Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/15949
DOI URL: http://dx.doi.org/10.21474/IJAR01/15949

ISSN NO. 2320-5407

RESEARCH ARTICLE

PREVENTING AND MINIMIZING ARC FLASH RISK IN POWER SYSTEM NETWORK

F.O. Eruotor[1] and M.O. Eruotor[2]

1. Electrical and Electronics Engineering Department Ambrose Ali University, Ekpoma, Nigeria.
2. Physics with Electronics Department Western Delta University, Oghara, Nigeria.

Manuscript Info

Manuscript History
Received: 30 October 2022
Final Accepted: 30 November 2022
Published: December 2022

Key words:-
Arc Flash, Bolt Fault, Short Circuit, Power-flow, System Design, Incident Energy, Protection

Abstract

Arc flash events have resulted in several accidents due to faults in electrical equipment that lead to a significant release of energy. This event is a hazard and threat to the Power System Security and due to the large energy release, plasma is generated, as pressure increases since it causes physical damage to equipment while life of system operators within the vicinity of its occurrence are at risk. Although arc flash is one of the electrical safety programs that have been in existence, arc flash hazard was not adequately addressed until recently. However, the Electric Arc phenomenon is relatively new in the Nigerian power industry, there are certain aspect that are yet to be treated by the available literature, hence it is the duty of this work to establish model for addressing the observed lapses. The design is adequately prepared for the power system security analysis using typical scenarios in industrial facilities that are prone to yield high incident energy levels. In line with the foregoing, the developed methodology is validated using a segment of the Nigeria's power industry as case study.

Introduction:-

It is essential to reduce the level of available energy that can be released in an arc flash at any point in an electrical system. Nonetheless, it is important to recognize that the main contributors to arc-flash events are human error and electrical equipment failure.

Human errors can include dropping tools or loose parts inside equipment; inadvertently connecting energized system with tools, parts, conductors, or cables or improperly aligning equipment while it is being inserted into live electrical bus such as a motor control center (MCC) or switchgear. Factors related to equipment failure can include lack of equipment maintenance, equipment failure, cable insulation failure or continued electrical fault occurrences that go uncorrected, causing premature component failures (i.e., overvoltage, overload, and overcurrent conditions). Therefore, it is important to establish and maintain regular preventive maintenance schedules for electrical equipment and systems, as well as to take immediate action to correct repetitive problems.

It is also important to point out that a suitable environment for electrical equipment is key to prevent the accumulation of dust or the buildup of corrosion and condensation, all of which can lead to improper equipment operation and/or premature equipment failure. Therefore, a clean, conditioned electrical room is warranted in places where major equipment such as substations, MCCs and switchgear are located. A clean equipment environment also

Corresponding Author:- F.O. Eruotor
Address:- Electrical and Electronics Engineering Department Ambrose Ali University, Ekpoma, Nigeria.

promotes safer working conditions for electrical maintenance personnel who must service electrical equipment while energized. This will ensure Power Integrity that concerns maintaining the quality of power from generation to consumption that gives high power integrity, meaning noise levels that are within tolerance.

Failure to apply overcurrent protective devices within their ratings can result in blast, explosion even fires. The consequent of arc flash is immediate, but the result of these incidents can damage equipment and cause severe injury, including burns. The arc flash boundary or restricted approach boundary, changes depending on the potential arc flash hazard. The arc flash boundary is calculated to 1.2 calories/cm^2 of incident energy. When the arc flash boundary is the furthest away, it becomes the line no one should pass without training and wearing of appropriate PPE.

From the foregoing; this work is focused on arc flash hazards and their assessment through the calculation of incident energy or heat flux and other technical information that is considered beneficial to the Energy Industry. To this end, this is achieved by developing a model toevaluate themagnitude of incident energy in the power system. Further to which a design protocol is established to reduce possibility of stress on the power system components as well as the overall restoration time of the faulty system back to service.

Design Methodology:-

This work utilized electrical Transient Analysis Program (ETAP) software for the short circuit calculation which is developed with its foundation squarely laid on the Newton-Raphson power flow technique. In which case, there are several different methods of solving the resulting nonlinear system of equations. This method begins with initial guesses of all unknown, variables (voltage magnitude and angles at Load Buses and voltage angles at Generator Buses). Further to this, the Taylor Series is adopted, with the higher order terms ignored, for each of the power balance equations included in the system of equations. The result is a linear system of equations that can be expressed as:

$$\begin{bmatrix} \Delta\theta \\ \Delta /V/ \end{bmatrix} = -J^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \quad (1)$$

Where ΔP and ΔQ are called the mismatched equations

$$\Delta P_i = -P_i + \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\cos\theta_{ik} + B_{ik}\sin_{ik}) \quad (2)$$

$$\Delta Q_i = -Q_i + \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\sin\theta_{ik} - B_{ik}\cos_{ik})$$

and J is a matrix of partial known as a Jacobian matrix which is expressed as follows:

$$J = \begin{bmatrix} \frac{\partial\Delta P}{\partial\theta} & \frac{\partial\Delta P}{\partial|V|} \\ \frac{\partial\Delta Q}{\partial\theta} & \frac{\partial\Delta Q}{\partial|V|} \end{bmatrix} \quad (3)$$

The linearized system of equations is solved to determine the next guess (m+1) of voltage magnitude and angles based on:

$$\theta^{m+1} = \theta^m + \Delta\theta \quad (4)$$

$$|V|^{m+1} = |V|^m + \Delta|V| \quad (5)$$

The process continues until a stopping condition is met.

Algorithm of the evaluation of Arc Flash Incident Energy

There are some critical components of the power network that must be subjected to fault analysis to determine their respective resilience to the occurrence of incident energy. This includes the power generator/utility, power transformer and other power equipment. Thus, Arc Flash Hazard Decision steps is as depicted in Fig. 1.

