Session Three

'Internal' versus 'External' Bolt Fault Current Contribution in Calculations for LV Arc Flash Hazard Assessment in Integrated Electrical Networks)

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Abstract

Performing Low Voltage (LV) Arc-Flash-Hazard Assessments (AFHA) on various electrical networks presents some unique differences in the scope of network modelling and the outcome of arc-flash-risk assessment results. The paper emphasises the need to analyse all electrical supplies – normal and backup (or alternative supplies).

When calculating the overall low voltage (LV) fault current contribution to determine the incident energy under a normal operating configuration; this condition may present lower incident levels than when connected to backup distribution/transmission networks. Depending on the fault rating of the distribution/transmission networks; such contribution may be significant. This paper reviews a study case in which 'backup' supplies provide higher fault currents than. Provision for backup is either in the form of remote distribution systems or local diesel generation. Included in these essential supplies are DC supply systems and uninterruptable power supply (UPS) systems. The arc-flash-hazard analysis process for this study case follows the nine steps prescribed in IEEE STD 1584–2002 and is performed in software ETAP Version 14.1.0.

1. Scope & nature of study

The scope and nature of the study is for an arc flash hazard (AFH) risk assessment of 415 V switchboards and circuit breakers in a gas storage facility. A comprehensive site investigation was undertaken and visual orientation obtained of electricity utilities 11 kV/ 415 V supply transformers (main and backup transformer supplies), clients local diesel generator unit; low voltage (LV) switchboards; LV circuit breakers, LV cabling, and general building layout. ETAP single line diagram (SLD) is illustrated in Appendix A.

The provided Arc-Flash Hazard assessment determines the three-phase bolted short circuit current; arc fault current; incident energy; flash-protection boundary; incident energy exposure; hazard risk category, protection clothing; and the limited, restricted and prohibited approach boundaries; and mitigation proposals.

All Arc-Flash Hazard Assessment calculations are in accordance with the applied standard *IEEE STD 1584 – 2002 IEEE Guide for Performing Arc-Flash Hazard Calculations*. Assessment is undertaken on the existing protection system settings. Recommendation of PPE and safety label requirements are in accordance to *NFPA 70E Standard for Electricity Safety in the Workplace (2015 Edition)*.

2. Methodology

The ETAP (Version 14.1.0) Load Flow; Short Circuit, and Arc Flash Assessment modules are applied in all calculations for this assessment. The equations listed in standards *IEEE STD 1584-2002 / IEEE 1584a 2004* and *NFPA 70E-2015* shall be applied in all calculations. The assessment process[1] within the report will be in accordance with *IEEE STD1584-2002*. Upstream circuit breaker relays/tripping devices feeding into the relevant switchboards are modelled. The upstream tripping devices for the relevant switchboards will be the fuse (*F1*) and main circuit breaker (*CB1*) immediately following the 11 kV/415 V 300 kVA distribution transformer.

The assessment is based on the following qualifications:

a) Switchboard arc-flash hazard assessment results are based on the operating of the immediate upstream circuit breaker.

b) Circuit breaker fault opening times are assumed to be the maximum available from the manufacturer's technical information.

c) 'Primary protection' operating time is considered and not 'extended protection' (or backup protection) operating time. This approach considers that the probability of a circuit breaker failure and an arc flash hazard risk occurring is 'highly improbable'.

[1] IEEE STD 1584-2002; Section 4. Analysis process; page 4

3. Arc-Flash Hazard Assessment

3.1 System & Installation Data

All study input data has been provided by the asset owner, and distribution power supply has been provided by the respective electricity utility. Electrical equipment and their layout have been provided from single line diagrams.

Electrical description and their ratings, cable details with drawing references were obtained with visuals of the overall site, 11 kV/415 V 300 kVA distribution supply transformer; diesel generator; LV fuse (F1); main circuit breaker (CB1); and switchboard MCC 833-PMCG-001. The distribution utility supply short circuit ratings for each source of supply (normal 'A' & alternative 'B') are listed in Table 1; and the distribution transformer being supplied from these sources parameters listed in Table 2. All motors are modelled at their ratings and with a power factor (PF) of 0.90.

