POWER SYSTEMS STUDIES
SHOCK & ARC FLASH HAZARDS
ARC FLASH HAZARD MITIGATION

Richard D. Reese, P.E.
Power Systems Manager
Industrial Tests, Inc.
4021 Alvis Court – Suite 1
Rocklin, California 95677
[Dick@indtests.com; 916-660-2837]
Presentation Sections

I. POWER SYSTEMS STUDIES

II. SHOCK & ARC FLASH HAZARDS

III. ARC FLASH HAZARD MITIGATION
PREMISE & DISCLAIMER

- This presentation was created to provide you with a broad overview of I. Power Systems Studies (PSS) and as a lead-in to the topics of II. (Shock and) Arc Flash Hazards (AFH) and III. AFH Mitigation and how the topics relate to PSS.
- As a primer, this and related presentation materials in no way substitute as a training course to gain Qualified Electrical Worker (QEW) or Qualified Persons (QP) certification.
- QEW certification can be obtained through a training organization such as American Trainco, Inc. (1-877-97-TRAIN) who offer a two-day seminar followed by online testing.

I. POWER SYSTEMS STUDIES

Richard D. Reese, P.E.
Power Systems Manager
Industrial Tests, Inc.
4021 Alvis Court – Suite 1
Rocklin, California 95677
[Dick@indtests.com; 916-660-2837]
PSS OVERVIEW

1. Purpose
2. Historical development
3. Process
4. Outcomes
1. PURPOSE

- A PSS consists of methodical analysis of a site or facility electrical power supply and distribution system as stipulated in a scope (or statement) of work (SOW).

- A PSS will always include several forms of analyses including short circuit, equipment rating and protection, and in today’s litigious society, should always include an Arc Flash Hazard Analysis to ensure compliance with the latest edition of NFPA 70E - Standard for Electrical Safety in the Workplace®

- A properly executed PSS will provide the customer (client) with:
  - a series of recommendations that if implemented will improve electrical power system safety, reliability, operation and maintenance.
  - reduced risk, which translates to cost savings through increased production, lower insurance premiums, and less liability if/when an on-the-job accident occurs.
2. HISTORICAL DEVELOPMENT

- Before PC’s, PSS analyses were performed by hand using slide rules, calculators and hand-drawn time-overcurrent protective device coordination curves (TCC).
- Even following the advent of PC’s, it took some time for PSS-specific software to come on to the market.
- There are now several industry and utility PSS programs available that range between less than $1k to over $100k.
- Program selection is dependent upon the type of site or facility under consideration and the technical extent of the PSS as set forth in the SOW. For example, different programs are usually used for commercial facilities as opposed to those used to study say a utility company transmission substation.
3. PROCESS

Data Acquisition

- Once the PSS fees have been quoted, accepted and a work contract is in place, the first step is field work (aka field investigation, data collection or data acquisition).

- Reference drawings and other filed documents pertaining to electrical apparatus are mined for relevant data.

- Reference drawings and documents and their accuracies are key PSS price determinants.

- Interviews with customer management, operations, and maintenance staff are beneficial in helping to gain an understanding of plant electrical infrastructure and problem history.

- In some cases the customer provides all of the data necessary to conduct a PSS and in others ITI obtains the data. Either way, each piece of electrical equipment within the study boundaries needs to be visited and documented.

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3. PROCESS (Cont’d)

Software

- ITI has two programs that we routinely use to perform PSS:
  - SKM Power Tools for Windows (PTW) – evolved from DAPPER & CAPTOR
  - ESA Easy Power (EP) – a more modern software package

- Generally speaking:
  - PTW is the preferred choice for conducting PSS on complex systems with multiple power sources and multiple tie feeders (e.g., a power generation and distribution system or a networked system).
  - EP is preferred for conducting PSS on smaller and less complex power distribution systems (e.g., commercial and industrial facilities).

- Between the two licenses, ITI has over $30,000 invested in studies software alone, with ongoing annual software maintenance fees in the thousands.
3. PROCESS (Cont’d)

Modeling

- Reference drawings and electrical equipment nameplate data gathered during the data acquisition stage are collated.
- This data is then used to create a One- or Single-Line Diagram and then a system model in PTW or EP that is typically referred to as an Impedance One-Line Diagram, a Z-Diagram, or as an Input Data One-Line Diagram.
- Completion of an accurate One-Line Diagram usually requires at least one revisit to the customer’s site to revise data or to obtain additional data.
- The resultant One-Line Diagram is a key outcome that serves not only as a living electrical representation of the electrical system, but also as the interface to the equipment database.
3. PROCESS (Cont’d)

INPUT DATA ONE-LINE DIAGRAM EXAMPLE
3. PROCESS (Cont’d)

Fault Flow & Equipment Rating

- Based on the modeled equipment data, the software is employed to calculate and display the results of short circuit analyses.

- The maximum values of short circuit current are adjusted as required by ANSI to account for the X/R ratios at each equipment location and those currents are then compared to equipment nameplate ratings.

- Equipment that is not rated to withstand and/or interrupt maximum available short circuit currents is identified and flagged as overdutied in an Equipment Evaluation Report.

- Failure to replace overdutied equipment may result in catastrophic failure and fire, and in addition to facility downtime, possibly injury or death.
3. PROCESS (Cont’d)
Equipment Rating (Duty) Assessment (Evaluation)

All Protection Devices - Equipment Evaluation Report Based on Balanced System Study Module Comprehensive Fault Analysis Bus Data

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>B395 200A</td>
<td>Fall</td>
<td>OJ2</td>
<td>208</td>
<td>56.10</td>
<td>*11.64</td>
<td>86.67</td>
<td>85.67</td>
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<td>N-Tin Fuse Link, 27kV</td>
<td>4150</td>
<td>*74.65</td>
<td>2.31</td>
<td>2.66</td>
<td>27.73</td>
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<tr>
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<td>COOPER</td>
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</tr>
</tbody>
</table>

(*LF Amps) failed to pass. Marginal 50% - Failed 50% of the continuous current ampacity.
(*Calc INT KA) failed to pass. Marginal 100% - Failed 100% of the device library interrupting rating.