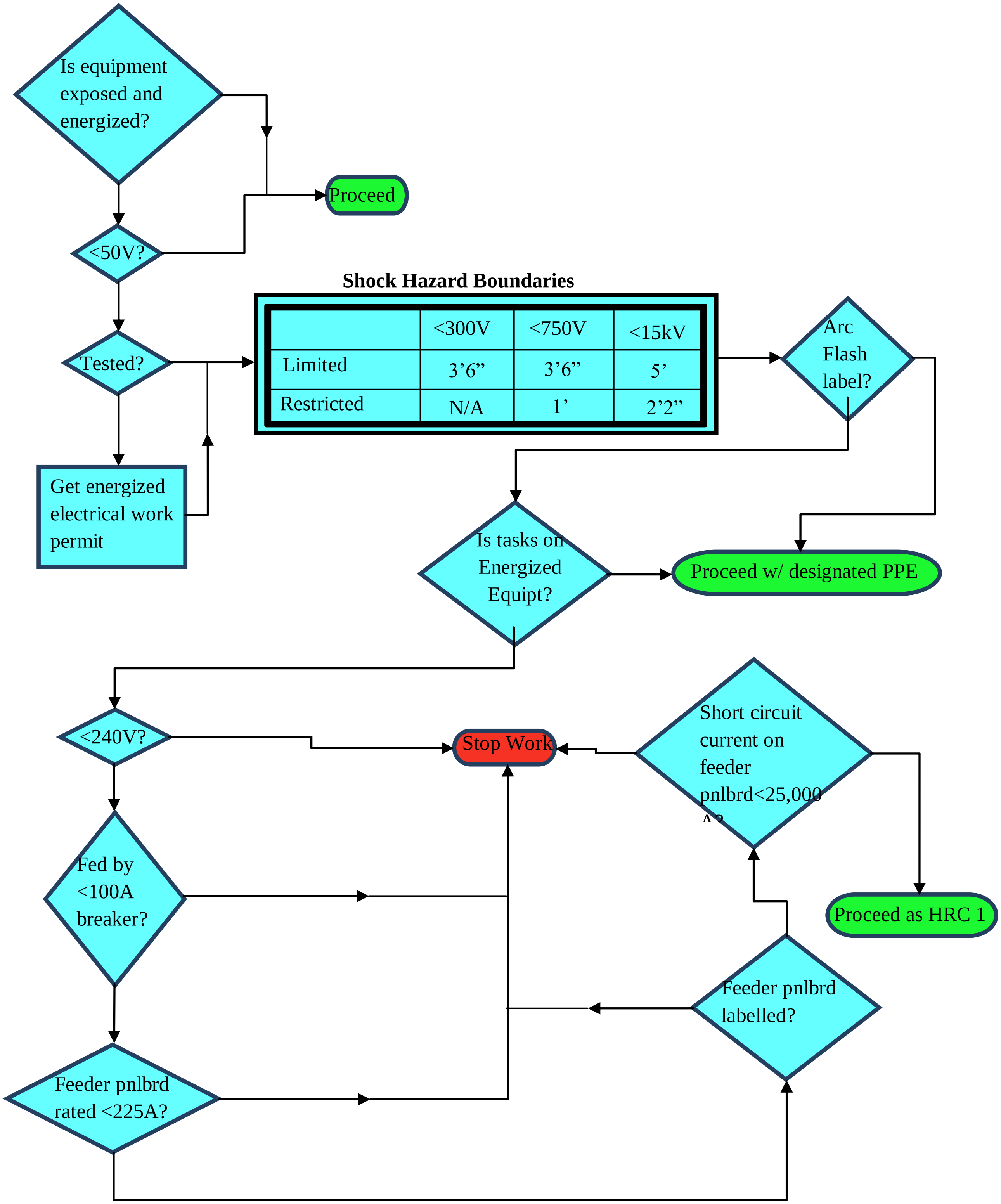

Fig. 1:- Flow chart of Arc Flash Hazard Decision Tree.

Themultiplestepsinvolved calculatinganarcingcurrent,usingthe obtainedresultto estimateincidentenergy,thenapplyingthatinformationtodetermineanarcflashboundary.

The first step in the arc-flash analysis is to calculate the arcing current. Arcing current is a short circuit via ionized gas between one live part and the ground or another live part (Kumpulainen, et al., 2008).Duetothearcresistance, thearccurrentisnotthesameastheavailable faultcurrent.Arcingcurrentisalwayslowerthantheboltedfaultcurrent (Murphy, 2008), (Doan, 2008).

FromtheIEEE-1584 empiricalderivedmodelforasystemunder1000Vand havinganavailable faultcurrentbetween 700A -106kA, thearcingcurrentcanbe calculatedasfollows (IEEE std. 1584, 2002):

$$l_g I_a = K + 0.662\, l_g I_{bf} + 0.0966V + 0.000526G + 0.5588V(l_g I_{bf}) - 0.00304G(l_g I_{bf}) \quad (6)$$

Where,

l_g	isthe$\log_{10}$
I_a	isarcingcurrent(kA)
K	is-0.153foropenconfigurationsand is-0.097forbox configurations
I_{bf}	isboltedfaultcurrentforthere-phasefaults(kA)
V	issystemvoltage(kV)
G	isthegapbetweenconductors(mm)

This work will consider the analysis of the effects of arc-flash exposure for technical personnel and engineers working on electrical equipment in a critical facility. Therefore, the K value is -0.097 to represent the arc occurring inside an electrical panel, switchboard, or motor control center. The system voltage V, for this project is 480 except when a step-down transformer is inserted to achieve a 208-volt feeder. The value for G is the gap spacing between the conductors or bus bars, which is dependent on equipment design. From the table below, the bus gap corresponding to low voltage switchgear is 32 (IEEE-1584, 2004; Das, 2012).

Table1 : - Classes ofEquipmentandTypicalBusGaps.

