeder. The spreadsheet determines a circuit length that will cause the HRC at the MCCs, bus ducts, splitters, or panels to increase at the end of a feeder to the next category or HRC. This is accomplished by comparing the calculated arcing fault at the end of the feeder to the threshold point. The threshold point was previously defined when referring to Figures 1 and 2.

The authors designed a spreadsheet that compares the calculated arcing fault current to the threshold point of the protective device at the line end of the feeder.

- If the fault current at the load end of the feeder is higher than the threshold point, then the HRC at the load end bus location does not increase to the next category.
- If the fault current at the load end of the feeder is lower than the threshold point, then the HRC at the load end bus location may increase to the next category and further analysis is required.

The spreadsheet model uses conservative values for threshold points:

- 50 X trip rating for MCCB trip ratings from 15–225 A
- 20 X trip rating for MCCB trip ratings from 250–600 A
- 20 X trip for MCP trip ratings from 3–1,200 A
- 25 X fuse amp rating for CLF from 15–600 A.

**Applying the Method at an Industrial Facility**

We will illustrate this method using an example from an arc flash hazard analysis study at an industrial location. Step 1 was performed from the utility connection at 27.6 kV down to a total of 280 locations at 600 V or below (MCCs and panels sized at 200 A or larger). In Step 2, a spreadsheet was developed for these 280 locations for protective device types MCCB, MCP, and CLF. The spreadsheet included calculations of the maximum cable length from each of the 280 locations out to a distance where the HRC will not increase to the next category. The maximum cable length (ft) is reported on the spreadsheet for each location called the “bus name,” and was provided for standard ratings of protective devices.

Table 3 shows an example of one of the rows of the spreadsheet. Note that Table 3 shows only a few of the trip ratings included, while the actual spreadsheet included all of the standard trip ratings that would be found in this type of equipment. The table shows maximum cable length for MCCBs with trip units rated from 15–60 A. For the bus name “200 A WIRE TR,” the HRC level will not rise above HRC = 0 as long as a 20-A feeder breaker’s cable distance is less than 160 ft. If there is a 60-A feeder breaker at “200 A WIRE TR,” then the downstream HRC = 0 as long as the cable distance is less than 100 ft.

A site survey was performed to identify the number of subfeeders that exceeded the distances in the

<table>
<thead>
<tr>
<th>Bus Name</th>
<th>Voltage (V)</th>
<th>Bolted Fault (kA)</th>
<th>X/R</th>
<th>HRC</th>
<th>Trip Rating (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 A WIRE TR</td>
<td>600</td>
<td>13.18</td>
<td>1.798</td>
<td>0</td>
<td>140 ft</td>
</tr>
</tbody>
</table>
that there were only 17 small-panel locations where the HRC level was higher than the location from where they were fed. This information was recorded in the arc flash report (see Table 4). If a small-panel location downstream of a panel or MCC did not have an arc flash hazard label, and the small panel was not on the list of locations in Table 4, then it would have the same HRC rating as the panel or MCC from which it was fed.

### Summary of Savings in Industrial Example

For the example presented in this article, applying accurate generalizations reduced the total number of locations that needed to be added to the computer model from 1,400 to 85. Thus, a reduction in the small-panel locations that required detailed analysis was \(\frac{1,400 - 85}{1,400} \times 100\% = 94\%\).

There were also savings in additional onsite data gathering and entry of information into the computer model. Savings were also realized in the reduction of additional arc flash hazard warning labels and the associated cost of installing these labels. In this example, only 17 additional arc flash hazard warning labels were required for the small panels.

### Conclusions

Performing an arc flash hazard analysis for all equipment locations likely to require examination, adjustment, servicing, or maintenance while energized can prove to be an enormous task. Developing innovative methods to reduce the scope of work without sacrificing the accuracy of the results is the goal of every engineer. This article presented a method that can be used to help reduce the number of equipment locations that must be analyzed using a commercial software package. In an industrial example, this method reduced the number of small feeder locations that required a detailed analysis by 94%. This resulted in a large reduction of onsite data collection, detailed modeling, and arc flash warning labels.