EQUIPMENT RATING
EVALUATION EXAMPLE
3. PROCESS (Cont’d)
TCC (As-Found)
3. PROCESS (Cont’d)
TCC’s (Recommended)

- If changes to the As-Found protection system are needed, new TCCs are produced.
- The customer receives not only the As-Found and Recommended TCCs, but also As-Found and Recommended protection settings tables (reports) that would typically be given to on-site ITI test engineers who would test, calibrate, and set the protective devices as recommended in the PSS report.
- If digital relay programming is specified in the SOW (e.g., for Schweitzer or GE Multilin relays), ITI will develop and upload all relevant setting parameters then check relay calibration and functions to ensure proper protection is provided.
3. PROCESS (Cont’d)
Other Analyses & Assessments

All of the following can be facets of a PSS:

- Power Quality (PQ)
- Voltage Regulation
- System Planning
- System Reliability
- Equipment Condition Assessments
- Standby Power Systems
- Transient Motor Starting (TMS)
- Dynamic Stability (DS)
- AFH Mitigation
- Power Factor Correction (PFC)
4. OUTCOMES

A typical comprehensive PSS report includes:

- Executive Summary
- Super Executive Summary (for complex studies)
- Introduction (scope and background)
- Electrical System Description
- Load Flow (sometimes) and Voltage Drop
- Fault Flow (Short Circuit) Analyses
- TCCs
- Equipment Rating Assessments
- Equipment Condition Assessments
- AFH discussion and General Recommendations
- Budget Cost Estimates
- Support Documentation
- AFH tabulation and thermal-transfer-printed AFH labels
II. SHOCK & ARC FLASH HAZARDS

Richard D Reese, P.E.
Power Systems Manager
Industrial Tests, Inc.
4021 Alvis Court – Suite 1
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AFH Overview

- NFPA 70E Evolution
- NFPA 70E Exemptions
- Hazards
  - Shock
  - Arc Flash
  - Arc Blast
- Boundaries
- PPE
- Labels
- NFPA 70E Compliance

Lots of AF videos on the web.

Arc flash explosion video.mpeg
Video 3.mpg

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NFPA 70E Evolution

- 1976 OSHA asks the NFPA to develop a consensus electrical safety standard
- 1979 First NFPA 70E edition of standard
- 1981 Second edition
- 1983 Third edition
- 1988 Fourth edition
- 1995 Fifth edition
- 2000 Sixth edition (introduction of the hazard/risk tables)
- 2004 Seventh edition (safe work practice emphasis)
- 2009 Eighth edition
- 2012 Ninth edition
NFPA 70E Exemptions

All except following covered by NFPA 70E - Standard for Electrical Safety in the Workplace®

- Installations underground in mines and self-propelled mobile surface mining machinery and its attendant electrical trailing cable.
- Utility where such installations:
  - a. Consist of service drops or service laterals, and associated metering, or
  - b. Are located in legally established easements or rights-of-way designated by or recognized by public service commissions, utility commissions, or other regulatory agencies having jurisdiction for such installations, or
  - c. Are on property owned or leased by the electric utility for the purpose of communications, metering, generation, control, transformation, transmission, or distribution of electric energy.
Hazards

General Electrical Hazard Categories:

- SHOCK
- ARC FLASH
- ARC BLAST
SHOCK

- Our control of electricity goes against nature in that through raised levels of voltage (potential) we force atoms to remain in an elevated state of activity. In nature, a near zero energy level (a quiescent state) is normal, and when not, results can be catastrophic (e.g., hurricanes, earthquakes, eruptions, lightning...).

- A human body (blood, tissue, nervous, lymphatic systems) can become part or all of the path of electrical current that seeks to return to its source to achieve quiescence. Muscle contraction, burns, and death are possible even at lower voltages. Full adverse health effects may be delayed.

- 30k nonfatal and 1k fatal shock accidents per annum with more than ½ of the fatalities occurring when servicing energized equipment operating at less than 600 volts.

- The higher the voltage, the greater the current conducted through a body.
SHOCK (Cont’d)

○ Body reactions or results to shock

<table>
<thead>
<tr>
<th>Current (I) in milliamps (mA)</th>
<th>Reaction or Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>.5 - 3</td>
<td>Tingling feeling</td>
</tr>
<tr>
<td>3 - 10</td>
<td>Muscle contractions &amp; pain</td>
</tr>
<tr>
<td>10 - 40</td>
<td>Let-Go threshold</td>
</tr>
<tr>
<td>30 - 75</td>
<td>Respiratory paralysis</td>
</tr>
<tr>
<td>100 - 200</td>
<td>Ventricular fibrillation</td>
</tr>
<tr>
<td>200 - 500</td>
<td>Heart seizes</td>
</tr>
<tr>
<td>1.5 amps (A)</td>
<td>Tissue and organ burn threshold</td>
</tr>
</tbody>
</table>
SHOCK (Cont’d)

- Two ways to receive a shock:
  - Step Potential
  - Touch Potential

- Personal Protective Equipment (PPE) with insulating properties reduces the risk of shock (e.g., rubber gloves, insulated-sole boots with FRP toes, insulated and properly rated tools and test equipment) along with common sense precautions (e.g., remove rings and other metal jewelry along with belt buckles, wear FR rated no-rivet jeans with Velcro fly, safety glasses with no metal parts).
More than 2k victims each year admitted to burn centers.