Classes ofEquipment	**TypicalBusGaps(mm)**
15kV Switchgear	152
5kV Switchgear	104
Low-Voltageswitchgear	32
Low-VoltageMCCsand Panel boards	25
Cable	13
Other	Notrequired

Thisreducesthe arcingcurrent of equation(1)to:

$$I_a = 10^{(-0.034\, +\, 0.0833\ lg\, I_{bf}\ )} \quad (7)$$

Theincident energyisavalue thatrepresentstheamountofthermalenergythata personisexposedtoatagiven distance.Incidentenergyismeasuredin Joulespersquare centimeter(J/cm^2)andisdefinedasawattsecond(IEEE std. 1584, 2002). The incident energy, normalized for an arc duration of 0.2 seconds and a distance of 24” can be calculated given the arcingcurrentaboveandusingthefollowingformula(IEEE std. 1584, 2002).

TheIncidentEnergynormalized could becalculatedasfollows:

$$l_g E_n = K_1 + K_2 + 1.081\, l_g I_a + 0.0011\, G \quad (8)$$

Where,

E_n	is normalized incident energy (J/cm^2)
K_1	is -0.792 for open box configurations (no enclosure) and is -0.555 for box configurations (enclosed equipment)
K_2	is 0 for ungrounded and high-resistance grounded systems and is -0.113 for grounded systems

I_a is arcing current from above
G is the gap between conductors (mm)

TheconstantsK1andK2aredependentuponthephysicalenclosureofthecircuit breaker.Sincecircuitbreakersaremountedinaswitchgear itis considered abox configuration.ThiswillgiveaK1valueof-0.555 and foragroundedsystem, thereforeaK2valueof-0.113isappropriate.

Thisreducesthenormalizedincidentenergyequation(8)to:

$$E_n = 10^{(-0.633+1.081\ l_g I_a)} \quad (9)$$

Foradifferentarcdurationand/ordistancefromthearc,thenormalized incident energycan beconvertedintotheactualincidentenergyasfollows (IEEE std. 1584, 2002):

$$E = C_f E_n (\frac{t}{0.2})(\frac{610^x}{D^x}) \quad (10)$$

Where,

E isincidentenergy(cal/cm^2)
C_f is1.0forvoltagesabove1kVandis1.5forvoltagesatorbelow1kV
E_n isnormalizedincidentenergy
t isarcingdurationinseconds
D isthedistancefrompossiblearcpointtotheperson(mm)
x isthedistanceexponent

Thisequationcanbereducedbyverifying systemparameters. For a 480volts system, $C_f$is1.5 and the valuefor thedistanceexponent X,isfurnishedbytheIEEE1584tablebelow.

Table 2:- Distance x Factors.

SystemVoltage	**EquipmentType**	**Distance X Factor**
208-1kV	OpenAir	2.000
208-1kV	Switchgear	1.473
208-1kV	MCCandPanels	1.641
208-1kV	Cable	2.000

ThevalueofDrepresents thedistancefromtheexposedenergized electrical conductortothemaintenance personnelworkingontheequipment.Thisvalueis standardized byIEEE1584depending ontheclassoftheenergizedelectricalequipment (IEEE std. 1584, 2002).

Table 3:- Classes of Equipment and Typical Working Distances.

Classesof Equipment	**Typicalworkingdistance(inches)D**
15kV Switchgear	36
5kV Switchgear	36
Low-VoltageSwitchgear	24
Low-VoltageMCCsand Panelboards	18
Cable	18
Other	TBD

Using X= 1.473andD=18”,reducestheincidentenergy of equation(9)to:

$$E = 2.295\ E_n (\frac{t}{0.2}) \quad (11)$$

Equations 7, 9 and 11 maynowbecombined intooneequationwhichexpresses theincidentenergyE asafunctionon I_{bf} andt,asfollows(Brown and Shapiro, 2006):

$$E = 2.295\,\{10^{(-0.670+0.901\ lg I_{bf})}\}(\frac{t}{0.2}) \qquad (12)$$

Notethat equation (12)is valid onlyforthe assumptionsmadeabove (i.e a CB in a box configuration),whicharefor apowercircuitbreakerinanelectricalsystemanalyzedbythis work(i.e.asolidly grounded480voltsystem,acircuitbreakermountedinalow-voltage switchgear,andat aworkingdistanceof18”).

Thearc-flashhazardanalysisprovidesimportantinformationthathelpsestablish asafety barrierforworkerswhenexposedtoenergizedequipment. Theincidentenergy levelthatwillcauseacurableburnorasecond-degree burnis1.2cal/cm^2 (Lee,1982). If a butanelighterisheld1cmaway fromaperson’sfingerfor1secondandthefingerisin theblueflame,asquare centimeterareaofthefingerwillbeexposedtoabout1.2cal/cm^2(IEEE std. 1584, 2002).Theentirepremiseofsafetyand arc flashisbasedonacurableor seconddegreeburn and, therefore,the incidentenergylevel of1.2cal/cm^{2}isanimportantvalue.The distance awayfromanexposedenergizedconductorthatiscalculatedat1.2cal/cm^{2}isknownas thearc-flashboundary.Thiscanbe calculatedbyrearrangingequation(10)andsolving fordistanceat anincidentenergyof1.2cal/cm^2.

$$D_b = \left[4.184 C_f E_n \left(\frac{t}{0.2}\right)\left(610^{\frac{x}{E_b}}\right)\right]^{\frac{1}{x}} \qquad (13)$$

Where,

D_b	istheboundaryfromthe arcingpointortheflashprotectionboundary
C_f	is1.5forvoltagesatorbelow1kV
E_n	isincidentenergynormalized
E_b	isincidentenergyatboundarydistance
t	istimeinseconds
x	isthedistanceexponentfromTable 1

Aftercomparingequations12and13,thedeterminingfactors fortheincidentenergy levelarethearcingcurrentthatresultsfromtheavailablefault currentandthetimethatthearcexposure exists.Thesefactorsarecontrolled bythe systeminwhichthecircuitbreakerisinstalledandtheinterrupting characteristicsofthe circuitbreaker.