Table 1: Gas Storage power supply short-circuit ratings

	Normal Distribution Power Supply 'A'			Alternative Distribution Power Supply 'B'		
SC Rating	MVAsc	X/R	kAsc	MVAsc	X/R	kAsc
3-Phase	10.46	0.73	0.549	15.5	0.73	0.814
1-Phase	25.688	2.435	0.823	23.245	2.435	1.22

Table 2: Gas Storage distribution supply transformer parameters

Description	Asset ID	Rating (MVA)	Type	Z (%)
Pole Mounted Transformer	784-TX-001	300	OIL	4%

3.2 Determining the System Modes of Operation

These are the three modes of operation with their respective loads provided by the asset owner:

- *Injection* total 189.9 kW
- *Extraction* total of 116.6 kW
- *Standby* total of 99.9 kW

The status (open or closed) for each operating mode and of all relevant circuit breakers are listed in Table 3.

Table 3: Gas storage facility circuit breaker status for three operating modes

CB ID	Description	Load (kW)	Extraction	Injection	Standby
CB1	Main Supply Circuit Breaker	N/A	Closed	Closed	Closed
CB2	Gas Injection Compressor Cooler Fan No. 1	30.0	Open	Closed	Open
CB3	Gas Injection Compressor Cooler Fan No. 2	30.0	Open	Closed	Open
CB4	Gas Injection Compressor Building Ventilation Fan 1	22.0	Closed	Closed	Closed
CB5	Gas Injection Compressor Building Ventilation Fan 2	22.0	Closed	Closed	Closed
CB6	Wellstream Cooler Fan 'A'	15.0	Open	Closed	Open
CB7	Wellstream Cooler Fan 'B'	15.0	Open	Closed	Open
CB8	Glycol Pump 'A'	2.2	Closed	Closed	Closed
CB9	Glycol Pump 'B'	Not Used	Open	Open	Open
CB10	Instrument Air Compressor	21.0	Closed	Closed	Closed
CB11	Distribution Board	32.7	Closed	Closed	Closed
CB12	Water Loadout Pump	11.2	Closed	Open	Open
CB13	Dehydrator KO Pump	5.5	Closed	Open	Open
CB14	Compressor Building Fan 1	Not Used	Open	Open	Open
CB15	Compressor Building Fan 2	Not Used	Open	Open	Open
CB17	Diesel Generator	N/A	Open	Open	Open
	Total load (kW) for each operating mode		116.9	189.9	99.9

3.3 Determine the Bolted Fault Currents (Ibf)

The maximum available three-phase balanced fault current (bolt current) is calculated in accordance with IEC6099.

Prior to calculating the bolted fault current, a load flow (LF) and short-circuit current (SCC) analysis is carried out. The LF analysis is performed to verify the technical integrity of the simulation model and the results for the maximum busbar voltages are listed in Table 4.

The results of the IEC 60909 maximum fault calculation methods are listed in Table 5. These bolted fault currents are applied in the remaining arc-flash hazard assessment process and calculations.

Table 4: Gas Storage maximum busbar voltages for 3 operating modes

Busbar	Extraction (% V) 'A'	Extraction (% V) 'B'	Injection (% V)	Standby (% V)	Diesel (% V)
MCC 825-PMCG-001	98.1	98.1	96.9	98.4	99.7
MCC 833-PMCG-001	98.0	98.0	96.7	98.3	99.6

Table 5: Gas Storage maximum 3-Phase Fault Current for 3 operating modes

Busbar	Extraction (kA) 'A'	Extraction (kA) 'B'	Injection (kA)	Standby (kA)	Diesel kA)
MCC 825-PMCG-001	7.09	7.98	7.88	6.89	2.87
MCC 833-PMCG-001	6.66	7.43	7.40	6.49	2.86

3.4 Determine the Arc Fault Current (I_a)

After calculating the maximum three-phase fault current, the arcing current (I_a) is calculated. I_a is typically lower than the bolted-fault current (I_{bf}) due to the arc impedance which dissipates energy via its resistance. The equation to calculate the former is contained[2] in IEEE STD 1584-2002 and is applicable for system voltages under 1,000 V.