Northern California has several burn care centers including Santa Clara Valley Medical Center [751 S. Bascom Ave., San Jose, CA 95128 (408-885-5000)]; St. Francis Memorial Hospital’s Bothin Burn Center [900 Hyde St., San Francisco, (415 353-6255)]; the UC Davis Regional Burn Center [(916) 734-3636].

Arc burns should always be treated at a burn center and not at a hospital.

Incident energy exposure measured in calories per square centimeter (cal/cm²) determines the severity of an arc flash injury.

A first-degree burn resulting from less than 1 cal/cm² exposure causes skin redness and mild pain (e.g., sunburn).
ARC (Cont’d)

- A second-degree burn resulting from 1.2 cal/cm² exposure causes blisters and pain and takes a couple weeks to heal.
- It is important to remember that incident energy of 1.2 cal/cm² exists at the edge of the Flash Protection Boundary that will be discussed shortly.
- A third-degree burn resulting from 1.5 cal/cm² exposure causes skin hardening and discoloration and may numb the skin.
- A victim of a third-degree burn can die from the burn damage or infections.
- Electric arcs can reach temperatures of 34k degrees F while the surface of the sun is around 11k degrees F (i.e., electric arc temperatures are roughly three times hotter than the sun).
ARC (Cont’d)

- Arc temperature in degrees F is roughly 1.5 times the fault current (e.g., the arc temperature of a 20 kA fault would be ~30k degrees F).
- The vaporized copper emanating from an arc flash incident expands 67k times in volume and forms an electrically charged plasma cloud (think of ball lightning).
Injuries received by the arc flash incident victim close to the faulted equipment are caused by:

- Energized plasma
- Hot gases
- Blast pressure
- CuO inhalation
- Flash
- Sound
- Electromagnetic pulse
So injuries to the victim closest to the arc include:

- Shock
- Burn
- Concussion and shattered bones
- Poisoning
- Blindness (cataracts later)
- Deafness
- Memory loss
ARC (Cont’d)

- Incident energy is dependent on fault current magnitude and duration: $I^2t$
- To ballpark fault current, divide supply transformer full-load current rating (FLA) by the transformer impedance (Z). All of this data is available on the transformer nameplate.
- For example:
  - For a 500 kVA, 480 V transformer with secondary FLA of ~600 A and 5% impedance, the 3-phase bolted fault current would be ~12 kA.
  - For a 2500 kVA, 480 V transformer with secondary FLA of ~3 kA and 5% impedance, the 3-phase bolted fault current would be ~60 kA.
ARC (Cont’d)

- Bearing in mind that 1.5 cal/cm² exposure causes a third-degree burn, the following in-the-box incident energy ranges in cal/cm² will be present 12-inches away from the fault for the listed fault currents when cleared in 6 cycles:
  - 16 kA 8 - 11 cal/cm²
  - 24 kA 9 - 14 cal/cm²
  - 38 kA 17 - 24 cal/cm²
  - 50 kA 32 - 38 cal/cm²

- If the fault lasted longer than the 6 cycles in the above examples, which would be a reasonable assumption (in fact we assume maximum arc durations of 2 to 1000 seconds), incident energies would be proportionally higher.
ARC (Cont’d)

- For incident energies greater than 40 cal/cm² at the equipment to be serviced, the equipment must be de-energized.
- Personnel farther from the fault can sometimes receive more severe injuries than those closer to the fault. Copper and steel shards and buckshot (coalesced from the gaseous state of the metals) injuries can be fatal.
BLAST

- Blast pressure injuries and how to protect personnel are not emphasized as much as shock and arc flash hazard protection in NFPA-70E.
- Unlike the ability to roughly predict shock and arc flash hazards, arc blast pressures will vary with the construction of the equipment.
- The main point to bear in mind is that arc blast pressures can be fatal, particularly in the vicinity of equipment labeled with Red Danger Labels since no safe PPE exists for working on such equipment in the energized state. Energies released during an arcing fault near red-labeled equipment (i.e., greater than 40 cal/cm²) are simply too high to protect against.
BLAST (Cont’d)

ICAM: Oil Circuit Breaker Explosion

Incident date: Saturday 5th September, 2009
BOUNDARIES

- Shock protection boundaries are based on tables.
- Results of calculations based on NFPA 70E or IEEE 1584 (the latter is now the industry consensus calculation standard) formulas that are typically performed by the PSS software, based on the data extracted from the One-Line Diagram, are used to determine the arc flash protection boundary (Flash Protection Boundary).
- The Flash Protection Boundary is defined as the minimum distance you must be away from the flash source to avoid receiving an incurable (second-degree 1.2 cal/cm² or greater) burn injury and is based on calculations or when permissible, tables in NFPA 70E.
BOUNDARIES (Cont’d)

- The Limited Approach Boundary is an **electrical** shock protection boundary not to be crossed by an unqualified person/s unless escorted by a qualified person.

- The Restricted Approach Boundary is an **electrical** shock protection boundary to be crossed only by qualified persons trained in shock prevention techniques and using PPE suited to the task to be performed.

- The Prohibited Approach Boundary is an **electrical** shock protection boundary that is not to be crossed and in which a body part, tool, or other object within the boundary will become part of the electrical circuit.

- In most cases the Flash Protection Boundary is greater than the Limited Approach Boundary.

- For LV (<600 V) systems where fault exposure < 5 kA-sec, NFPA 70E defines the default Flash Protection Boundary as 4-feet.