Figure 1showsacircuitbreakertimecurrentcurvewiththearcing currentcrossingit.

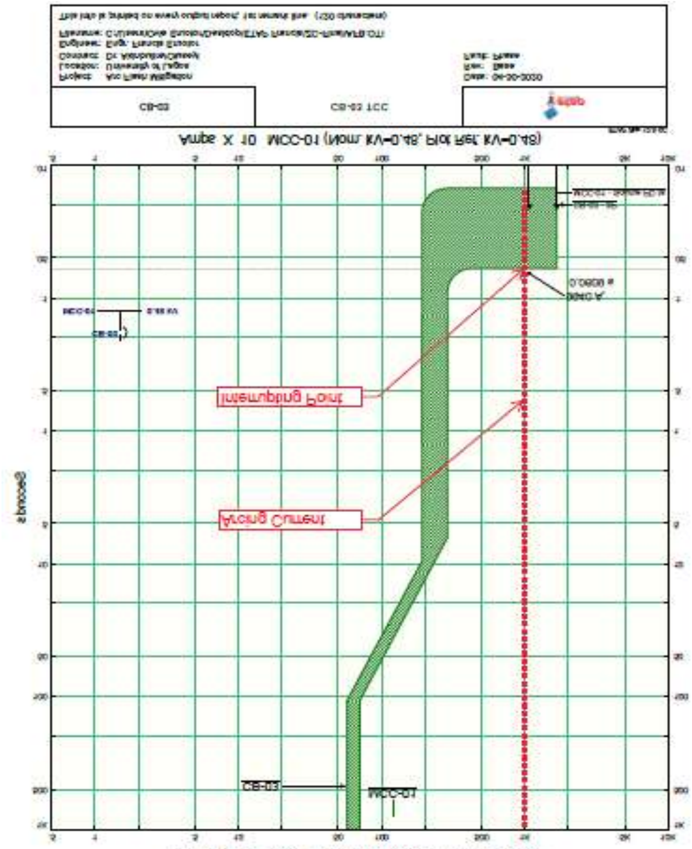

Figure1:- CircuitBreakerTCCInterruptingArcingCurrent.

Hereitisshownthatanarcingcurrentofapproximately 9.94kAisinterruptedby thecircuitbreaker CB-01atatimeof0.0609seconds.Thisentireprocessis recalculated atafaultcurrentlevelof85%lessthanthereportedAFC.Thisallowsfora worse-case scenarioifthefaultcurrentislowerthananticipated.Thisarcingcurrentis simultaneouslyplottedagainsttheprotectivedevicecurveandtheslowestinterrupttime isusedincalculatingtheincidentenergy.Figure 2showsbotharcingcurrentsplotted againstMCC-01.

