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MANAGING ARC FLASH: A Risk Management Approach

Steve Williams
Engineers Australia - Electrical College
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ARC FLASH – RELEVANCE?

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- Higher Safety Awareness & OHS Legislation
- Statistics – Less Electrocutions; More Burns
- Larger Systems & Higher Fault Currents
- Ageing Switchgear (& still expected to function!)
- Demand for Production –> Live Work
- Less Maintenance Staff (trained)
- Increased Litigation & Insurance Costs
- Software Technology Advancements

ARC FLASH CHARACTERISTICS

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- Arcing Electrical Fault a.k.a. Arc “Flash” or Fireball
- An Arc Flash consists of:
  - Radiant heat and light
  - Plasma cloud (super-heated ionised gas)
- Copper & Aluminium is vaporised (Cu expands 44,000 times!)
- Pressure waves shear bolts, destroy panels (& burst ear drums!)
- Molten metal & shrapnel – conductors, steel, insulation
- Ignition of clothing several meters away
- Energy involved?
  - A 10kA arc blast (480 volts) is equivalent to 8 sticks of dynamite!
- HV behaves differently to LV!

BOLTED FAULT vs. ARC FAULT

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LV Bolted faults:

- Low impedance and high current
- Energy is contained by the conductor (bus or cable)
- Cleared quickly by circuit breakers or fuses (Inst. trip)
- Arcing is confined within the circuit breaker or fuse
- Relatively low safety risk to personnel

LV Arcing faults:

- High impedance (air) results in lower current (~30-40%)
- Energy released into surrounding air
- Persist longer (Inverse Time)
- Propagate along bare bus
- High release of heat and blast energy
- Are very destructive and dangerous to personnel

SOME CAUSES OF ARC FLASH

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- Accidental contact
- Dropped tools
- Faulty / Inappropriate test equipment
- Incorrect device removal / operation
- Corrosion / Conductive dust particles
- Deteriorating or poor insulation
- Misalignment of moving contacts
- Entry of foreign body (rodent, snake)
- Equipment operating beyond its limits or lifespan

SOME CAUSES OF ARC FLASH

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- **Accidental contact**
- **Dropped tools**
- **Faulty / Inappropriate Test Equipment**
- **Incorrect Removal / Operation / Modification**
- Corrosion / Conductive dust particles
- Deteriorating or poor insulation
- Misalignment of moving contacts
- Entry of foreign body (rodent, snake)
- Equipment operating beyond its limits or lifespan

HUMAN ERROR

SOME CAUSES OF ARC FLASH

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- Accidental contact
- Dropped tools
- Faulty / Inappropriate Test Equipment
- Incorrect device removal / operation
- **Corrosion / Conductive dust particles**
- **Deteriorating or poor insulation**
- **Misalignment of moving contacts**
- **Entry of foreign body (rodent, snake)**
- **Equipment operating beyond its limits or lifespan**

