43rd IIEE ANNUAL NATIONAL CONVENTION

By : Engr. Jozane F. Jalbuena, PEE

About the Lecturer

ENGR. JOZANE F. JALBUENA, PEE

- Professional Electrical Engineer, PEE 3981
- Project Management and Electrical Consultant
- Wide Experience in Energy, Electrical, Environmental Management System
- Certified Hazardous Material and Waste Emergency Responder
- Environmental Management System Lead Auditor, AJA

RESONANZ TG Inc. 2011 – Present

- Vice President – Construction
- PCAB - Authorized Managing Officer
- Consultant

Toyota Motor Philippines Corporation:
1991-2011

- Utility Engineering Head
- Resident Electrical Engineer
- Energy Management Auditor
- Environmental Lead Auditor

Institute of Integrated Electrical Engineer

- Life Member
- 2012 Southern Luzon Governor
- Northern Laguna 2008 Chapter President,
- (Awarded 2008 Most Outstanding Chapter)
- 2010 Region IV Deputy Governor
- TWG Committee Member

BACK GROUND

1. Unknown Arc Flash Incident Energy

2. Selection of PPE for EEW, arc flash incident energy were not considered.

3. Arc Flash Incident Energy, Safe Boundary , Required PPE are not written in the Panel Board Safety Warning

Republic of the Philippines
DEPARTMENT OF PUBLIC WORKS AND HIGHWAYS
OFFICE OF THE SECRETARY
Manila

12-19-30 N

In order to attain an electrically safe environment and pursuant to Section 1301 of the National Building Code (PD 1096) and Article 1.3.2 of the Philippine Electrical Code, all Building Officials are hereby enjoined to be stricter in approving Building Permits by requiring the submission of electrical plans that include design analysis showing all the calculations of short circuits, voltage drop and other essential data as requisite for the issuance of Electrical Permit. Likewise, existing buildings, factories and infrastructures with substantial electrical load shall be subjected to inspections and that an updated design analysis and calculations is required to ensure that fire and life safety requirements are being complied.

DOLE - OSHS

OCCUPATIONAL SAFETY AND HEALTH STANDARDS
AS AMENDED
DEPARTMENT OF LABOR AND EMPLOYMENT MANILA

1004 : Special Inspection, Investigation and Review

(1) Any worker or representative of workers or any concerned person who believes that a violation of any provision of this Standards threatens physical harm or imposes imminent danger to life, may request an inspection by giving full particulars or details regarding such violation or danger to the Regional Labor Office or duly authorized representative. If upon appraisal of such notification, the Regional Office or its duly authorized representative finds reasonable ground to believe that a violation has really been committed or danger exists, a special inspection or investigation shall be conducted immediately. The complainant shall be notified in writing of the outcome of such investigation or inspection, immediately upon its completion.

(2) The Secretary of Labor and Employment on his own initiative or on complaints of the workers, shall review any failure or refusal of the Regional Labor Office or duly authorized representative to order compliance or issue recommendation with respect to such complaint or reported violation.

Engr. Jozane F. Jalbuena, PEE

DOLE - OSHS

1005: Duties of Employers, Workers and other Persons

(1) Each employer covered by the provisions of this Standards shall:

a. furnish his workers a place of employment free from hazardous conditions that are causing or are likely to cause death, illness or physical harm to his workers;

b. give complete job safety instructions to all his workers, especially to those entering the job for the first time, including those relating to the familiarization with their work environment, hazards to which the workers are exposed to and steps taken in case of emergency;

c. comply with the requirements of this Standards; and

d. use only approved devices and equipment in his workplace.

[REPUBLIC ACT NO. 11058]

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AN ACT STRENGTHENING COMPLIANCE WITH tor
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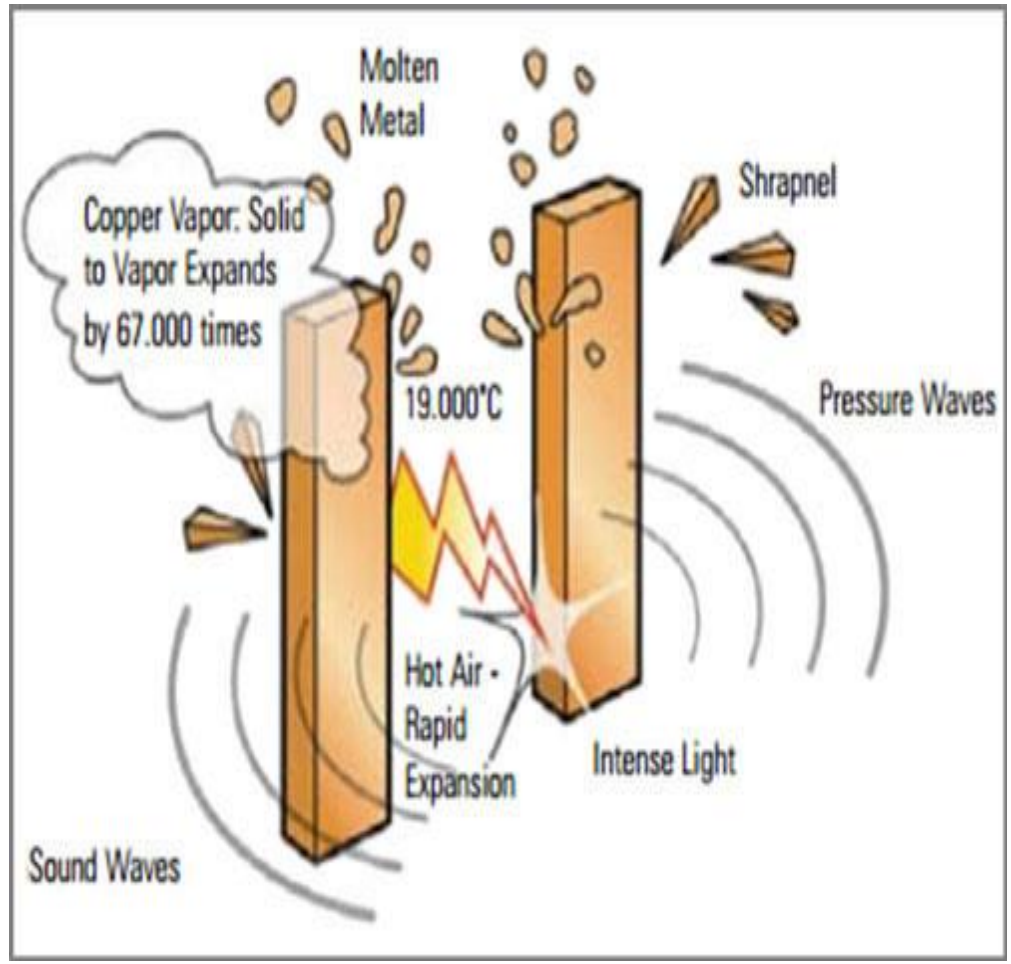
shall make such employer, contractor or subcontractor liable for an administrative fine not exceeding One hundred thousand pesos (P100,000.00) per day until the violation is corrected, counted from the date the employer or contractor is notified of the violation or the date the compliance order is duly served on the employer. The amount of fine imposed shall depend on the frequency or gravity of the violation committed or the damage caused: *Provided, however*, That the maximum amount shall be imposed only when the violation exposes the workers to a risk of death, serious injury or serious illness.