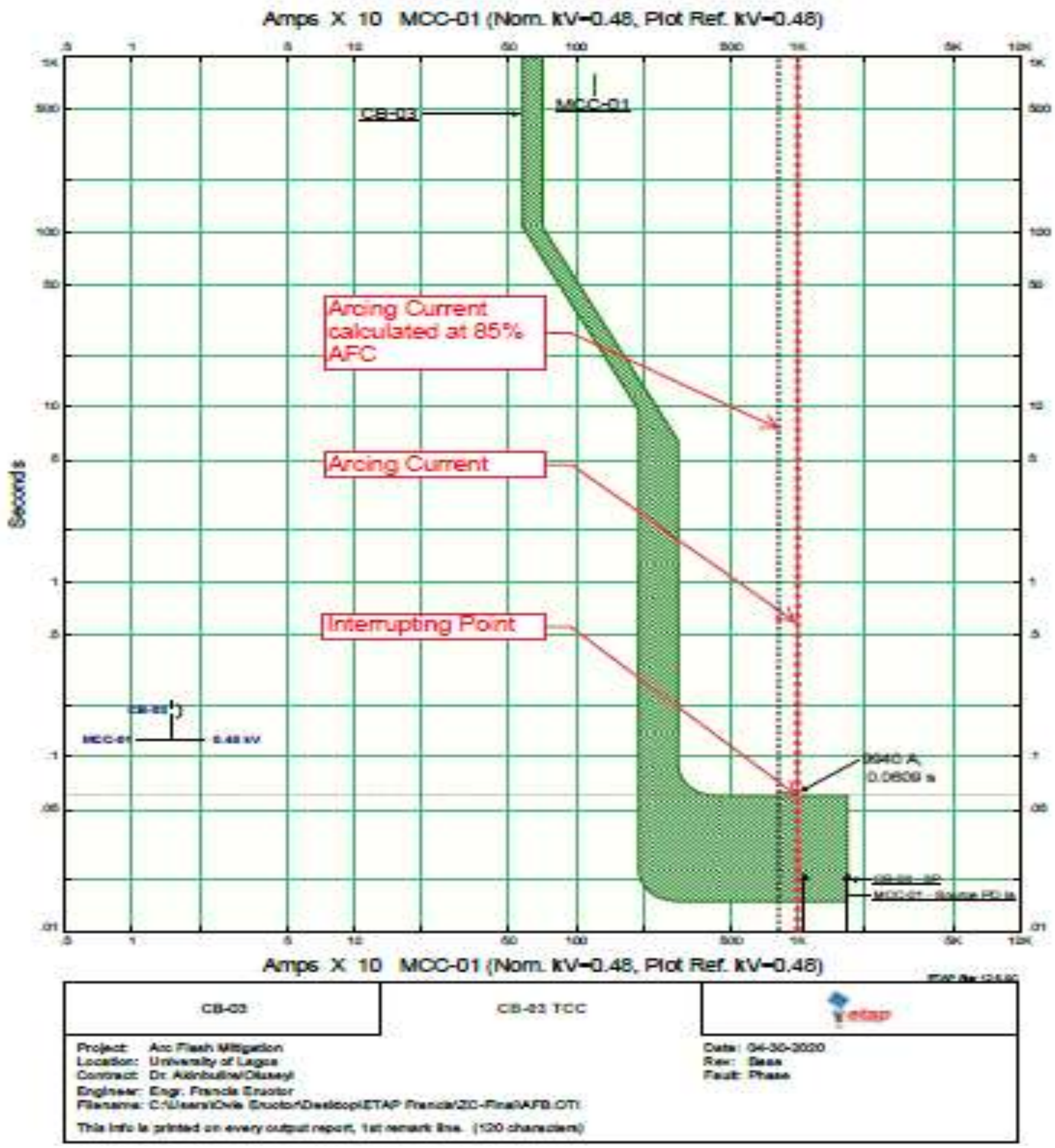

Figure2:- CircuitBreakerTCCInterruptingArcingCurrents.

Thisinformation canbeusedintheequations abovetocalculatetheincident energyfor MCC-01.Thecomputer simulation outputresultsareshowninthe One-LineDiagraminFigure 3.

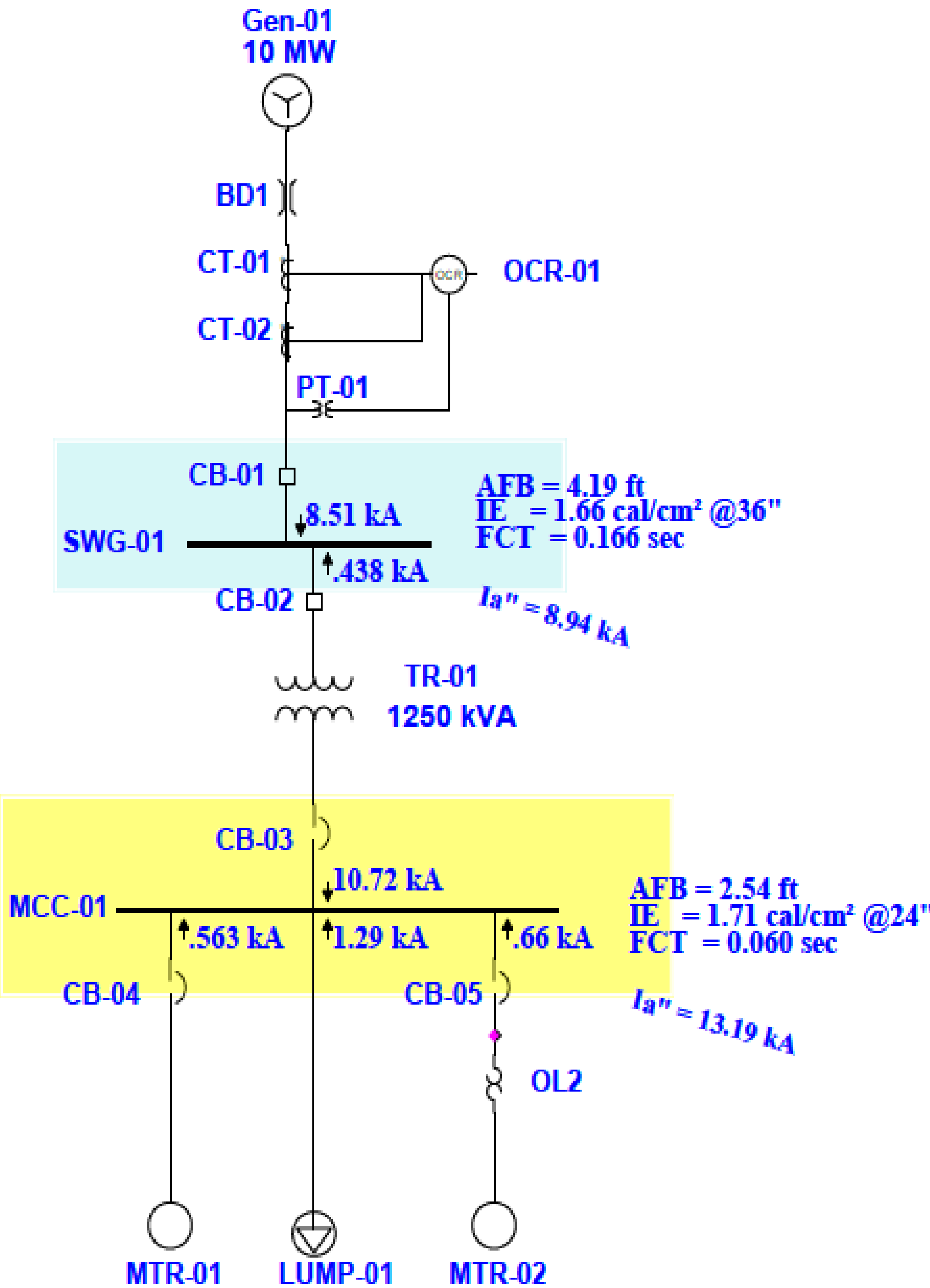

Figure3: -One-Line Diagram showing MCC-01 IncidentEnergy.

Withthisinformationofanincidentenergylevelof 1.44 cal/cm^2,theElectrical Engineercan now selectclothingand personalprotectiveequipmentrated for arc-flash safety.Theclothingandequipment selectedmustalways haveanarcflashratinggreater thantheincidentenergyoftheelectricaldevicetobemaintained.Sincetheincident energy levelcanhave a multitude of valuesranging from0.1cal/cm^{2}up to over 40cal/cm^2,theamountofdifferentclothingdevicescouldbeenormous.Therefore,theconcept of groupingtheincidentenergylevelsintocategoriesarose.