POOR MAINTENANCE

EXAMPLE - 415V ARC FLASH

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EXAMPLE - 415V ARC FLASH

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EXAMPLE - 690V ARC FLASH

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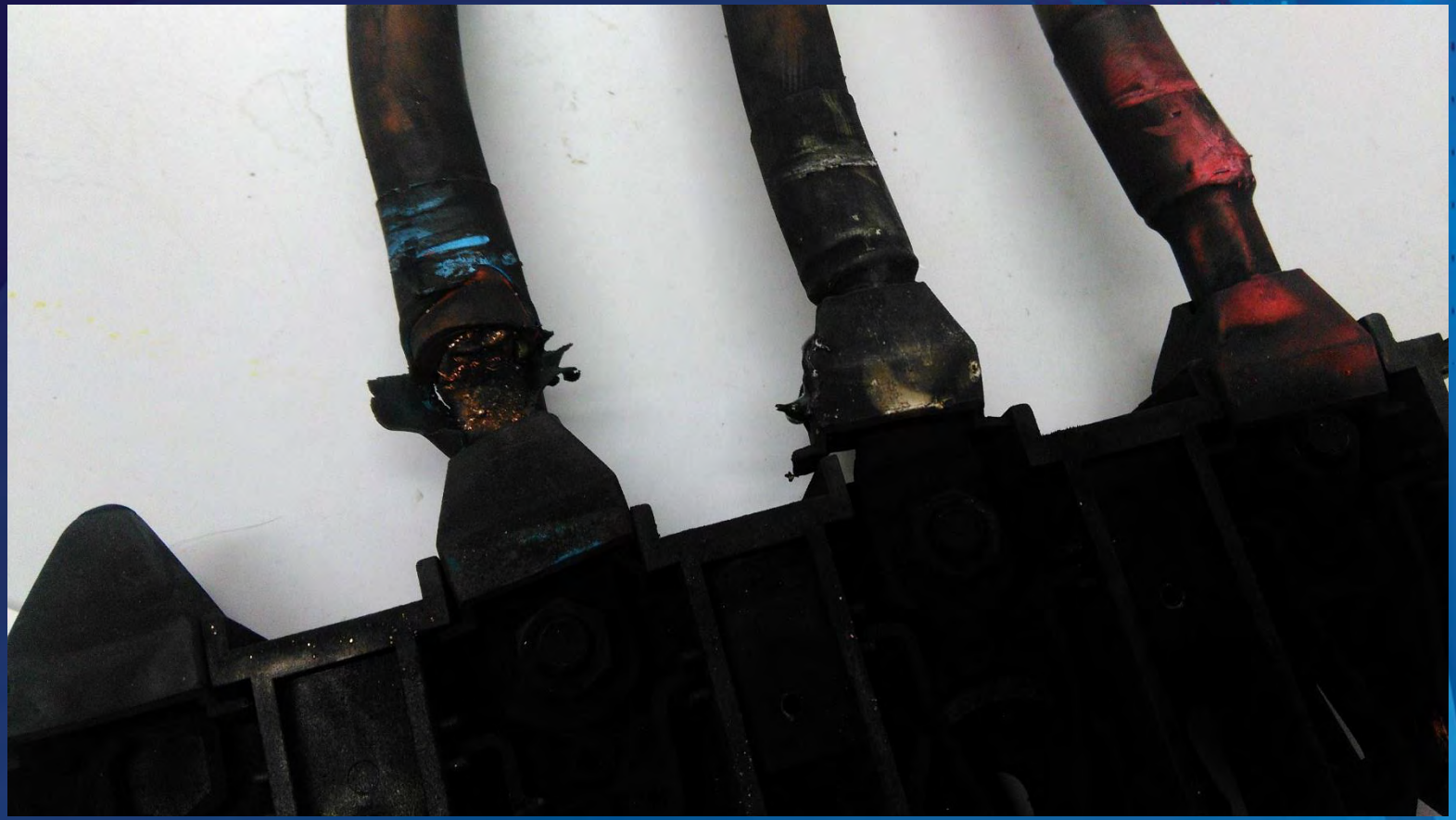

EXAMPLE - 690V ARC FLASH

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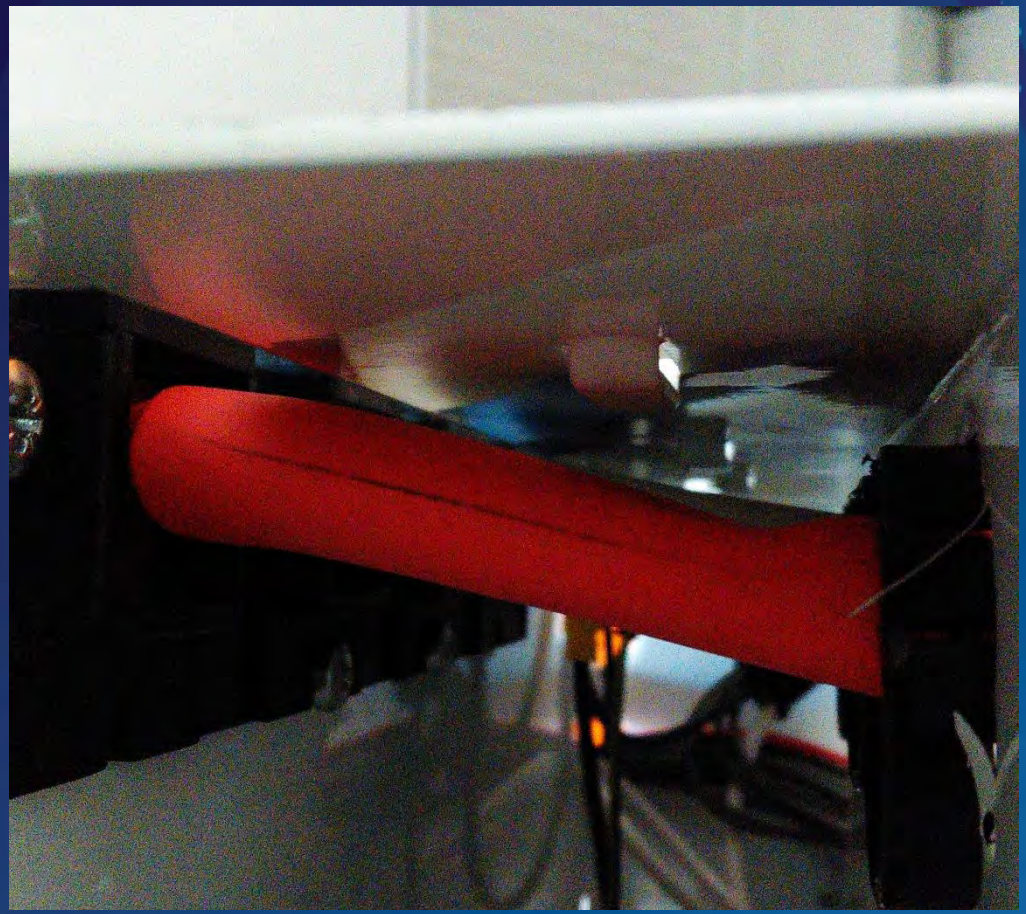