What is Arc Flash?

Discharge of electricity through a combination of ionized air and vaporized conductor material.

The conductive material is vaporized by temperatures in an arc which can be as high as 19,426 ºC (35,000ºF)



Arc Flash Accident

Electrocuted OFW in Saudi home after 2 y

By: Tina G. Santos - Reporter / @santostinaINQ Philippine Daily Inquirer / 03:01 AM May 23, 2012

Alfred Salmos, the overseas Filipino worker who was severely electrocuted in Saudi Arabia two years ago, is finally home.

Alfredo Salmos

Salmos arrived at Ninoy Aquino International Airport Terminal 1 on a Saudi Air flight from Jeddah at 12:50 p.m. Tuesday. He was welcomed by his family who turned emotional on seeing him.

From the airport, Salmos proceeded to the Coconut Palace to meet Vice President Jejomar Binay with his siblings Epifania Reem Salmos-Colina and Junny Salmos.

Why do we need to calculate *Arc Flash Incident Energy and Arc Flash Boundary*?

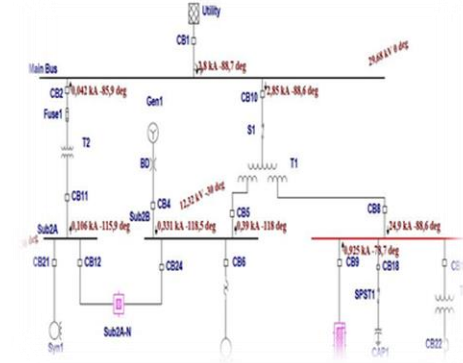
Electrical Safety Improvement; elimination of electrical fire hazard and fatal incident…

1. Risk mitigation, **INCIDENT ENERGY** reduction

2. Determine a correct PPE requirement for electrical works, base on the calculated **INCIDENT ENERGY**

3. Work place safety distance **ARC FLASH BOUNDARY**

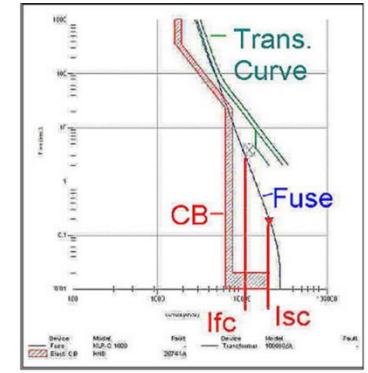
FACTORS INFLUENCE ARC FLASH ENERGY



1. Short Circuit Current

- Bolted Fault Current

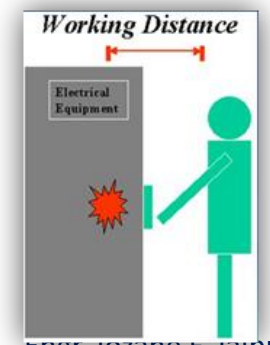
2. Time Current Curve, Protective Coordination



- Arc Fault Current
- Bolted Fault Current

3 . Distance to Arc Fault

- Working Distance ; is the total distance from the live parts to panel enclosure and from the enclosure to the personnel standing



How to Determine Arc Flash Incident Energy?

The Arc Flash analysis requires the completion of a **Short Circuit Study and a Coordination Study**.

The results of the Arc Flash calculations are based on the calculated values of ***fault current magnitudes found in the short circuit study*** and ***the associated clearing times of overcurrent protection devices as determined by the coordination study***.

NFPA 70E Arc Flash Method

$$E_{ARC} = 1038.7\, D_A^{-1.4738} \times t_A\, [0.0093\, F^2 - 0.3453F + 5.9673]$$ ***Arc in a Cube Box***

$$E_{ARC} = 5271\, D_A^{-19593} \times t_A\, [0.0016\, F^2 - 0.0076F + 0.8938]$$ ***Arc in a Open Air***

Where :

E_{ARC} - Incident Energy, cal/cm^2

D_A - Working Distance (IEEE 1584 Table 3) or verify at the site

t_A - Device Tripping Time / Clearing Time (IEEE 1584 Table 1)

F - Short Circuit Current, kA

IEEE 1584 - 2002 - TABLE 1

Table 1—Power circuit breaker operating times[a]

Circuit breaker rating and type	Opening time at 60 Hz (cycles)	Opening time (seconds)
Low voltage (molded case) (< 1000 V) (integral trip)	1.5	0.025
Low voltage (insulated case) (< 1000 V) power circuit breaker (integral trip or relay operated)	3.0	0.050
Medium voltage (1–35 kV)	5.0	0.080
Some high voltage (> 35 kV)	8.0	0.130

[a]This table does not include the external relay trip times.

System Parameters per IEEE 1584

System Voltage (kV)	Calculation Factor (C_f)	Equipment Type	Gap (G) (mm)	Distance factor (x)	Working Distance (D) (mm)	Enclosure Configuration (K_1)	Grounded or Ungrounded (K_2)	Unique Constant (k)
0.208 - 1	1.5	Open Air*	10	2.000	455	-0.792	-0.113	0.6945
							0	0.5354
			40	2.000	455	0.792	-0.113	0.6437
							0	0.4962
		Switchgear	32	1.473	610	-0.555	-0.113	0.6841
							0	0.5274
		MCC and Panels	25	1.641	455	-0.555	0.113	0.4304
							0	0.3318
		Cable	13	2.000	455	-0.792	-0.113	0.6893
							0	0.5314
>1 5	1.0	Open Air	102	2.000	455	-0.792	-0.113	0.8252
							0	0.6362
		Switchgear*	13	0.973	910	-0.555	-0.113	1.5890
							0	1.2250
			102	0.973	910	-0.555	-0.113	1.2683
							0	0.9778
		Cable	13	2.000	455	-0.792	-0.113	1.0339
							0	0.7970
>5 - 15	1.0	Open Air*	13	2.000	455	0.792	-0.113	1.0339
							0	0.7970
			153	2.000	455	-0.792	-0.113	0.7252
							0	0.559*
		Switchgear	153	0.973	910	-0.555	0.113	1.1146
							0	0.8593
		Cable	13	2.000	455	-0.792	-0.113	1.0339
							0	0.7970

* Minumum and maximum values are shown for a range of typical bus gaps (G).