Arc Flash Hazard Analysis

arc-flashhazardanalysis involves performing afaultcurrentanalysisandaprotectivedevicecoordinationstudy.Anarc-flash hazardanalysis isacontinuationoftheshort-circuitstudyand protective-devicecoordination study (IEEE std. 1584, 2002). The results from theshort-circuitstudyareused todeterminetheavailable faultcurrentatelectricalequipment locationsandhelpstoproperlyspecifyequipmentwithstandratingsandinterruptingcapabilities.The resultsfromtheprotective-devicecoordinationstudygiveusinformationonthetimethe systemtakestoisolateoverloadorfaultconditions.Theresultsoftheshort-circuit and protectivedeviceevaluationareused incombinationtogivethenecessaryinformation required toperformanarc-flash hazardanalysis. Theresultsofthearc-flash hazard analysisareusedtoidentifytheflash-protectionboundaryandtheincidentenergyat assignedworkingdistancesthroughoutanypositionorlevelintheelectricalsystem (IEEE std. 1584, 2002).

Arc Flash Hazard Risk Categories

Whileincidentenergypredictionwasbeingresearched,therewerealsostudies beingconductedonhowtoprotectworkersintheeventofanarc-flash.

TheArcFlashHazardAnalysisgivesusanincidentenergy levelataspecified workingdistancefromthesource ofthearc.ThisenablesustoselectPersonal Protective Equipment(PPE) thatisratedabove the incident energy.Althoughthe conceptof wearingPPEthatissuitedforthetaskissimple,thedifferentincidentenergylevelscan benumerous.Therefore,theimplementationofhazardriskcategories wasinstitutedinto thePPEselectionprocess.The hazard risk category levels are:0, 1, 2, 3and4whichcorrelatestomaximum incidentenergylevels(cal/cm^2)of 1.2,4,8,25, 40. This allowsfor anelectricaldeviceto belabeledpercategoryandtheselectionofPPEcanbematchedthesameway.

Table4: -HazardRiskCategories andPPECharacteristics.

HazardRiskCategory (HRC)	**TypicalProtective ClothingSystems**	**RequiredMin.PPE ArcRating (cal/cm^2)**
0	Non-melting, flammable Materials (Natural ortreated materials withatleast4.5 oz/yd^2)	1.2
1	FR pantsandFR shirt,or FRcoverall	4
2	CottonUnderwear,plusFR shirtandFRpants	8
3	CottonUnderwear,plusFR shirtandFRpantsandFR coverall	25
4	CottonUnderwear,plusFR shirt and FR pants and multi-layerflash suit	40

The One-linediagramfor SWG-01 and MCC-01cannowincludeahazardriskcategory alsoknownasaPPECategoryasshownbelowinFigure 4.

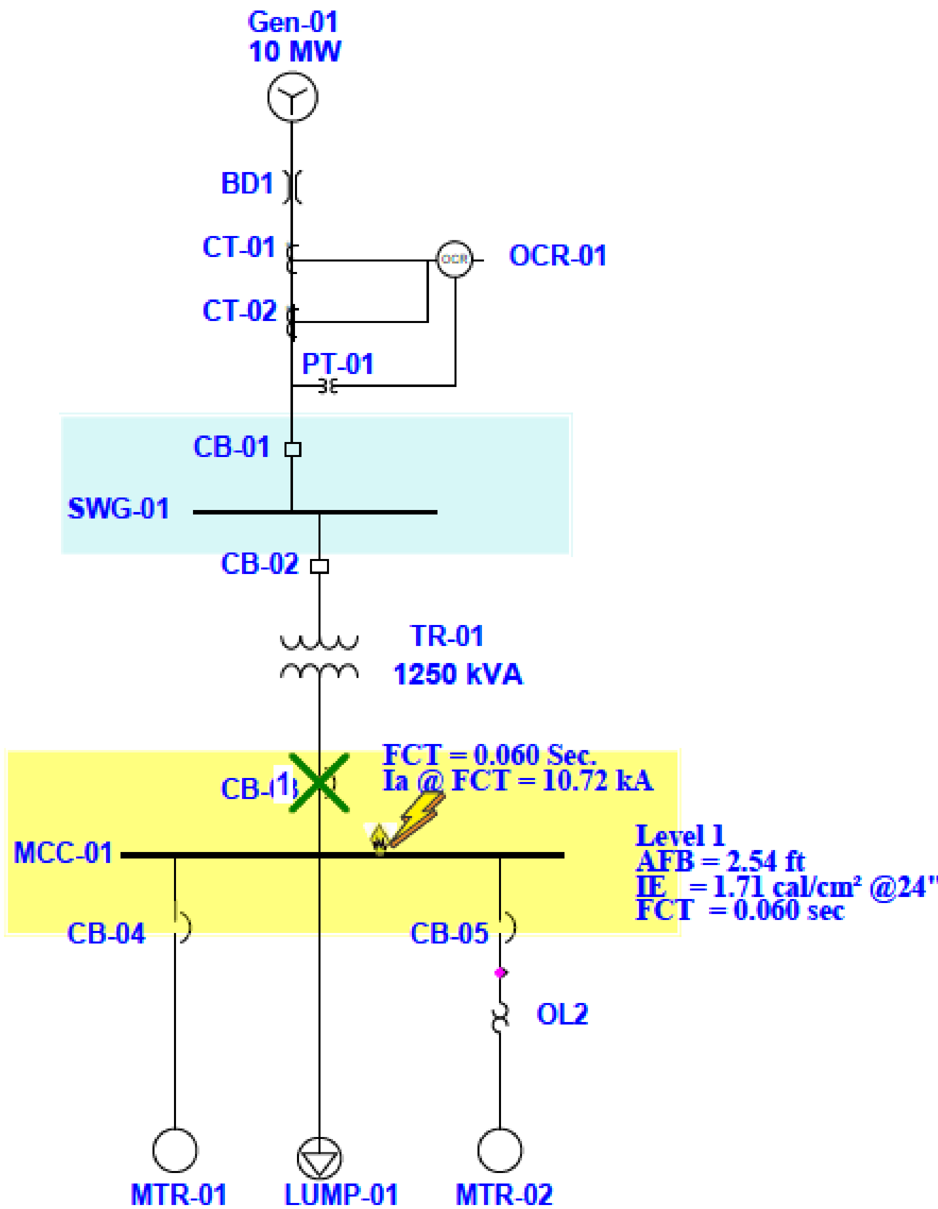

Figure4: -One-Line Diagram ShowingIncident Energy and Hazard Risk Category.