MISCONCEPTION #1

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WRONG!

Arc Flash Management = Arc Fault Containment

- Arc Fault Containment:
  - Is the tested ability of a switchboard to safely contain an arcing fault, to avoid damage to adjacent switchgear and/or injury to an operator, while in its designed operational state.

    i.e. **with the doors and panels *closed and secured!***
- Arc Flash Management:
  - Is the combination of measures applied to an installation to minimise the risk of an arcing fault injury to an electrician who is carrying out a task on a switchboard……..

    with the doors or panels *opened!*

MISCONCEPTION #2

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Need to wear calculated PPE when switching (i.e. doors closed and secured)

WRONG!

- In USA, NFPA 70E (2015) standard is now clear:

  "Normal operation of electric equipment is permitted with no extra PPE when all of the following conditions are satisfied:

  - The equipment is properly installed;
  - The equipment is properly maintained;
  - All equipment doors are closed and secured;
  - All equipment covers are in place and secured; and
  - There is no evidence of impending failure."

MISCONCEPTION #3

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HV Arc Flash risks are higher than LV

WRONG!

- High Voltage:
  - Low fault impedance – faster clearing times
  - Switching procedures normally required
  - Larger working distance to conductors
- Low Voltage:
  - Higher fault impedance - slower clearing times
  - Worker complacency – “it’s only 415V!”
  - Lack of procedures
  - Closer proximity to conductors

ARC FLASH PPE STANDARDS

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- **International (USA):**
  - IEEE 1584 – *Guide for Performing Arc Flash Hazard Calculations*
  - NFPA 70E - 2015 Edition – *Standard for Electrical Safety in the Workplace*
- **Australia & New Zealand:**
  - AS/NZS 4836:2011 - *Safe working on or near low-voltage electrical installations and equipment*
  - (Aust) ENA NENS 09-2014 – *Guideline for Selection, Use and Maintenance of PPE for Electrical Arc Hazards.*
  - **None are legislated (except mining)**
  - **But OH&S Duty of Care applies!**

AS/NZS 4836:2011

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- Safe working on or near ***LV*** installations
  - Revised in May 2011 to include Arc Flash Safety
  - Emphasises Risk Assessment & Risk Management
  - Competent person must identify risk for work within 3m of exposed energised conductors
  - Assess and reduce risk, e.g. Establish Policy & Procedures, Switch off, Isolate/Tag, Erect Barriers, etc
  - Lists suitable Safety Equipment and Tools (but FR not AR)
  - PPE is not first line of defence, but to be used as a precautionary measure
  - Does not utilise Incident Energies to select HRC & PPE