System parameter values are based on IEEE Standard 1584™-2002, Tables 2, 3, & 4.

Table 4.11: Hazard/Risk Classification as per NFPA 70-E (2004)

Incident energy that will cause a just treatable burn or second degree about 5.0 $J/cm^{2.}$ or 1.2cal/cm^2 for instance human figure expose to butane light in 1 second at 1cm away, expose area is about cm^2, the finger are exposed to about 5.0 J/cm^2 or 1.2cal/cm^2

Hazard Risk Category, HRC	Incident Energy	
	From (cal./cm^2)	To (cal./cm^2)
0	0.00	1.2
1	1.2	4.0
2	4.0	8.0
3	8.0	25.0
4	25.0	40.0

Hazard Category and PPE / Clothing Rating

HRC	Incident Energy		PPE / Clothing Description	Clothing Layers	Required Min. Arc Rating of PPE Cal/cm^2
	From (cal./cm^2)	To (cal./cm^2)			
0	0.00	1.2	Untreated Cotton	1	N/A
1	1.2	4.0	FR Shirt & Pants	1	4
2	4.0	8.0	Cotton Under wear+ FR Shirt & Pants	1 or 2	8
3	8.0	25.0	Cotton Under wear + FR shirt & Pant + FR Coverall+ hood	2 or 3	25
4	25.0	40.0	HRC 3 requirement + Flash Suit	3 or More	40

PPE REQUIREMENT PER CATEGORY

Hazard Risk Category 0

Untreated Cotton

Hazard Risk Category 1

FR Shirt & Pants

Hazard Risk Category 2

Cotton Under wear
+ FR Shirt & Pants

Hazard Risk Category 3

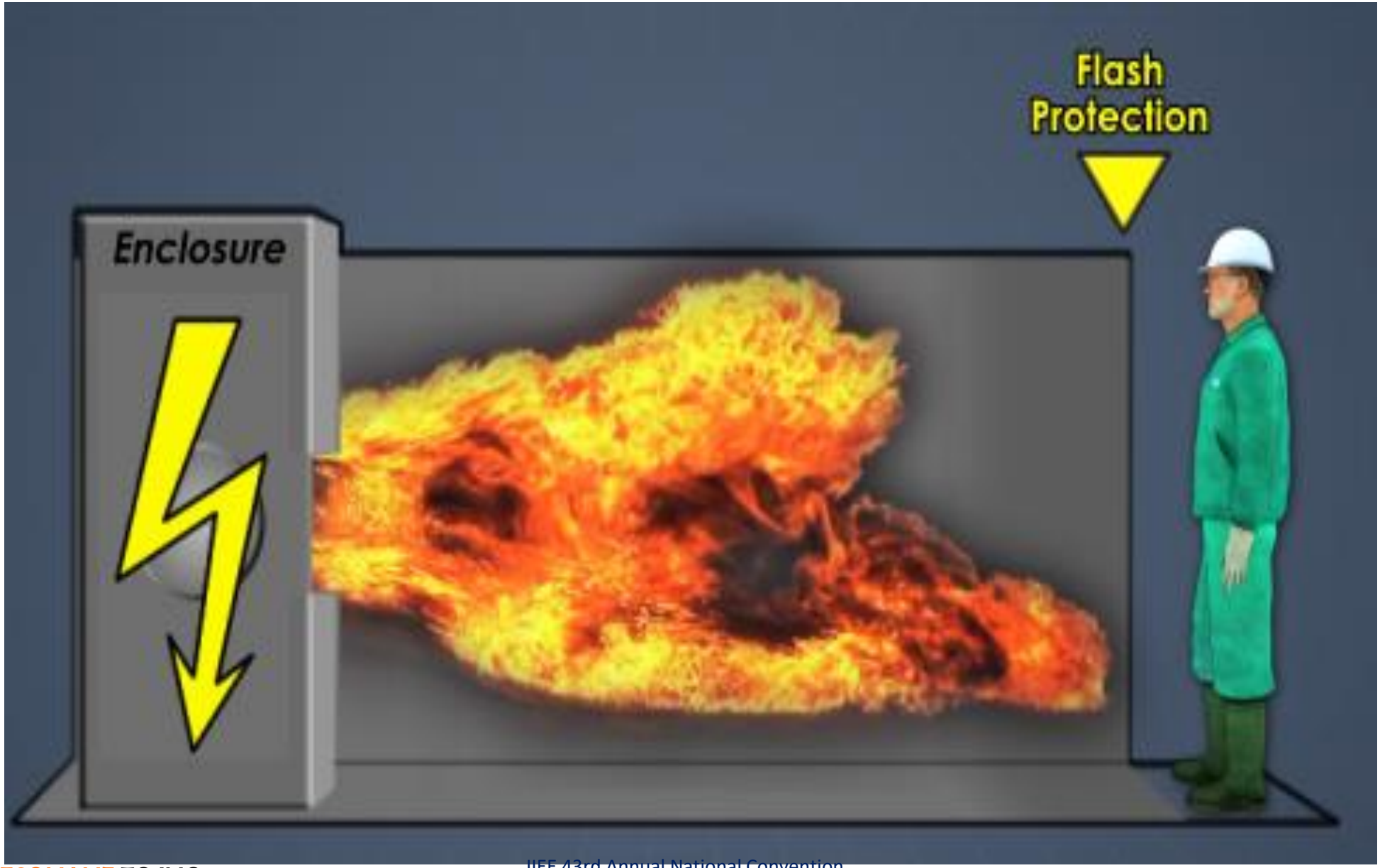
Cotton Under wear
+ FR shirt & Pant
+ FR Coverall
+ hood