PerTable 4 ,thehighesthazardriskcategoryislevel4,withamaximum incidentenergyof40cal/cm^2.WhilePPEiscertainlyavailableinratingswellabove 40cal/cm^2,workingnearexposedenergizedelectricalequipmentabove40cal/cm^{2}is discouraged (Doan, 2008).However, the greaterthannormalemphasis should be placed on de-energizingthe equipmentat such highincidentenergylevels.

Arc Flash Warning Label

The purpose of Arc Flash Warning Labels is to warn personnel of the potential hazards of electrical equipment they might be working on. The label shows what action they should take to reduce the hazard.

Labeling is required for any piece of electrical equipment that may need examination, adjustment, service, or maintenance while energized, creating the potential for an arc flash incident to occur. Arc flash hazard labels must be placed on any piece of electrical equipment where workers might need to perform work while the equipment is still energized. Items that should have arc flash warning labels typically includes:

1. Switchboards/Panelboards/Distribution Boards.
2. Industrial Control Panels.
3. Enclosed Circuit Breakers.
4. Motor Control Centers.
5. Disconnects/Safety Switches (fused)
6. Inverters.
7. UPS.

Equipment Labeling

Switchboards, panelboards, industrial control panels, meter socket enclosures and motor control centers that are likely to require examination, adjustment, servicing, or maintenance while energized must be field marked with a label containing all the following information (Montana, 2012):

a. Nominal System Voltage
b. Arc Flash Boundary
c. Available incident energy and the corresponding working distance
d. Available 3 phase bolted current
e. Hazard/Risk Category (0 through 4)
f. The date that the label was applied
g. Other explanatory information as desired

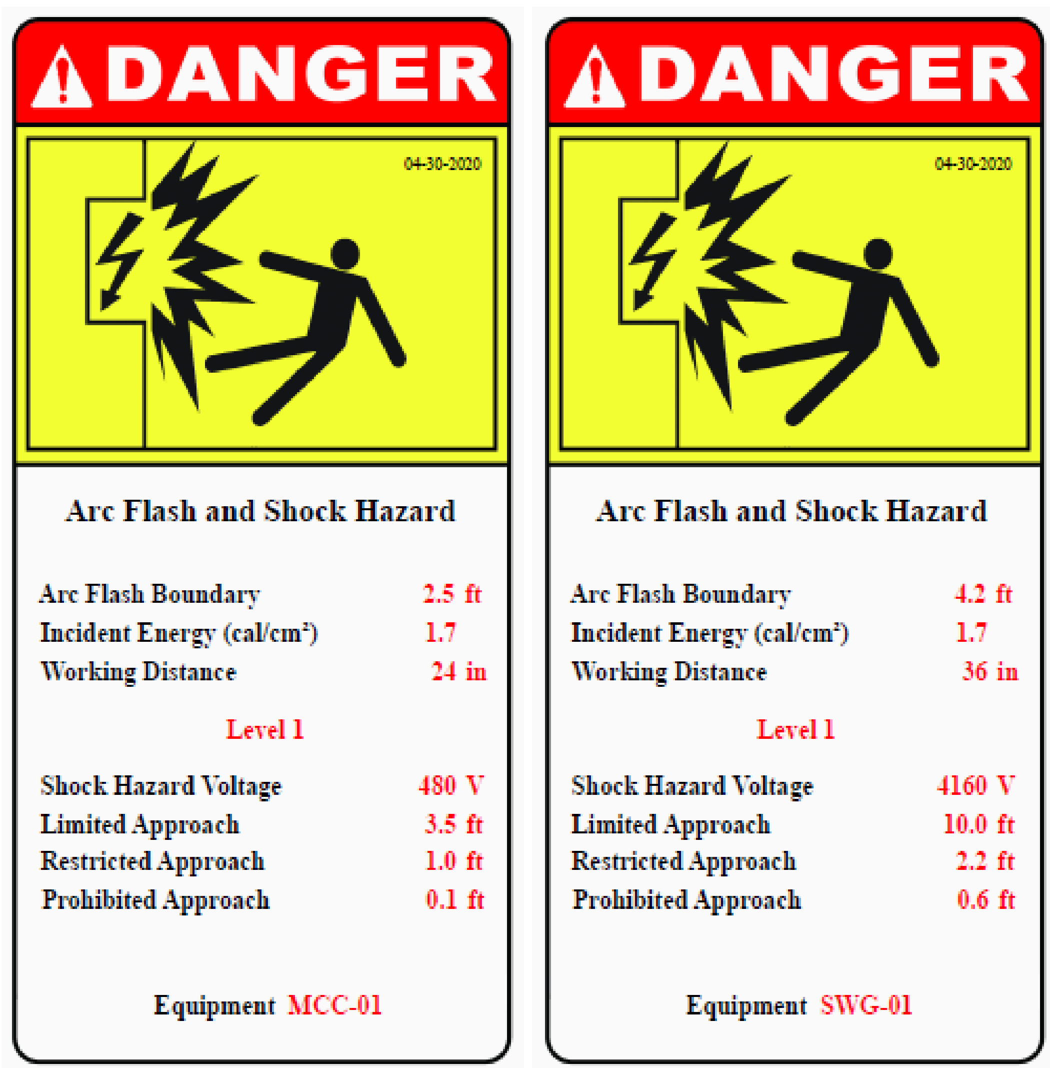

Figure 5: - Arc Flash Warning Label for Major Equipment.