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BOUNDARIES (Cont’d)

- Flash Protection Boundary
- Limited space
- Limited approach boundary
- Restricted space
- Restricted approach boundary
- Any point on an exposed energized electrical conductor or circuit part (e.g., bus bar, circuit breaker terminal, motor terminal).
- Prohibited space
- Prohibited approach boundary (same as energized conductor)
**BOUNDARIES (Cont’d)**

Extract from NFPA 70E-2012, Table 130.4(C)(a)
Approach Boundaries to Energized Electrical Conductors or Circuit Parts for Shock Protection for Alternating-Current Systems
(All dimensions are distance from energized electrical conductor or circuit part to employee chest or face.)

<table>
<thead>
<tr>
<th>Voltage Range (Volts)</th>
<th>Limited Approach Boundary (Inches)</th>
<th>Restricted Approach Boundary (Inches)</th>
<th>Prohibited Approach Boundary (Inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>300</td>
<td>42</td>
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</tr>
<tr>
<td>750</td>
<td>42</td>
<td>12</td>
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<tr>
<td>15000</td>
<td>60</td>
<td>26</td>
<td>7</td>
</tr>
<tr>
<td>36000</td>
<td>72</td>
<td>31</td>
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</tr>
<tr>
<td>46000</td>
<td>96</td>
<td>33</td>
<td>17</td>
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<td>72500</td>
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</tr>
<tr>
<td>800000</td>
<td>285</td>
<td>191</td>
<td>185</td>
</tr>
</tbody>
</table>

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PPE

- Properly rated PPE is a must for energized work.
- The AF Warning Label serves as a guide to the minimum PPE required and is consulted as a first step in a Job Briefing and Planning Checklist that is ultimately the basis for the Energized Electrical Work Permit that must be approved in writing by company management prior to commencement of live work.
- Regular cotton work clothing won’t ignite at energy levels up to 1 - 2 cal/cm² while heavy denim may not ignite in the 5 - 10 cal/cm² range. However, AF energy levels are typically much higher.
- Caution: Do not use bleach or fabric softener when cleaning FR rated clothing since it will diminish or eliminate the FR capabilities.
PPE (Cont’d)

- Cotton underwear no longer recommended and the term FR rated has been replaced by AR rated (arc resistant).
- Typical PPE provided by an employer for use by each employee includes:
  - HV gloves (air-test daily and before each use, replace or electrically test rubber liners every 6 months, can be kept in storage for up to one year without being tested)
  - Non-conductive face and chin shield
  - Balaclava
  - FR long-sleeve shirts
  - FR denim slacks
  - FRP toe, insulated sole boots (steel toe optional)
  - Non-conductive hard hat
  - Safety glasses (non-metallic)
  - Insulated tools and handling equipment meeting ASTM 1505 specifications
## WARNING

Arc Flash and Shock Hazard
Appropriate PPE Required

<table>
<thead>
<tr>
<th>Distance</th>
<th>Description</th>
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<tbody>
<tr>
<td>6' - 6&quot;</td>
<td>Flash Hazard Boundary</td>
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<tr>
<td>10.5</td>
<td>cal/cm2 Flash Hazard at 18 Inches</td>
</tr>
<tr>
<td>#3</td>
<td>PPE Level</td>
</tr>
<tr>
<td></td>
<td>Cotton underwear plus FR shirt &amp; FR pants plus FR coverall</td>
</tr>
<tr>
<td>0.48</td>
<td>kV Shock Hazard when cover is removed</td>
</tr>
<tr>
<td>3' - 6&quot;</td>
<td>Limited Approach</td>
</tr>
<tr>
<td>1' - 0&quot;</td>
<td>Restricted Approach - Class 00 Voltage Gloves</td>
</tr>
<tr>
<td>0' - 1&quot;</td>
<td>Prohibited Approach - Class 00 Voltage Gloves</td>
</tr>
</tbody>
</table>

Equipment Name: COMM AUX SWGR
COMPLIANCE

- OSHA 29 CFR 1910.132 (d) requires employers to assess the workplace to determine if hazards are present and then select and have employees use appropriate types of PPE to protect themselves.
- A Workplace Hazard Assessment must be verified through written certification that states the particular workplace evaluated.
- Articles 110, 120, and 130 in NFPA 70, The National Electric Code, stipulate many safety requirements including labeling.
- More recently, NFPA 70, Article 240.87 has placed an added burden on management to take steps to mitigate arc flash hazards where circuit breakers are not equipped with instantaneous trip functions.
COMPLIANCE (Cont’d)

- There are only two exceptions that permit work on energized equipment operating at more than 50 volts to ground:
  - De-energizing would increase the hazard (i.e., result in more danger to employees and/or others).
  - Testing and troubleshooting that require systems to be operating.

- In many cases, an Energized Electrical Work Permit is not required for the latter as long as appropriate PPE is worn and safe work practices are followed.

- Considering just the financial impact, severe injury or death caused by an electrical accident in a facility that has not complied with NFPA 70, NFPA 70B and NFPA 70E requirements will cost the company a minimum of $2.2 M, which is enough to put many companies out of business, not to mention additional fines and possible prison time for any management staff found to be criminally negligent.
MITIGATION

- There are many means to reduce incident energy levels in existing or new plants; summarized here and elaborated upon in Part III:
  - Arc Reduction Maintenance System (ARMS)
  - Remote circuit breaker racking mechanisms
  - Arc resistant/diversion switchgear
  - Reduced supply transformer ratings (increased quantity)
  - System reconfiguration (e.g., segregated buses)
  - Reduced supply transformer primary fuse ratings
  - Differential protection schemes
  - Bypass switches to permit equipment removal for servicing
  - Zone selective interlocking (ZSI)
  - Reduced energy let-through (RELT)
None of the safety measures discussed here are effective without initial and ongoing training and adherence to the Energized Electrical Work Permit process.