Hazard Risk Category 4

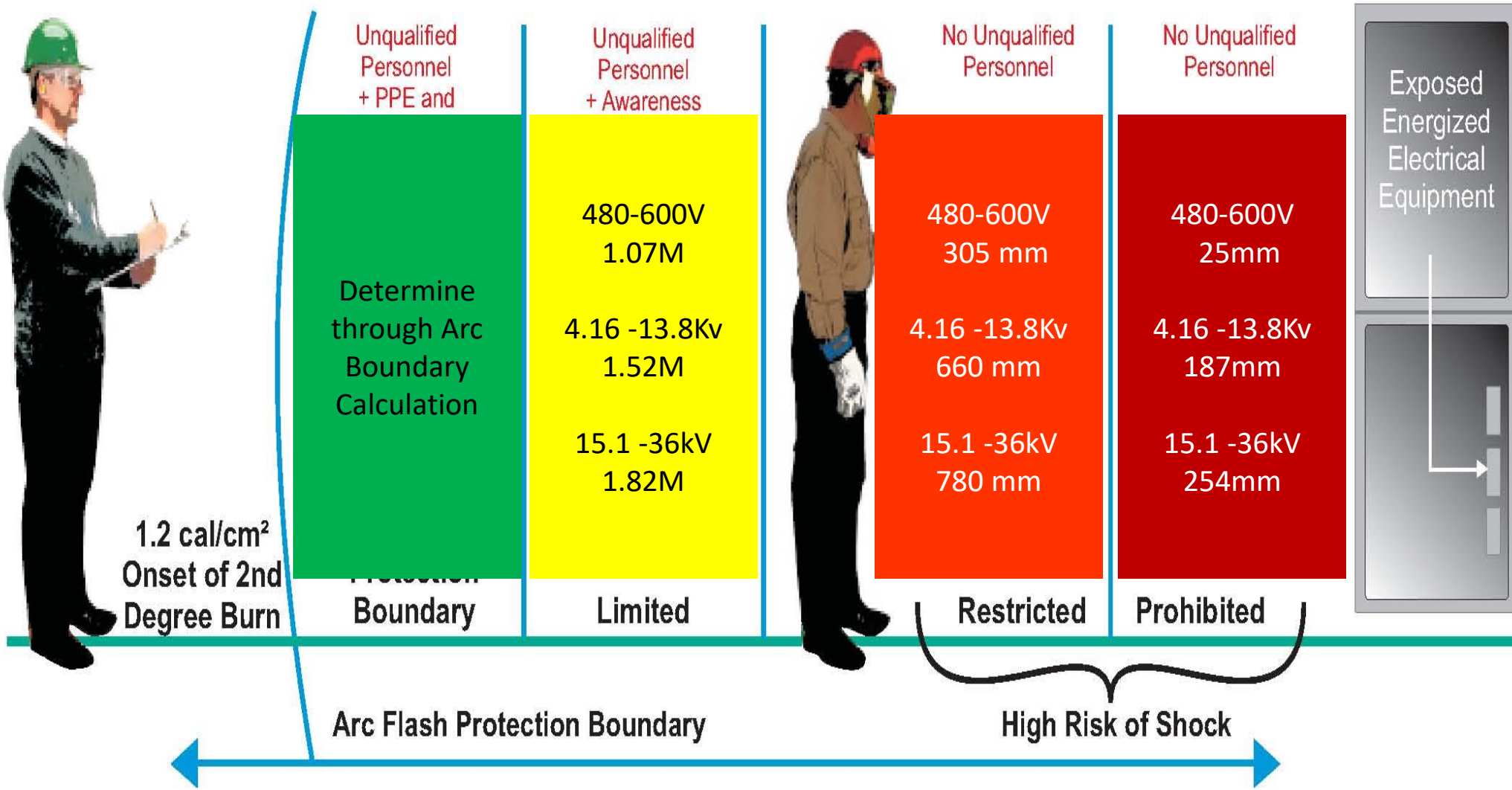
HRC 3 requirement
+ Flash Suit

Using Arc Flash Suit / Correct PPE

Boundaries for Arc Flash Protection



Boundaries for Arch Flash Protection and Shock Approach Limits



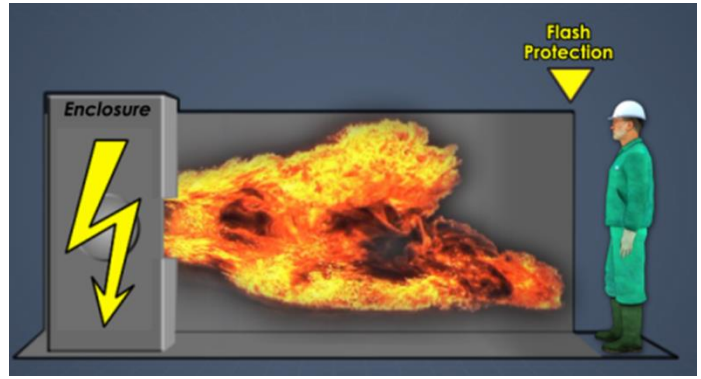
Determine Flash Protection Boundary, NFPA 70E

$$D_B = D\left(\frac{E}{E_B}\right)^{1/X}$$

Where:

D_B = distance of the boundary from the arcing point (see note)
D = working distance (see note)
E = maximum incident energy at working distance in cal/cm^2
E_B = incident energy at boundary, usually 1.2 cal/cm^2 for arcing time > 0.1s.
x = distance exponent factor (see Table 4.12)

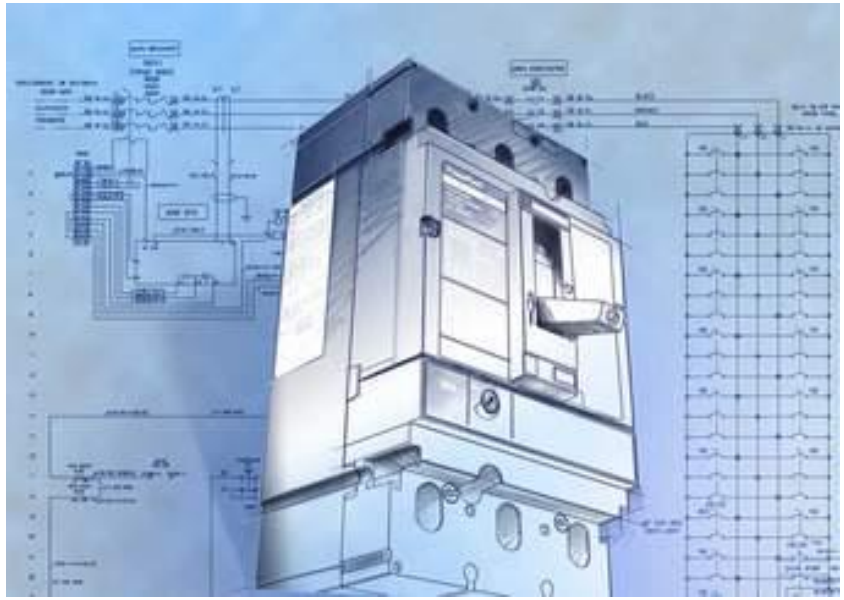
Note:
Distances D_B and D must both be in the same units. They can be expressed in inches or mm.