AS/NZS 4836:2011

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TABLE 9.2 GUIDE TO THE SELECTION OF PERSONAL PROTECTIVE EQUIPMENT			
TASK	**CURRENTS UP TO AND INCLUDING 100 A**	**CURRENT EXCEEDING 100 A AND UP TO AND INCLUDING 400 A**	**CURRENTS EXCEEDING 400 A**
Work (isolated and verified)	Footwear Protective clothing (if required) Eye protection (if required) Gloves (if required) Hearing protection (if required) Safety helmet (if required) Respiratory protection (if required)	Footwear Protective clothing (if required) Eye protection (if required) Gloves (if required) Hearing protection (if required) Safety helmet (if required) Respiratory protection (if required)	Footwear Protective clothing (if required) Eye protection (if required) Gloves (if required) Hearing protection (if required) Safety helmet (if required) Respiratory protection (if required)
Switching, isolating, removing fuses or links	Footwear Protective clothing Eye protection Gloves (if required) Hearing protection (if required) Safety helmet (if required) Respiratory protection (if required)	Footwear Protective clothing Eye protection Gloves Hearing protection (if required) Safety helmet (if required) Respiratory protection (if required)	Footwear Protective clothing Eye protection Gloves Hearing protection (if required) Safety helmet (if required) Respiratory protection (if required)
Isolation verification, testing or fault finding	Footwear Protective clothing Eye protection Gloves Hearing protection (if required) Safety helmet (if required) Respiratory protection (if required)	Footwear Protective clothing* Eye protection Gloves Arc flash suit and hood (if required) Hearing protection (if required) Safety helmet (if required) Respiratory protection (if required) Face shield (if required)	Footwear Protective clothing* Eye protection Gloves Face shield Arc flash suit and hood (if required) Hearing protection (if required) Safety helmet (if required) Respiratory protection (if required)
Live electrical work	Footwear Protective clothing* Eye protection Insulating gloves Arc flash suit and hood (if required) Flame-resistant gloves (if required) Face shield (if required) Safety helmet (if required) Hearing protection (if required) Respiratory protection (if required)	Footwear Protective clothing * Eye protection Safety helmet Insulating gloves Arc flash suit and hood (if required) Flame-resistant gloves (if required) Face shield (if required) Hearing protection (if required) Respiratory protection (if required)	Footwear Protective clothing * Eye protection Insulating gloves Flame-resistant gloves Arc flash suit and hood Hearing protection Respiratory protection (if required)

ENA NENS 09-2014

ELECTRICAL ENGINEERING SPECIALISTS

- *National Guideline for Selection, Use and Maintenance of PPE for Electrical Arc Hazards*
- Published by Energy Networks Association, Aust.
- Great improvement over previous version
- Uses Risk Assessment process
- Compares two calculation methods:
  - IEEE 1584
  - NENS 09 (based on 2013 Ausgrid research)
- Very focussed on the PPE garments, fabrics and properties

TERMINOLOGY

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- ***"Arc Flash Incident Energy"***
  - The amount of thermal energy a surface (or person) is exposed to at a set distance from an arc, typically the called the Working Distance. Units used are ***cal/cm² (!?)***
- ***"Arc Flash Boundary"***
  - The approach limit at which a person would be expected to receive a just curable burn on exposed skin (1.2 cal/cm^2) if an arc flash were to occur. Inside this limit, a person may experience second degree burns.

OLD ARC FLASH PPE CATEGORIES

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PPE Rating Table		
Incident energy rating in cal/cm^2	Arc Flash Hazard/Risk Category	PPE Category
N/A	0	0
0-4	1	1
>4-8	2	2
>8-25	3	3*
>25-40	4	4
>40	X	N/A

PPE controls are not suitable for incident energies in excess of 40 cal/cm^2.
Alternative controls shall be implemented.

EXAMPLES OF PPE CATEGORIES

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PPE – Categories 1 & 2

PPE – Categories 3 & 4

LATEST APPROACH

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- Site Specific Categories
  - User defined in software
- Based on PPE Clothing Selected:
  - Improvements in clothing materials
  - Need to consider environment
  - Lifespan depends on washing

SO WHAT'S THE PROBLEM?

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GOOD LUCK!

- Just do some calcs and buy some PPE?
- Very few plants are static
  - Equipment Modifications
  - Plant power system changes
  - Utility changes
  - Staff changes
- Arc Flash Risks will therefore change with time.
- …….You need a long term Arc Flash Strategy!

WHERE DO YOU START?