Some contend that NFPA 70E compliance is not an OSHA mandate and therefore compliance is not necessary; however, one electrical incident that leads to an OSHA investigation will confirm that compliance is an obligation that no one can ignore.
III. ARC FLASH HAZARD MITIGATION

Richard D Reese, P.E.
Power Systems Manager
Industrial Tests, Inc.
4021 Alvis Court – Suite 1
Rocklin, California 95677
[Dick@indtests.com; 916-660-2837]
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Arc flash hazard (AFH) mitigation – broad-brush topics:
- Impacts
- Safety Codes & Standards
- Regulatory Compliance
- Hazard Types
- PPE vs Mitigation
- Types
- Techniques (~ a dozen)

For current and more in-depth coverage of the topics, search IEEE Xplore and visit web Q&A sites like the following:
- arcflashforum.com
- eng-tips.com
Arc Flash Hazard (AFH) Mitigation is a broad and challenging safety topic that affects all aspects of electrical power systems. For example:

- Design
- Construction
- Operation
- Maintenance
- Production
- Profit
The main documents that govern electrical safety in the workplace for work in the U.S.

- NFPA 70 – 2011 (National Electrical Code)
- NFPA 70E – 2012 (Standard for Electrical Safety in the Workplace)
- NFPA 70B – 2010 (Recommended Practice for Electrical Equipment Maintenance)
- NESC – 2012 (National Electrical Safety Code)

For work in Canada:

- CSA Z462-12 (Workplace Electrical Safety) & C22.1-12 (Canadian Electrical Code)

Latest editions may not have been adopted in your region, but this presentation presumes that the latest editions are in effect and that work is performed in the US.
AFH MITIGATION – REGULATORY COMPLIANCE
Arc Flash Hazard Mitigation - Sep 2012

- Electrical work in some workplaces is governed by NFPA 70/70E (e.g., work in industrial, commercial and institutional facilities).
- Work at others is governed by the NESC (i.e., at electric utility company sites/infrastructure), a Code that now includes LV systems in the 50 – 1000 V range.
- With regard to arc flash hazard mitigation, although NFPA 70E and the NESC requirements differ, the mitigation techniques presented herein can be applied to work conducted under either one.
- And as an aside, some may claim that since OSHA has not adopted NFPA 70E, OSHA will not enforce AFH requirements in NFPA 70E. See [http://www.osha.gov/](http://www.osha.gov/) and search on “70E” for relevant discussion of this topic.
Need to be aware of arc flash and shock hazards at all times when working on or around electrical equipment, but AFHs are generally of concern in LV systems whereas shock hazards are generally of concern in MV/HV systems.

A PSS INCLUDING AN AFH STUDY AND LABELS CONSTITUTES THE FIRST STEP IN AN ENERGIZED ELECTRICAL WORK PERMIT PROGRAM.
o Arc blast pressure is an oft overlooked hazard that will receive more attention and emphasis as safety standards evolve. For example, a 100 cal/cm² AR suit [AR (arc rated) in NFPA 70E-2012 replaced FR (fire-resistant) used in previous editions of 70E] will do little to protect a worker exposed to the pressure wave and the debris created by an arc flash where incident energies are high.

o And what about the use and reliance on PPE to protect us from AFHs? Do we depend on PPE too much and consequently do too little to prevent or mitigate AFHs?

o PPE can create a false sense of security, is costly, uncomfortable and reduces production, and should really be treated as Plan B.

o We also need to bear in mind that many AFH mitigation techniques presume circuit breakers will always open. Breaker failure would result in a substantial increase in arc energy that will continue to grow until after the next upstream protective device opens the faulted circuit. In such cases, PPE would prove inadequate.
The phrase “The best defense is a good offense” never rang truer.

AFH mitigation is both the main line of “defense” and “offense” in the context of this discussion.

The overriding premise is to de-energize and only work on systems when they are in a proven zero energy state, but since this may not always be possible and since legacy designs have not factored in the risk to workers from AFHs (and to some extent shock hazards), AFH mitigation is of prime concern in any workplace.

When using electrical means, AFH mitigation is accomplished by reducing time \((t)\) in the proportional energy equivalent of \(V \cdot I \cdot t\) or \(I^2 \cdot t\).

Mechanical/physical AFH mitigation techniques are another option and rely on keeping workers well outside the flash protection boundary. AFH energies are inversely proportional to increasing distance-squared \((1/d^2)\).

Voltage \((V)\) and current \((I)\) are not readily reducible in existing facilities, thus \(t\) and \(d\) are the main AFH mitigation tools, and to some extent \(I\) via overcurrent protection pickup settings.
Many AFH mitigation techniques have been developed in the recent past and many more will be developed as safety codes and standards evolve.

The one factor that all mitigation techniques rely on is proper and timely equipment maintenance as set forth in NFPA 70B and ANSI/NETA Standards.

As part of any power system study (PSS) conducted on an existing facility, ITI urges inclusion of an equipment physical condition assessment.

Another key value of a PSS is revelation of high incident energies and their locations, which then lead the engineer conducting the PSS to recommend appropriate AFH mitigation techniques.
Slides following present a compendium of the most common AFH mitigation techniques (schemes) in use today to help make work safer when work on energized LV and MV electrical systems is necessary.