Result And Discussion:-

Arc Flash Hazard Mitigation

Several steps are required to adequately mitigate Arc Flash Hazard.

Table5:- Arc Flash Simulation Methods.

Scenario ID	Arc Flash Method	ArcingCurrent(kA)	I.E. (cal/mm^2) for 2.0 sec
Case 1	Half Cycle (Ia")	9.06	**1.67**
Case 2	Half Cycle (Ia')	8.72	**1.61**
Case 3	Decay Method (Ia" - Ia)	9.06	**1.39**

Table 6:- Incident Energy at various distances.

Arc in Open Air								**Arc in Cubic Box**					
Arc Duration		Arc Flash Bound [ft]	Distance from Arc Electrodes (inches)					Arc Flash Bound [ft]	Distance from Arc Electrodes (inches)				
Second	Cycle		18	24	30	36	48		18	24	30	36	48
0.004	0.25	0.6	0.22	0.12	0.08	0.05	0.03	0.7	0.37	0.24	0.17	0.13	0.09
0.008	0.50	0.9	0.43	0.24	0.15	0.11	0.06	1.1	0.73	0.48	0.35	0.26	0.17
0.033	2.00	1.8	1.72	0.97	0.62	0.43	0.24	2.8	2.93	1.92	1.38	1.06	0.69
0.050	3.00	2.2	2.58	1.45	0.93	0.65	0.36	3.6	4.40	2.88	2.07	1.59	1.04
0.067	4.00	2.5	3.44	1.94	1.24	0.86	0.48	4.4	5.87	3.84	2.77	2.11	1.38
0.083	5.00	2.8	4.31	2.42	1.55	1.08	0.61	5.1	7.34	4.80	3.46	2.64	1.73
0.100	6.00	3.1	5.17	2.91	1.86	1.29	0.73	5.8	8.80	5.76	4.15	3.17	2.08
0.133	8.00	3.6	6.89	3.87	2.48	1.72	0.97	7.1	11.74	7.68	5.53	4.23	2.77
0.167	10.00	4.0	8.61	4.84	3.10	2.15	1.21	8.2	14.67	9.60	6.91	5.29	3.46
0.333	20.00	5.7	17.22	9.69	6.20	4.31	2.42	13.1	29.35	19.21	13.83	10.57	6.92
0.500	30.00	7.0	25.83	14.53	9.30	6.46	3.63	17.3	44.02	28.81	20.74	15.86	10.38
0.667	40.00	8.0	34.44	19.37	12.40	8.61	4.84	21.0	58.69	38.42	27.66	21.14	13.84
0.833	50.00	9.0	43.05	24.22	15.50	10.76	6.05	24.5	73.36	48.02	34.57	26.43	17.30
1.000	60.00	9.8	51.66	29.06	18.60	12.92	7.27	27.7	88.04	57.63	41.48	31.71	20.76
1.167	70.00	10.6	60.27	33.90	21.70	15.07	8.48	30.8	102.71	67.23	48.40	37.00	24.22
1.333	80.00	11.4	68.88	38.75	24.80	17.22	9.69	33.7	117.38	76.84	55.31	42.29	27.68
1.500	90.00	12.1	77.49	43.59	27.90	19.37	10.90	36.5	132.06	86.44	62.23	47.57	31.14
1.667	100.00	12.7	86.10	48.43	31.00	21.53	12.11	39.2	146.73	96.05	69.14	52.86	34.60
1.883	110.00	13.3	94.71	53.28	34.10	23.68	13.32	41.8	161.40	105.65	76.06	58.14	38.06
2.000	120.00	13.9	103.33	58.12	37.20	25.83	14.53	44.3	176.08	115.26	82.97	63.43	41.52

Arc Flash Considerations

The calculations of incident energy on bus fault MCC-01 (Figure 4) are shown in Table 5 and Table 6. This gives an incident energy release of 1.71cal/cm^2: though not extremely dangerous. Relays OCR-01 must operate to clear the bus fault. A bus differential scheme will be invariably provided, this bus fault will be removed quickly, and all the breakers on this bus tripped. This will reduce the incident energy to 1.71 cal/cm^2.

A fault at this location, say in the incoming section of transformer incoming breaker CB-03 sees two sources of fault current, one from the utility source through 1.25 MVA transformer and the other contributed by the loads. The generator will be tripped in a short time, approximately six cycles, assuming five - cycle rated breakers and one cycle operating time of generator differential relay. But due to rotating inertia of the generator, the fault continues to be fed by the generator. NEMA standard requires that a generator should be capable of withstanding a three - phase bolted fault at its terminals for 30 seconds, without injury, when operating at its rated kVA and power factor, at 5% overvoltage with fixed excitation (NEMA, 1993).

An ETAP simulation will show that the fault will continue to be fed with decaying magnitude for many seconds, even though the field circuit breaker is tripped, and the generator excitation is removed.

The available computer - based programs do not account for this decay after the generator breaker is opened. The generator side terminal compartment of the circuit breaker continues to be fed from this fault current releasing additional incident energy.

It is prudent to calculate the additional incident energy released by hand for a period of 2 seconds. The generator transient fault current for this duration will give conservative results.

Conclusion &Recommendation:-

Reducing personal injuries from arc flash events should be the main goal of any arc flash hazard assessment. Many facilities have locations where the arc flash energy levels are extremely high. These dangerous areas require electricians and technicians to wear heavy layers of personal protective equipment (PPE) when working on energized equipment. Unfortunately, in some areas, this PPE can increase the chances of heat stroke and other heat-related problems

Design engineers have a few options to reduce system voltage or fault currents. However, the best and most direct way to reduce arc flash hazards is to reduce fault-clearing times.

We have looked at several ways to reduce the arc flash energy in a facility. Arc flash energy can be reduced by (in order of effect): decreasing the trip times; reducing fault currents; and increasing the working distance.

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