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Understand your current Risks:

$$D_B = \left[C_f E_n \left(\frac{t}{0.2} \right) \left(\frac{610^x}{E_B} \right) \right]^{\frac{1}{x}}$$

For the Lee method

$$D_B = \sqrt{5.12x10^5 V I_{bf} \left(\frac{t}{E_B} \right)}$$

where:

D_B	is the distance of the boundary from arcing point (mm)
E_n	is the incident energy (cal/cm^2) normalized for time and distance
C_f	is a calculation factor 1.0 for voltages above 1kV 1.5 for voltages at or below 1kV
t	is the arcing time (seconds)
E_B	is the incident energy in cal/cm^2 at the boundary distance
x	is the distance exponent from Table 1
I_{bf}	is the bolted fault current for three-phase faults (symmetrical RMS)(kA)

ck.

INTERPRET YOUR STUDY

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- Be careful…… common issues:
  - Confusion
  - Conflict
  - Misunderstanding
  - Over-reaction
- Result: Bad decisions
- Most common mistakes?
  - Jumping straight to a PPE selection process
  - Broad brush approach for the whole site

EVALUATE THE RISKS

Likelihood / Consequence	Level	Rare The event may occur in exceptional circumstances. Less than once a year	Unlikely The event could occur at some time. At least once a year	Moderate The event will probably occur at some time. At least once in 6 months	Likely The event will occur in most circumstances. At least once per month	Certain The event is expected to occur in all circumstances. At least once per week
		1	2	3	4	5
Negligible No injuries. Low financial loss.	0	0	0	0	0	0
Minor First-aid treatment. Moderate loss.	1	1	2	3	4	5
Serious Medical treatment required. High financial loss. Moderate environment implications. Moderate loss of reputation. Moderate business interruption.	2	2	4	6	8	10
Major Excessive, multiple long term injuries. Major financial loss. High environmental implications. Major loss of reputation. Major business interruption.	3	3	6	9	12	15
Fatality Single death.	4	4	8	12	16	20
Multiple Multiple deaths and serious long term injuries.	5	5	10	15	20	25

Legend

Risk Rating	Risk Priority	Description
0	N	No Risk: The costs to treat the risk are disproportionately high compared to the negligible consequences.
1-3	L	Low Risk: May require consideration in any future changes to the work area or processes, or can be fixed immediately.
4-6	M	Moderate: May require corrective action through planning and budgeting process.
8-12	H	High: Requires immediate corrective action.
15-25	E	Extreme: Requires immediate prohibition of the work, process and immediate corrective action.

IDENTIFY BEST CONTROLS

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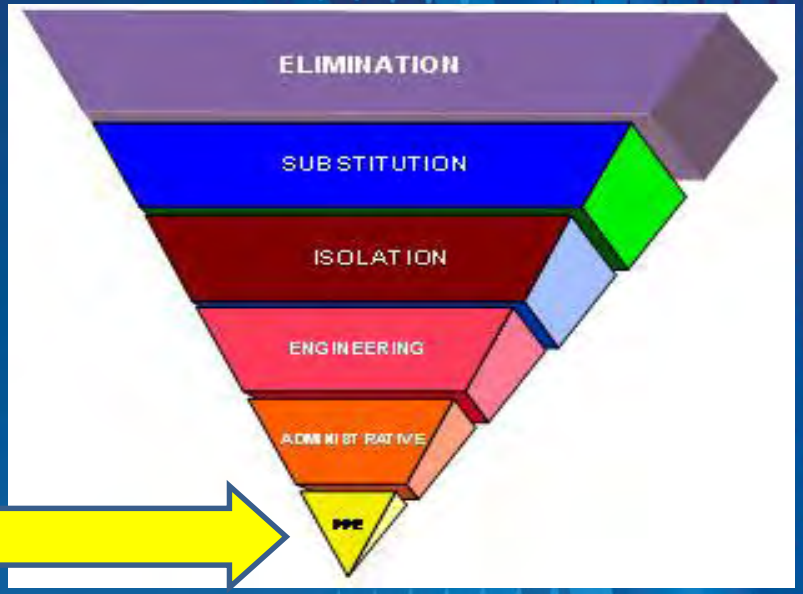
- Use Hierarchy of Controls
- Individual reviews required
- Use a standard process
- But…… Keep It Simple!
- PPE only as last choice