The Schemes are not presented in any particular order, the listed Pros and Cons are limited to key points and some Schemes are synergistic.
<table>
<thead>
<tr>
<th>SCHEME DESCRIPTION</th>
<th>MECHANISM</th>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE-ENERGIZE, LOCKOUT &amp; TAGOUT, TEST FOR ZERO ENERGY STATE AND GROUND</td>
<td>SWITCHING</td>
<td>BEST POST-DESIGN OPTION IN TERMS OF WORKER SAFETY AND COMPLIES WITH INTENT OF NFPA 70E AND THE NESC</td>
<td>MAY NOT BE POSSIBLE (e.g., IF TESTING AND TROUBLESHOOTING OR IF DE-ENERGIZATION COULD ENDANGER OTHERS SUCH AS IN A HOSPITAL OR WHERE AN EXOTHERMIC PROCESS IS UNDERWAY) GOES AGAINST POWER SERVICE PROVIDER MISSION TO PROVIDE UNINTERRUPTED SUPPLY SWITCHING, TESTING AND GROUNDING REQUIRED TO ACHIEVE A ZERO ENERGY STATE WILL EXPOSE A WORKER TO SHOCK AND ARC FLASH HAZARDS</td>
</tr>
<tr>
<td>SCHEME DESCRIPTION</td>
<td>MECHANISM</td>
<td>PROS</td>
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</tr>
<tr>
<td>B EQUIPMENT REPLACEMENT</td>
<td>SUBSTITUTION</td>
<td>ELIMINATES AGED EQUIPMENT THAT IS LESS RELIABLE (e.g., OCBs and ACBs) AND THAT HAS REDUCED INSULATION INTEGRITY PRESENTS AN OPPORTUNITY TO REDUCE FAULT CURRENTS BY REPLACING LARGE TRANSFORMERS WITH MULTIPLE SMALLER UNITS THAT WILL LIMIT FAULT ENERGY LET-THROUGH INCREASED PRODUCTION AND PROFITS OVER THE LIFE OF THE EQUIPMENT REDUCED PPE COSTS LESS CONSTRAINED SYSTEM OPERATING CONFIGURATIONS</td>
<td>COSTLY, THUS HARD TO JUSTIFY UNLESS THERE ARE OTHER FACTORS THAT SUPPORT REPLACEMENT HAVE TO OVERCOME THE &quot;IF IT AIN'T BROKE, DON'T FIX IT&quot; MENTALITY PRODUCTION LOSSES DUE TO OUTAGES SCHEDULED FOR EQUIPMENT REPLACEMENT</td>
</tr>
<tr>
<td>SCHEME DESCRIPTION</td>
<td>MECHANISM</td>
<td>PROS</td>
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<tr>
<td>C</td>
<td>AFH MITIGATION THROUGH DESIGN</td>
<td>IMPROVED SAFETY OVER THE LIFE OF THE EQUIPMENT</td>
<td>INCREASED UPFRONT CAPITAL EXPENDITURE FOR ADDED DESIGN, EQUIPMENT FEATURE COSTS AND ADDITIONAL COMMISSIONING</td>
</tr>
<tr>
<td></td>
<td>CUSTOMIZED DESIGN</td>
<td>INCREASED PRODUCTION AND PROFITS OVER THE LIFE OF THE EQUIPMENT</td>
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<td></td>
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<td>REDUCED PPE COSTS</td>
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<td></td>
<td></td>
<td>LESS CONSTRAINED SYSTEM OPERATING CONFIGURATIONS</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>PROVIDES COST-EFFECTIVE OPPORTUNITIES TO INCORPORATE PROTECTIVE DEVICE COMMUNICATIONS TO ENABLE FAST-TRIP CAPABILITIES</td>
<td></td>
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## AFH MITIGATION – SCHEME D

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<table>
<thead>
<tr>
<th>SCHEME DESCRIPTION</th>
<th>MECHANISM</th>
<th>PROS</th>
<th>CONS</th>
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</thead>
<tbody>
<tr>
<td>D Fuse Replacement</td>
<td>Substitution</td>
<td>Faster acting fuses (e.g., replace RK5 dual-element time-delay fuses with RK1 fuses) may reduce the hazard risk category (HRC) downstream potential for current-limiting by adding resistance in the fault flow path</td>
<td>Replacement cost-benefit ratio is typically high</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>Current-limiting fuses only limit fault currents when actual fault currents are high enough (a low impedance fault), so current-limiting effect is ignored in a PSS.</td>
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<td></td>
<td></td>
<td></td>
<td>Fixed time-overcurrent characteristic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Safety issues during replacement</td>
</tr>
<tr>
<td></td>
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<td>Spares stock tracking and costs</td>
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<table>
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<tr>
<th>SCHEME DESCRIPTION</th>
<th>MECHANISM</th>
<th>PROS</th>
<th>CONS</th>
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</thead>
<tbody>
<tr>
<td>E ARC-RESISTANT SWITCHGEAR AND MCCs</td>
<td>REDIRECTS ARC FLASH ENERGY</td>
<td>PERMITS WORK IN CLOSE PROXIMITY TO SWITCHGEAR</td>
<td>HIGHER COST FOR PURCHASE AND SPECIAL CONSTRUCTION REQUIREMENTS (TOPHAT AND EXHAUST)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>INEFFECTIVE IF ENCLOSURE INTEGRITY IS BREACHED (e.g., AN OPEN DOOR)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>CANNOT BE RETROFITTED</td>
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</table>
## AFH MITIGATION – SCHEME F

Arc Flash Hazard Mitigation - Sep 2012

<table>
<thead>
<tr>
<th>SCHEME DESCRIPTION</th>
<th>MECHANISM</th>
<th>PROS</th>
<th>CONS</th>
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</thead>
<tbody>
<tr>
<td>F ARC REDUCTION MAINTENANCE SYSTEM (ARMS) aka ENERGY REDUCING MAINTENANCE SWITCHING or REDUCED ENERGY LET-THROUGH (RELT)</td>
<td>MORE TYPICALLY RETROFIT</td>
<td>A PROVEN APPROACH APPLICABLE IN MOST FACILITIES CAN BE READILY RETROFITTED RELIES ON OVERCURRENT PROTECTION RELAY MULTIPLE SETTINGS GROUPS (MSG) IN MV/HV SYSTEMS IN LV SYSTEMS RELIES ON LVPCB ARMS-EQUIPPED TRIP UNITS CAN TEMPORARILY DISABLE RECLOSING IN SYSTEMS WHERE RECLOSING IS NORMALLY ACTIVE</td>
<td>TYPICALLY A LOW COST APPROACH, BUT HAVE TO WEIGH COST VS BENEFIT, PARTICULARLY IN LV SYSTEMS (e.g., ~$5k PER LVPCB NOT INCLUDING THE MONITORING SYSTEM) RISKS NUISANCE TRIPPING CAUSED BY MOTOR STARTING WHILE IN ARMS MODE RISKS NUISANCE TRIPPING IF ARMS IS INADVERTENTLY LEFT ACTIVE NEED AN ARMS MONITORING SYSTEM AND OPERATOR TRAINING REQUIRES TWO AFH LABELS AND SIGNAGE EASY TO MIS-APPLY AND THINK YOU ARE SAFE WHEN YOU ARE NOT</td>
</tr>
</tbody>
</table>