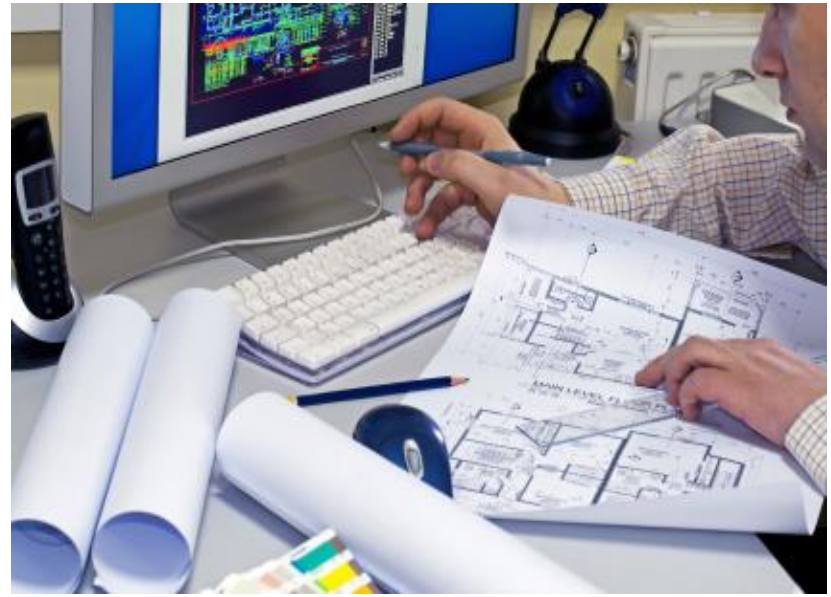


Panel Board Warning

Why Arc Flash Happened?

- **Poor Electrical Design**
  - Power System Study were not performed
  - Not Cost Effective Design





Why Arc Flash Happened?

- **Poor Electrical System Management**
  - Additional load in the system, fault current were not reviewed and adjust devise setting and rating.
  - Defective Circuit Breaker were replaced with lower kAIC
  - Poor Maintenance program.

Why Arc Flash Happened?

- **Personnel Skills and Qualification**
  - Hazard identification
  - Mitigate Hazard
  - Operate Electrical Equipment
  - Electrical Installation

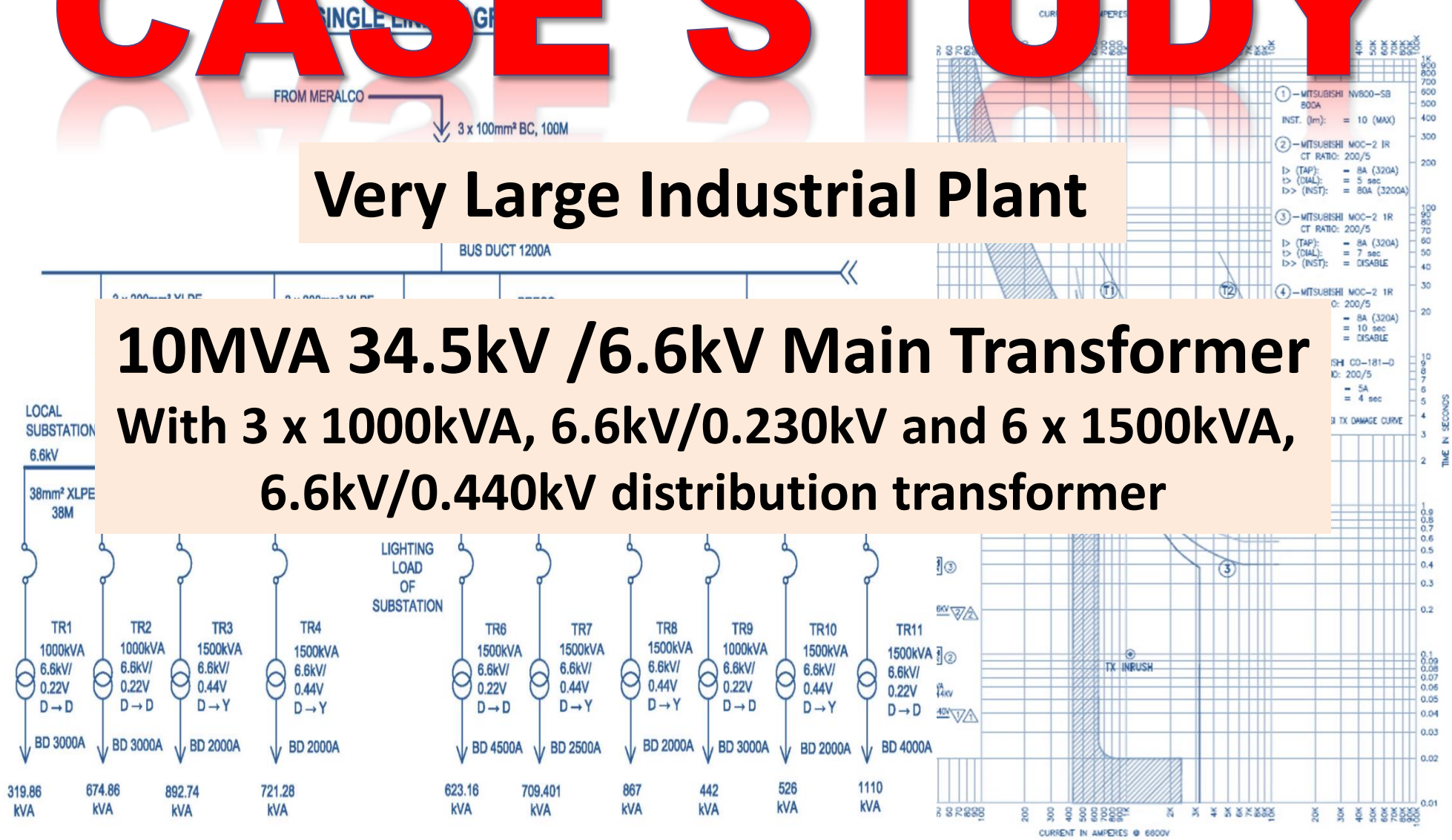
- **Procedure / Policy**
  - No established procedure for switching
  - No Policy / Procedure on Electrical Energized Work

CASE STUDY

Very Large Industrial Plant

10MVA 34.5kV /6.6kV Main Transformer

With 3 x 1000kVA, 6.6kV/0.230kV and 6 x 1500kVA, 6.6kV/0.440kV distribution transformer



OBJECTIVE OF THE STUDY

- **Identify and Quantify SAFETY**
  - ✓ Remove hazards and prevent explosion of electrical equipment when faults occur

- **Ensure RELIABILITY**
  - ✓ Protective devices shall operate only when they are called for during faulted conditions
  - ✓ Only the faulted portion of the electrical system should be isolated
  - ✓ Back-up protective system should operate if primary protection as first line of defense fails to operate

Scope of the Study

Load Flow Study

- ✓ Determine the voltage, current, active and reactive power of the electrical system including the reactive power compensation.

Short Circuit Study

- ✓ Computer simulations of three-phase and single line-to-ground faults according to ANSI/IEEE 242 standards

Comparison of Short Circuit Duties

- ✓ Determine safety margin of protective devices
  - Compare protective device duty and the calculated maximum possible fault currents that the device will interrupt

Scope of the Study

Protection Coordination

- ✓ Determine settings of protective devices
  - Plot of Time-Current Characteristics of Circuit Breakers and Relays against normal and fault currents.