REVIEW MITIGATION OPTIONS

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- Options vary in:
  - Effectiveness
  - Capital cost
  - Production interference
  - Worker acceptance
- Preferably use multi-layer approach
- Most effective options:
  - Reduce fault levels & clearing times
  - Reduce likelihood of occurrence
- Document your outcomes & reasons

MITIGATION OPTIONS

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- Substitution Options:
  - Minimal cost at initial design stage
  - Isolate elsewhere (that has lower risk)
  - Replacement of older switchboards with improved segregation, better insulated busbars, etc
  - Replace older OCBs with VCBs or SF6
  - Replace older protection relays with modern faster acting units, and more setting adjustments
  - Replace manual racking with motorised racking
  - Replace MCCBs with fuses (& MCCBs have limitations)
  - Provide better (safer) Test-for-Dead equipment

MITIGATION OPTIONS

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- Engineering Solutions:
  - Reduce fault levels by changing network configuration
  - Reduce fault clearance times by installing enhanced relay protection (cable diff; transformer diff)
  - Select more sensitive relay settings, or dual settings
  - Install arc fault detection relays
  - Install arc quenching schemes (new switchboards)
  - Remove operator from risk:
    - Remote switching control
    - Remote circuit breaker racking schemes

MITIGATION OPTIONS

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- Administrative Options:
  - Improve maintenance and switching procedures
  - Establish S.O.P.s for common tasks
  - Improve operator training and awareness programmes
  - Train & encourage electrical personnel to use self risk assessments in typical situations
  - Limit access to switch rooms and switchgear
  - Eliminate live work on/near exposed conductors

MITIGATION OPTIONS

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- Employee Training
  - Defining and Evaluating Competencies
  - Course Content and Facilitation
  - Existing Electrical Employees & Contractors
  - New Electrical Employees & Contractors
  - Non Electrical Personnel (even management?)
  - Risk Assessment Techniques
  - Refresher Courses & Toolbox Meetings

MITIGATION OPTIONS

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- Long Term Engineering Issues
  - Accuracy & validity of **Electrical Drawings**
  - Equipment identification & **labelling** – one system!
  - Specifications & selection of **New Equipment**
- Arc Flash Change Management Procedures
  - Equipment additions & modifications
  - Upgrading older Equipment
  - Fault studies & protection settings
  - Updates to Arc Flash Studies
- Technical Support Arrangements

RISK ASSESSMENT – EXAMPLE 1

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- 415V MCC 4000A incomer; 12 years old, modern
- 2500kVA transformer with >40kA Fault Level
- Rackable design; openings
- Arc Fault Containment issues
- Frequency -> Likelihood
  - Switching – tested & reset monthly
  - Maintaining – isolated; inspected annually
- Consequence -> Risk?
- What are Mitigation Options?

RISK ASSESSMENT – EXAMPLE 2

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- Dragline Sub, >15 years old
- 6.6kV Vac Breaker – Push In
- Arc Fault Containment?
- No on-board 66kV Breaker
- Frequency -> Likelihood
  - Insertion & removal while live
  - Switching – tested & reset monthly
- Consequence -> Risk?
- What are Mitigation Options?

IF MITIGATION IS NOT POSSIBLE….

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- PPE Solutions:
  - Review remaining unmitigated risks
  - Select appropriate PPE to suit
  - Clothing trials & selection
  - Clothing replacement programme
  - Switchroom kits
  - Contract staff(?)

ARC FLASH MANAGEMENT PLAN

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- Formal Management Plan:
  - Official Company Document
  - Integrated with safety documentation
  - Integration with other technical documentation
  - Sign off by management (and OH&S)
  - Reviewed annually
- Protection against litigation (?)
- Justification for upgrades & improvements

ONGOING CONTROVERSIES:

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- Quantifying the Australian/NZ Arc Flash issue….
  - *Statistics, statistics, statistics (States & Definitions)*
- IEEE 1584 calculations are flawed….
  - *Change is coming, but don't wait*
- What Standards should you use?
  - *Read & seek advice*
- Standards keep on changing….
  - *But do nothing, and you will achieve nothing*
- Workers dislike & avoid the PPE….
  - *Involve your workers in the process*

IN CONCLUSION…….

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Let's protect our workers against THIS!

THANK YOU

- Questions?

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