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BY WAY OF EXAMPLE, IF RACKING A CIRCUIT BREAKER IN OR OUT, CONFIRM WHICH UPSTREAM ARMS PROTECTIVE DEVICES NEED TO BE SWITCHED TO ARMS MODE. WILL NOT BE THE ONE TO BE RACKED.

ENABLE 52-DPUPS1-MAIN ARMS TO RACK OUT 52-UPS2B-FDR.
<table>
<thead>
<tr>
<th>SCHEME DESCRIPTION</th>
<th>MECHANISM</th>
<th>PROS</th>
<th>CONS</th>
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<tbody>
<tr>
<td>G HRC REDUCTION VIA PROTECTIVE DEVICE COORDINATION [SEE HIGHLIGHTED SETTINGS IN TCCs FOLLOWING THAT DEMONSTRATE THE EFFECT CIRCUIT BREAKER SETTINGS CAN HAVE ON HRC; IN THIS CASE THE STD SETTING]</td>
<td>PROTECTIVE DEVICE SETTINGS ADJUSTMENTS</td>
<td>RELATIVELY EASY TO IMPLEMENT AT THE PSS STAGE WITH THE RIGHT OVERCURRENT PROTECTIVE DEVICE, CAN INTRODUCE A DELAYED SHORT TIME AND/OR INSTANTANEOUS RESPONSE — CURVE SHAPING CAN RETROFIT EXISTING OVERCURRENT PROTECTION SYSTEMS WITH PLUG &amp; PLAY REPLACEMENTS</td>
<td>MAY SACRIFICE COORDINATION DUE TO TIGHTER TIME SEPARATION NEED TO RETHINK PROTECTION PHILOSOPHY</td>
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</table>
## AFH MITIGATION – SCHEME H
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<tr>
<th>SCHEME DESCRIPTION</th>
<th>MECHANISM</th>
<th>PROS</th>
<th>CONS</th>
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</thead>
<tbody>
<tr>
<td>H</td>
<td>OPTICAL AFH PROTECTION DETECTS SIMULTANEOUS CURRENT SURGE AND ARC FLASH</td>
<td>OPTICAL-OVERCURRENT RELAYS</td>
<td>FIRST GENERATION SUBJECT TO NUISANCE TRIPPING SINCE ONLY DETECTED THE FLASH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EXTREMELY FAST RESPONSE</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>SPOT OR DISTRIBUTED APPLICATION</td>
<td>APPLICABLE TO ENCLOSED GEAR</td>
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<td></td>
<td></td>
<td></td>
<td>TO ENSURE PROPER COORDINATION, COMMUNICATIONS NEEDED BETWEEN MULTIPLE RELAYS</td>
</tr>
<tr>
<td>SCHEME DESCRIPTION</td>
<td>MECHANISM</td>
<td>PROS</td>
<td>CONS</td>
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<tr>
<td>I INCREASE WORKING DISTANCES: REMOTE CONTROLLED OPERATIONS LV CONTROL SMART MCCs (EXTERNAL PIN-OUT) REMOTE RACKING (IN AND OUT) REMOTE OPERATORS (CHICKEN SWITCHES) I-R SCAN PORTS</td>
<td>ELECTRICAL AND MECHANICAL</td>
<td>ENSURES WORKERS ARE ABLE TO BE OUTSIDE THE FLASH PROTECTION BOUNDARY DURING TIMES WHEN AFHs ARE MORE LIKELY TO OCCUR</td>
<td>EQUIPMENT, PROCEDURAL AND TRAINING COSTS REMOTE OPERATORS MAY BE EXPENSIVE AND DIFFICULT TO RETROFIT DOES NOT IMPROVE LOCAL AND DOWNSTREAM EQUIPMENT PROTECTION</td>
</tr>
</tbody>
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AFH MITIGATION – REMOTE RACKING

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REMOTE RACKING

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AFH MITIGATION – I-R PORT
Arc Flash Hazard Mitigation – Sep 2012