The results for both the bolt current and arc current are listed in Table 6.

Table 6: Gas Storage maximum arc fault currents for 3 operating modes

Busbar	Extraction (kA) 'A'	Extraction (kA) 'B'	Injection (kA)	Standby (kA)	Diesel (kA)
MCC 825-PMCG-001	3.52	3.86	3.71	3.47	1.50
MCC 833-PMCG-001	3.85	3.71	3.56	3.33	1.49

3.5 Protective Device Characteristics & the Duration of the Arcs

The fault clearing time (FCT) is a major factor affecting the calculation of the incident energy. The FCT is the time required to clear the fault (arc to get extinguished by an opening protective device) and is determined from the time current characteristic curves (TCC) or the definite times of each protective device that is considered to be a source protective device.

[2] Section 5.2 Arcing current; equation (1); page 10

The calculation process assesses the protection functional unit and decides whether the upstream protection or local protection will apply based on the forgoing criteria. The duration of the arc includes the trip time and opening time of the protective device.

3.5.1 Operation modes from distribution supply

This risk assessment bases all immediate upstream protective devices as relevant for the protection of all studied switchboards. These upstream protective devices include the LV fuse on the distribution 11 kV / 415 V 300 kVA supply transformer 784-TX-001 and the SCHNEIDER ELECTRIC NSX630 moulded case circuit breaker. The trip device for the NSX630 circuit breaker is a SCHNEIDER ELECTRIC Micrologic 2.3 solid state trip device.

The LV fuse (rating 400 A) on the distribution supply transformer 4667T is a 415 V BUSSMANN Model EF HRC fuse. The Technical Details and Time current curve characteristics are provided in the manufacturers Technical Data 4120.

3.5.2 Operation modes from diesel generator supply

The immediate upstream protective device is the 415 V diesel generator circuit breaker. This is a SCHNEIDER ELECTRIC NSX250 moulded case circuit breaker. The trip device for the NSX250 circuit breaker is a SCHNEIDER ELECTRIC Micrologic 2.2 (NSX) solid state trip device.

3.6 Document System Voltages & Classes of Equipment

In accordance[3] with IEEE 1584-2002, the system voltages and classes of equipment for Gas Storage site is 'Low-voltage MCC' category. Typical bus gaps of 25 mm are applied in calculations for the normalised incident energy.

3.7 Select the Working Distances

The incident energy calculation is based on the distance from the person's face and body to the potential arc source. In accordance[4] with IEEE 1584-2002, 'low-voltage MCC' working distance from the front of the panel to the centre of the potential arc is estimated to be 455 mm.

3.8 Determine the Incident Energy for all Equipment (E)

The equation to calculate the incident energy is contained[5] in IEEE STD 1584-2002 with calculated results in Table 7.

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[3] IEEE STD 1584-2002; Section 4.6 Step 6: Document the system voltages & classes of equipment; page 8

[4] IEEE STD 1584-2002; Section 4.8 Step 7: Select the working distances; page 8

[5] IEEE STD 1584-2002; Section 5.2 Arcing current; equation (1); page 10

Table 7: Gas Storage Incident Energy for 3 operating modes

Busbar	Extraction (cal/cm^2)	Extraction (cal/cm^2)	Injection (cal/cm^2)	Standby (cal/cm^2)	Diesel (cal/cm^2)
MCC 825-PMCG-001	27.22	20.60	30.09	26.53	See NOTE below
MCC 833-PMCG-001	30.35	23.24	33.77	29.52	

NOTE: The incident energy for the diesel generator mode has to be limited to a fault clearing time of 2.0 sec. Actual fault clearing time is > 15 sec which results in the incident energy being > 65 cal/cm^2. Limitation to 2.0 sec is in accordance[6] with IEEE STD.

3.9 Determine the Flash-Protection Boundary for all Equipment

The arc flash boundary is quantified as that distance where the incident energy is no longer considered a major hazard to unprotected personnel (i.e. wearing minimum PPE). This is taken to be the distance where the incident energy equals 1.2 cal/cm^2 or 5 J/cm^2 (threshold for a second-degree burn).