Arc Flash

- ✓ Determine the flash protection boundary in accordance with NFPA 70E; the arch-flash incident energy; require labeling and personnel protective equipment.

FOUND DEFICIENCY IN THE ELECTRICAL SYSTEM AND RECOMMENDATION

DEFICIENCY – IMPACT – RECOMMENDATION

Voltage Drop

Deficiency	Impact	Recommendation
Voltage of Feeder line exceed maximum 3% voltage drop as required by the PEC 2009.	- Voltage deficiency generate addition heat to the cable and that shorten the life of insulation, result to insulation failure. - Equipment Down Time. Affects the plant productivity	- Install addition cable in parallel to the existing. - Reduction of Loads / - Re circuiting

Cable No.	From	To	Source Voltage (V)	kVA (Demand)	Demand Current (A)	Cable Type	Size (mm2)	Cable Per Phase	Length (m)	Wire Effective Z	Voltage drop(V)	Voltage drop(%) <3%	Receiving Voltage (V)	Remarks
LC -A 40	BUSDUCT A214	LP-HY3	213	37.15	100.70	THHN	38	1	86	0.16	7.9	3.69%	205	Failed
A215	MD5 - A215	MTS Panel	220	132.60	348.00	THHN	250	1	180	0.05	17.8	8.08%	202	Failed
W213	MDB 6	MCC CT	220	187.85	493.00	THHN	500	1	105	0.04	11.8	5.34%	208	Failed
E24	ATS-E220	LP-O	220	34.18	89.70	THHN	38	1	150	0.16	12.23	5.56%	208	Failed
LC-T053	BUSDUCT T-215	E Coat Oven	212	95.74	260.73	THHN	200	1	85	0.053	6.67	3.15%	205	Failed
LC-T055	BUSDUCT T-215	E-Coat Incenirator	212	75.73	206.25	THHN	125	1	95	0.073	8.12	3.83%	204	Failed

CIRCUIT BREAKER INTERRUPTING CAPACITY DEFICIENCY

PANEL/CB. I.D.	KV	Cont. I (Amps)	Duty kAIC	Short Circuit Current (kA)	Circuit Breaker kAIC Assessment
MDB-7	0.44			49.27	
CB-1		800	42		Failed
CB-2		800	42		Failed
CB-3		800	42		Failed
CB-4		800	42		Failed
CB-5		800	42		Failed
CB-6		800	42		Failed
CB-7		800	42		Failed
CB-8		800	42		Failed
CB-9		800	42		Failed
CB-10		800	42		Failed
CB-11		800	42		Failed
CB-12		800	42		Failed
MDB-8	0.44			49.27	
CB-1		800	42		Failed
CB-2		800	42		Failed
CB-3		800	42		Failed
CB-4		800	42		Failed
CB-5		800	42		Failed
CB-6		800	42		Failed

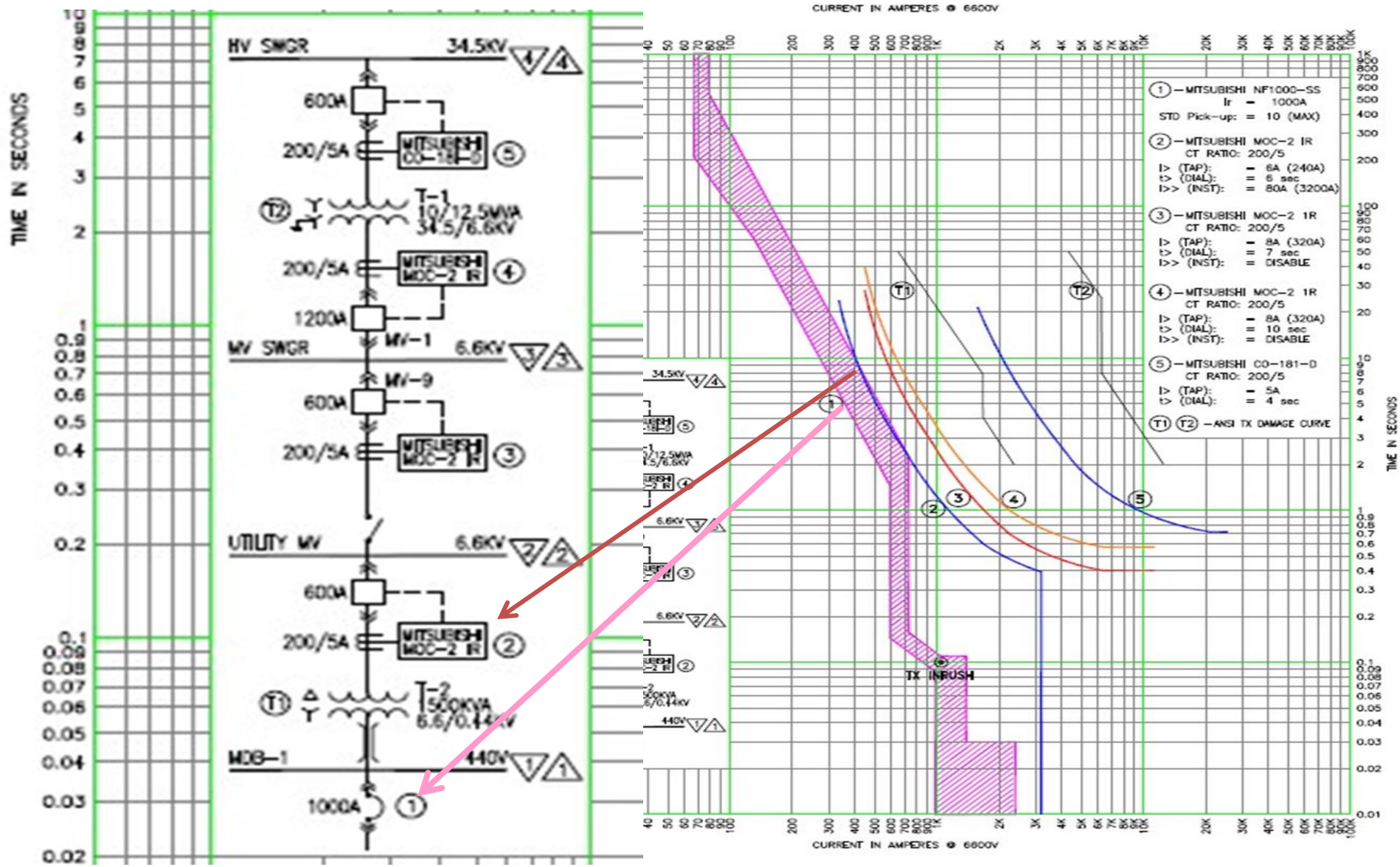
Circuit Breaker Duty Comparison

Deficiency	Impact	Recommendation
- Low interrupting capacity rating of the circuit breaker compared to the available fault current in the system	- Explosion of Circuit Breaker when fault occurred. • Possible cause of fire • Personnel Injury	- Replace circuit breaker with low interrupting capacity compared to fault current