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<th>MECHANISM</th>
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<tbody>
<tr>
<td>J ZONE SELECTIVE INTERLOCKING (ZSI) LOW IMPEDANCE BUS DIFFERENTIAL (LIBD) HIGH IMPEDANCE BUS DIFFERENTIAL (HIBD)</td>
<td>COMMUNICATING OR INTERCONNECTED OVERCURRENT RELAYS</td>
<td>ZSI PROVIDES A FAST-ACTING PRIMARY LINE OF LV FAULT DEFENSE WITH BACKUP PROTECTION IN THE FORM OF THE COORDINATED PROTECTION SYSTEM TWO LEVEL ZSI (MAIN TO FEEDERS) IS COMMON, BUT CAN GO UP TO THREE LEVELS EITHER BUS DIFFERENTIAL SCHEME WILL PROVIDE HIGH SPEED CLEARING OF FAULTS THAT OCCUR INSIDE THE MV OR LV SWITCHGEAR WITHIN THE ZONE OF PROTECTION NOW AN ACCEPTED MITIGATION TECHNIQUE IN LV SWITCHGEAR MAY BE ABLE TO OVERLAP WITH TRANSFORMER DIFFERENTIAL PROTECTION FOR MORE COMPLETE AFH MITIGATION</td>
<td>ZSI COMMUNICATION LINKS IF NOT PROPERLY TESTED AND MAINTAINED MAY MAKE ZSI INOPERABLE AND THAT WILL RESULT IN HIGHER AFH INCIDENT ENERGY THAN THAT SHOWN ON THE AFH LABEL WHERE MOTOR FAULT CONTRIBUTION ON A FEEDER IS SIGNIFICANT, ZSI MAY NOT FUNCTION PROPERLY SINCE ZSI LOGIC RELIES ON FEEDER CIRCUIT BREAKER SHORT TIME PICKUP TO DETERMINE WHETHER THE FEEDER CIRCUIT BREAKER DETECTS THE FAULT (i.e., DO NOT WANT A FEEDER CIRCUIT BREAKER TO DETECT AN UPSTREAM FAULT) LIBD AND HIBD ARE EXPENSIVE SOLUTIONS LIBD PROTECTION PERMITS USE OF SHARED CTs WHEREAS HIBF MUST HAVE DEDICATED CTs, WHICH MAY NOT BE ABLE TO FIT ON SWITCHGEAR CIRCUIT BREAKER BUSHINGS CT SATURATION IS AN ISSUE</td>
</tr>
</tbody>
</table>
# SCHEME DESCRIPTION | MECHANISM | PROS | CONS
---|---|---|---
K | ARC ENERGY CAPTURE | OPTICAL TRIGGER | FAST RESPONSE, REDUCES HRC, CAN BE RETROFITTED | SOME SWITCHGEAR DAMAGE AND CONSEQUENT DOWNTIME, APPLICABLE TO LV AND NOT MV GEAR, LIMITED NUMBER OF ARC ENERGY CAPTURES BEFORE REPLACEMENT, EQUIPMENT DAMAGE REDUCED AND THUS FASTER RECOVERY, BUT WORKERS COULD STILL BE INJURED
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<tr>
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<th>MECHANISM</th>
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</thead>
<tbody>
<tr>
<td>L PARTIAL DISCHARGE SENSING</td>
<td>FAILURE PREDICTION</td>
<td>REDUCES AFH RISKS THUS IMPROVES SAFETY FOR WORKERS</td>
<td>COST</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NO SURPRISES</td>
<td>AT THIS TIME, ONLY JUSTIFIABLE IN LARGE AND/OR HIGHLY CRITICAL</td>
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<tr>
<td></td>
<td></td>
<td>ON-LINE MONITORING PERMITS PREDICTIVE FAILURE ANALYSIS OF SWITCHGEAR, GENERATORS, BUS, CABLES, MOTORS AND TRANSFORMERS</td>
<td>FACILITIES</td>
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<tr>
<td></td>
<td></td>
<td>CONTINUAL MONITORING WITH PD ALARM</td>
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<td></td>
<td></td>
<td>IMPROVED PRODUCTION</td>
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<td>SCHEDULED OUTAGES FOR REPAIRS</td>
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<td>REDUCES SPARES INVENTORY</td>
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<tr>
<td>SCHEME DESCRIPTION</td>
<td>MECHANISM</td>
<td>PROS</td>
<td>CONS</td>
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<tr>
<td>M</td>
<td>RESISTANCE GROUNDED OF NEUTRAL</td>
<td>INSERTION</td>
<td>HIGH-RESISTANCE GROUNING (HRG) OF 480 V SYSTEMS TO LIMIT GROUND FAULT CURRENTS TO THE 5 A TO 10 A RANGE (i.e., THE GROUND FAULT CURRENT MUST BE GREATER THAN THE SYSTEM CAPACITIVE CHARGING CURRENT) REDUCES AFH ENERGIES PRODUCED FOR THE MOST COMMON TYPE OF FAULT</td>
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<td>GREATER CONTINUITY OF SUPPLY SINCE HRG RESISTANCE-LIMITED GROUND FAULTS CAN REMAIN ON-LINE FOR A NOMINATED PERIOD OF TIME WHILE FAULT LOCATION AND REPAIR CAN BE ARRANGED</td>
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<td></td>
<td></td>
<td></td>
<td>HRG REDUCES INCIDENCE OF 3-PHASE FAULTS</td>
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<td></td>
<td>RESISTANCE GROUNDED OF MV SYSTEMS TO LIMIT GROUND FAULT CURRENTS TO THE 200 A TO 400 A RANGE REDUCES AFH ENERGIES PRODUCED FOR THE MOST COMMON TYPE OF FAULT</td>
</tr>
<tr>
<td>SCHEME DESCRIPTION</td>
<td>MECHANISM</td>
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<tr>
<td>N</td>
<td>SENSORS</td>
<td>GOOD BACKUP PROTECTION WHEN USED IN CONJUNCTION WITH OTHER AFH MITIGATION TECHNIQUES</td>
<td>RELATIVELY FAST, BUT SLOWER THAN OPTICAL PROTECTION SCHEMES APPLICATIONS AND DEVELOPMENT EVOLVING</td>
</tr>
</tbody>
</table>
For all of your power system study, electrical equipment calibration and testing, and shock and arc flash hazard mitigation services, please contact Industrial Tests, Incorporated. As a NETA certified company with a perfect safety record and active projects in Northern and Southern California, Nevada, and Oregon and pending projects in Washington and Alaska, Industrial Tests is the go to company for you.

4021 Alvis Court – Suite 1
Rocklin, California 95677
916-632-8378
888-809-8550

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