The flash-protection boundary is calculated by applying[7] IEEE 1584-2002 with calculated results listed in Table 8.

The establishment of a safe work area will prevent a person from entering the arc flash boundary during switching, racking, electrical work, testing, cover removal or visual inspection unless they are wearing the appropriate PPE. Where the arc flash boundary extends beyond the access doors to the installation then barricades shall be erected controlling access when activities identified are taking place. Barricades shall be consistent with the requirements for a restricted access barrier as defined 'in-house' standards/policies or national standards.

Table 8: Gas Storage Maximum Flash-Protection Boundary for 3 operating modes

Busbar	Extraction (m) 'A'	Extraction (m) 'B'	Injection (m)	Standby (m)	Diesel (m)
MCC 825-PMCG-001	3.06	2.59	3.26	3.02	1.68
MCC 833-PMCG-001	3.27	2.78	3.49	3.22	1.68

[6] IEEE STD 1584-2002; Section B.1.2 Data-normal tab; page 76
[7] IEEE STD 1584-2002; Section 5.5: Flash-protection boundary; (pp.12)

4.0 Hazard/Risk Category Determination

The Hazard/Risk category level is determined by comparing the calculated incident energy in cal/cm^2 against the ranges specified[8] in the NFPA 70E-2015 Informative Annex H.3-NFPA 70E 2015. Of relevance is Table H.39(b) Guidance on Selection of Arc-rated Clothing and Other PPE for Use When Incident Energy Exposure is Determined.

The identity of Hazard Levels in accordance with NFPA 70E-2015 are listed in Table 9; and the risk categories for each operation mode is listed in Table 10.

Table 9: ETAP NFPA 70E 2105 defined hazard levels

Hazard Level	Incident Energy (cal/cm^2)
A	1.2
B	12
C	40

Table 10: Gas Storage Hazard/Risk Categories for 3 operating modes

<table>
<tr><th>Busbar</th><th>Extraction (kA)</th><th>Extraction (kA)</th><th>Injection (kA)</th><th>Standby (kA)</th><th>Diesel (kA)</th></tr>
<tr><td>MCC 825-PMCG-001</td><td>C</td><td>C</td><td>C</td><td>C</td><td rowspan="2">NOTE</td></tr>
<tr><td>MCC 833-PMCG-001</td><td>C</td><td>C</td><td>C</td><td>C</td></tr>
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6.0 SUMMARY

This report calculates a worker's potential exposure to arc flash energy, which may be required for the purpose of injury prevention and determination of appropriate levels of Personal Protective Equipment (PPE).

Initial protection settings on the MICROLOGIC 2.3 of CB1 results in fuse F1 extinguishing before CB1 operates. By changing these trip settings, it is possible to reduce the maximum calculated fault clearing time, incident energy and the Hazard Category.

What is important to note is the results when the plant is supplied from either the primary source – 'A'; or alternatively, from an alternative source 'B'. The source with the highest fault level provides the greatest fault current contribution. In this case 7.09kA versus 7.98kA for 'A' & 'B' respectively. However, for these particular protection setting, the higher fault current does not necessarily result in a higher incident energy (IE). The higher the fault current, the faster is the protection operating time which reduces the IE for

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[8] NFPA 70E-2015; Page 86

27.22 cal/cm^2 to 20.60 cal/cm^2 for 'A' & 'B' respectively. Similarly, the Boundary Distances are reduced from 3.06m to 2.59m respectively.

References

1. Practical Solution Guide to Arc Flash Hazards; Chet Davis, P.E., Conrad St. Pierre, David Castor, P.E., Robert Luo, PhD, Satish Shrestha; ESA, Inc.; 2003.
2. IEEE 1584TM Guide for Performing Arc-Flash Hazard Calculations.
3. NFPA 70E 2012 Standard for Electrical Safety in the Workplace.
4. J.C. Das; Arc Flash Hazard Analysis & Mitigation; IEEE Press; 2012
5. Robert Morel; Cahier technique no. 154; LV circuit-breaker breaking techniques no. 154; LV circuit-breaker breaking techniques.