Installed 42kAIC Circuit Breaker

Replaced : Circuit Breaker 62kAIC Circuit Breaker

PROTECTIVE RELAY COORDINATION



DEFICIENCY – IMPACT – RECOMMENDATION

Protective Relay Coordination

MDB-1

Deficiency	Impact	Recommendation
▪ Blue tripping curve touch or intersect with Pink tripping curve, meaning if there is fault at compressor side, 1200AT circuit and the MDB 1 will trip off. Entire MDB1 load will be affected.	• The entire MDB 1 load will be affected. • 3 compressors and cooling tower will be affected • Unwanted production Line stop	• Replace protective relay with wide tripping range and with inverse time delay

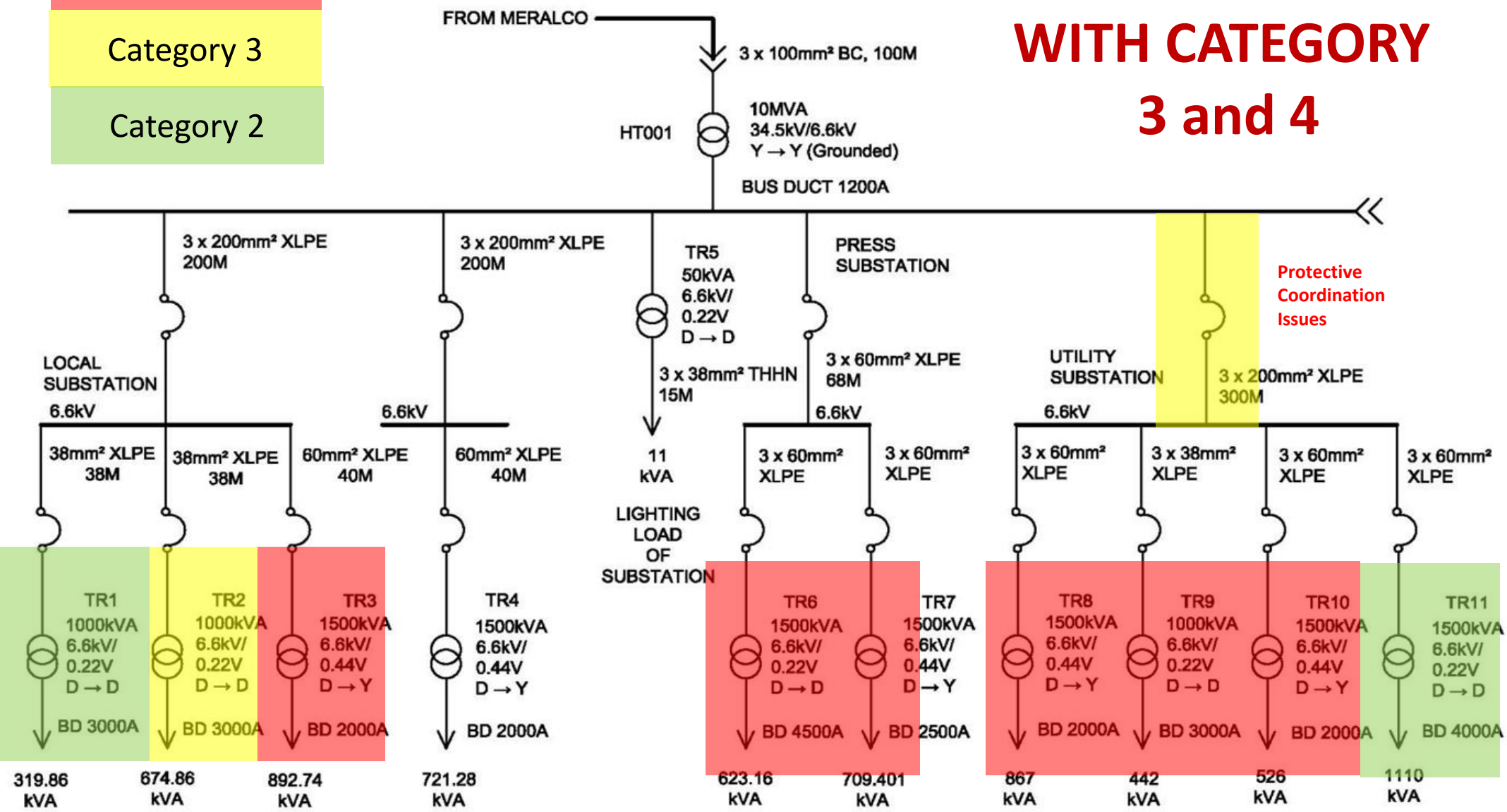
SINGLE LINE DIAGRAM

Category 4

Category 3

Category 2

ARC FLASH WITH CATEGORY 3 and 4



- No Transformer secondary protection
- Circuit breakers at LVSG, kAIC rating is lower than the short circuit current

CATEGORY 3 AND 4 ARC FLASH SUMMARY

Bus Information			Total Fault Current, kA		Arc Flash Analysis Results			
Panel Name	Nominal Voltage (kV)	Type	Bolted	Arcing	Fault Clearing Time (Cycles)	Incident Energy (Cal/cm²)	Flash Protection Boundary (ft)	Hazard/ Risk Category
MDB-5	0.22	Switchgear	44.60	11.89	36.00	30.224	13.40	4
MDB-6	0.22	Switchgear	43.79	11.74	27.00	22.362	10.92	3
MDP-220V (PRESS)	0.22	Switchgear	57.98	14.24	27.00	27.550	12.59	4
MDP-440V (PRESS)	0.44	Switchgear	38.36	17.63	27.00	34.691	14.72	4
UTILITY MV SWITCHGEAR	6.60	Panel board	10.36	10.05	27.00	14.815	19.85	3
MDB-1	0.44	Switchgear	37.05	17.14	27.00	33.651	14.42	4
MDB-2	0.22	Switchgear	46.77	12.29	36.00	31.311	13.73	4
MDB-3	0.44	Switchgear	33.81	15.91	28.80	33.129	14.27	4

NFPA 70-E : Table 220.6(B)(9)(A) Hazard Risk Category Classifications Notes: 0.03Sec = 2 Cycle