### Acknowledgement

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### References


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### Table 4. Small-Panel Locations Where HRC Was Higher Than the Upstream Location.

<table>
<thead>
<tr>
<th>Label #</th>
<th>Bus Name</th>
<th>Protective Device Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>255</td>
<td>*57EP104</td>
<td>PD-57EP906-104</td>
</tr>
<tr>
<td>256</td>
<td>*57EP105</td>
<td>PD-57EP906-133</td>
</tr>
<tr>
<td>260</td>
<td>*57EP113</td>
<td>PD-57EP905-113</td>
</tr>
<tr>
<td>261</td>
<td>*57EP133</td>
<td>PD-57EP904-133</td>
</tr>
<tr>
<td>262</td>
<td>*LP11&amp;LP13 66</td>
<td>PD7/9/11/13</td>
</tr>
<tr>
<td>263</td>
<td>*LP12&amp;LP14 66</td>
<td>PDB/10/12/14</td>
</tr>
<tr>
<td>264</td>
<td>*LP7&amp;LP9 66</td>
<td>PD7/9/11/13</td>
</tr>
<tr>
<td>265</td>
<td>*LP8&amp;LP10 66</td>
<td>PD8/10/12/14</td>
</tr>
<tr>
<td>266</td>
<td>*_PANEL-RP-3A</td>
<td>PD-RDP3A-RP3A</td>
</tr>
<tr>
<td>267</td>
<td>* PANEL-RP-3B</td>
<td>PD-RDP3A-RP3B</td>
</tr>
<tr>
<td>268</td>
<td>* PANEL-RP-3C</td>
<td>PD-RDP3A-RP3C</td>
</tr>
<tr>
<td>269</td>
<td>*RP-3C</td>
<td>PD-RDP3A-RD3P3C</td>
</tr>
<tr>
<td>270</td>
<td>*RP-4A</td>
<td>PD-RDP3A-RP4A</td>
</tr>
<tr>
<td>271</td>
<td>*WELDRECEPT</td>
<td>PD-PDP12B-WELD</td>
</tr>
</tbody>
</table>

The result of the additional analysis in the commercial software package revealed that out of the 85 new subfeeders that were modeled, there were only 17 small-panel locations with HRC downstream that was greater than the HRC at the upstream MCC or panel location. Based on this analysis, it was concluded that all other small-panel locations in the power system that were fed from panels and MCCs would have the same HRC as the upstream location that feeds them.

The electrical workers at this site were instructed that there were only 17 small-panel locations where the HRC was greater than the upstream location. This software package revealed that out of the 85 new subfeeders that were modeled in Step 1, only 17 additional arc flash hazard warning labels were required for the small panels.

A conservative estimate of the total number of subfeeders was obtained by assuming that there were at least five at each of the 280 locations. An estimated total of 1,400 (280 × 5) locations required investigation on site to determine if the circuit length exceeded the values in the spreadsheet. The results of the site survey indicated that there were only 85 feeders where the circuit length was exceeded. For each of the 85 additional feeders, additional data gathering at the site was required to enable the power system engineer to add these feeders to the commercial software package model that was created in Step 1. This additional information is summarized below:

1. circuit name
2. feeder protective device manufacturer
3. feeder trip unit or fuse ampere rating
4. feeder protective device configuration
5. feeder configuration, which is one of the following:
   - conduit (magnetic or nonmagnetic)
   - free air spacing

The result of the additional analysis in the commercial software package revealed that out of the 85 new subfeeders that were modeled, there were only 17 small-panel locations with HRC downstream that was greater than the HRC at the upstream MCC or panel location. Based on this analysis, it was concluded that all other small-panel locations in the power system that were fed from panels and MCCs would have the same HRC as the upstream location that feeds them.