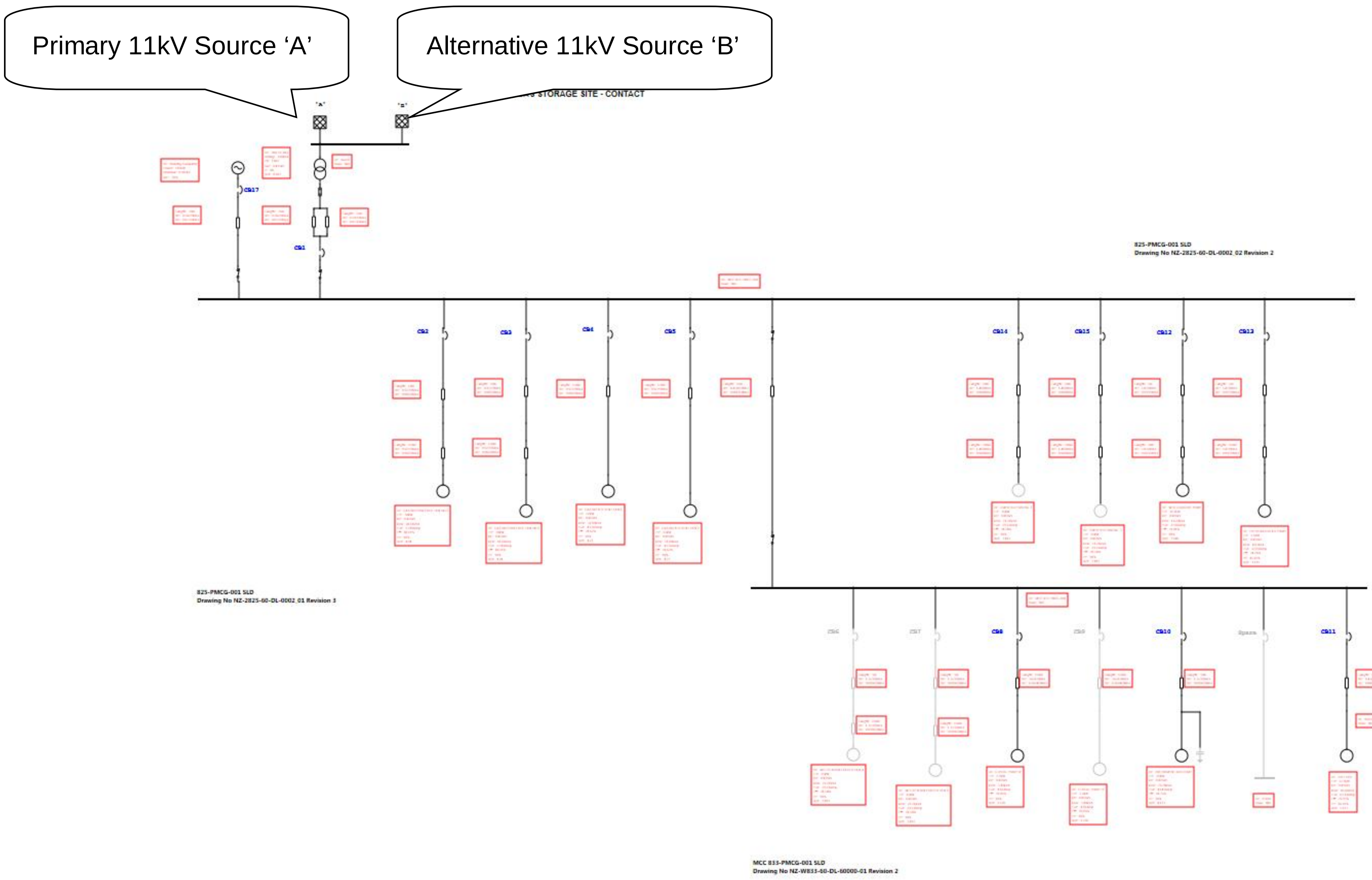

Figure A.1: ETAP Single Line Diagram