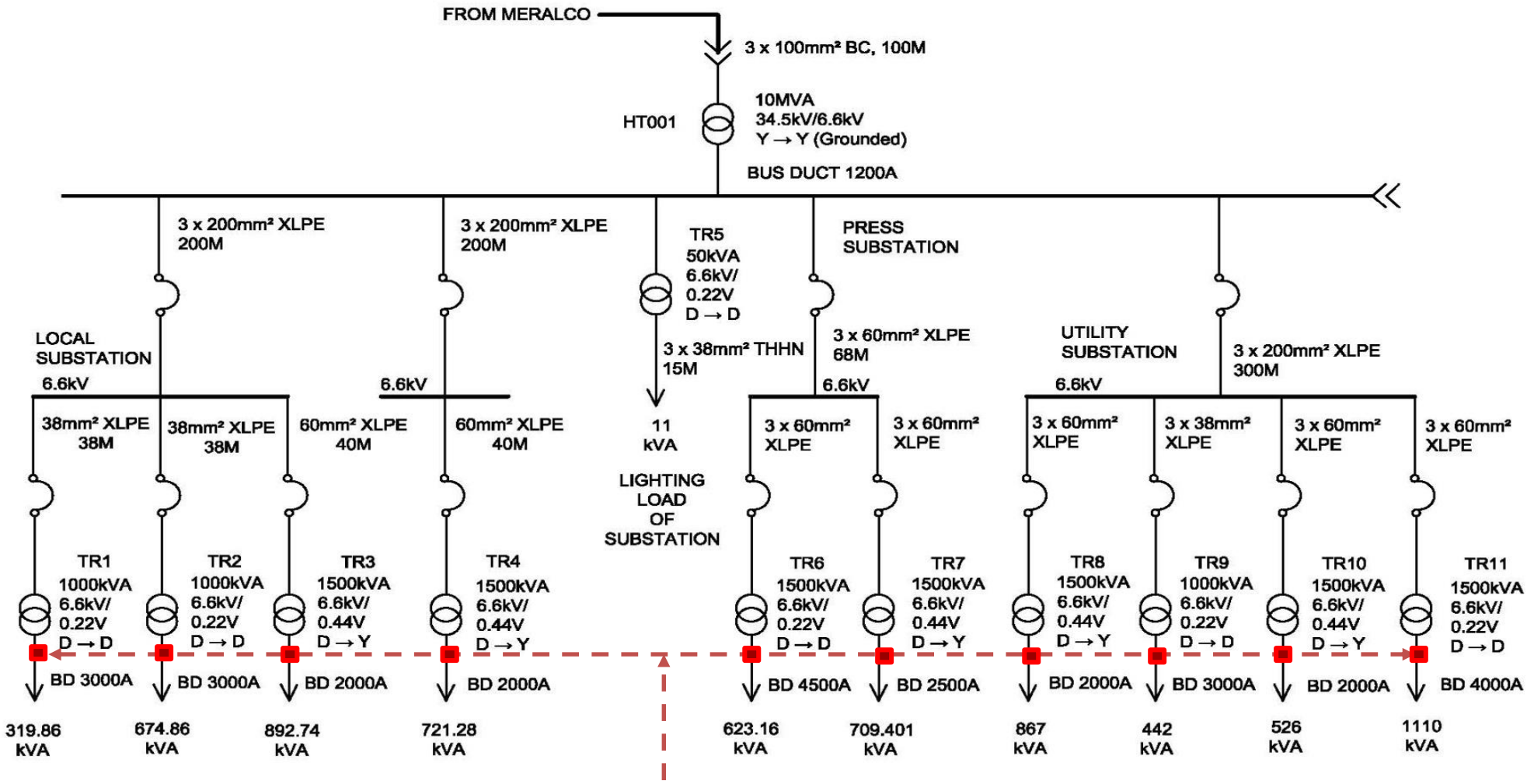
Laboratory Simulation of Arc Flash Incident

Arc Flash Category 4, Incident Energy : more than 30 cal/ cm^2

Schneider Training Video Material

LVSG IMPROVEMENT

SINGLE LINE DIAGRAM



New Installed Air Circuit Breaker

Incident Energy Reduction

Installing Circuit Breaker

FAULTED BUS	SYSTEM VOLTAGE (kV)	WORKING DISTANCE (mm.) Per IEEE 1584	3PH FAULT CURRENT (kA)	ARC DURATION (sec)	ARC FLASH ENERGY (cal/cm^2), per NFPA70E	RISK CATEGORY	PROTECTION BOUNDARY, Feet
PP-220	0.23	610	57.79	0.03	4.91	1	2.361
PP-230	0.44	610	38.36	0.03	1.84	1	1.299
MDB1	0.44	610	37.05	0.03	1.71	1	1.241
MDB2	0.23	610	49.77	0.03	3.40	1	1.887
MDB3	0.44	610	33.81	0.03	1.42	0	1.107
MDB5	0.23	610	44.60	0.03	2.61	1	1.605
MDB6	0.48	610	43.79	0.03	2.50	1	1.563

Arc Flash Incident Energy Reduction

Incident Energy Reduced from 30cal/cm^2 to 0.3 cal/cm^2

The Arc Flash Incident Energy Reduction Program

Objective :

Reduce Arc Flash Incident Energy from category 3 and 4 to Category 0 or 1.

1. Replace all circuit breaker with deficiencies in interrupting capacity
2. Installed main Air Circuit Breaker at Low Voltage Distribution Panel
3. Replace analog protective relay in digital and set the new coordinate protective relay setting
4. Perform regular maintenance program of the electrical system, conduct regular Ultrasonic Scanning
5. Training of Maintenance Personnel

Summary

Study identifies the opportunity for the electrical improvement that will addressed plant electrical safety and reliability concerns;

1. **High potential of electrical fire and loss of lives;**
    a) ARC FLASH INCIDENT
    b) Heating of cable due to voltage drop
    c)Boundary Approach were not determine

2. **Power System reliability;**
    a) Protective relay were not properly coordinated
    b) Unwanted tripping of production equipment due to voltage drop

Thank You !

Maximum incident energy at working distance

Table 4.10: Tolerances for IEEE 1584 incident energy estimates.

Voltage/ Type of Enclosure	Maximum Tolerance (% of Calculated Incident Energy)	
	For adjusted arc current [a]	For IEEE 1584 arc current [b]
Low voltage arc in open air	66%	85%
Low voltage arc in box	63%	64%
Medium voltage arc in open air	93%	54%
Medium voltage arc in box	50%	52%

a. This is using the arc current after adjusting for random variations (upper and lower bounds); b. This is using the arc current from IEEE 1584 formula.

Arc Flash Accident

AT – Ampere Trip, tripping rating of a circuit breaker

What does it mean a Circuit Breaker with 300AT, 35kAIC and 400AF?

kAIC – kilo Amperes Interrupting Capacity , maximum current interruption capacity of circuit breaker.

AF -- Frame Ampere rating/frame size, so in this case the 400 AT, same frame size with 300AT circuit breaker.

How to determine the kIAC rating of the circuit breaker?

By Short Circuit Calculation and comparison the Circuit Breaker Catalog

Arc Flash Suit