Power System Analysis Guidelines

TEM336

Revision Control

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Document Consultation

Revision	Name	Position	Comments Received	Date
4	Gerard Anderson	Senior Electrical Engineer	Y	May 2017
4	Andy Paranagama	Program Engineer	Y	May 2017
4	Paul Bourboulas	Project Manager IMSR	Y	May 2017
4	TEG		Y	May 2017

Contents

1 Introduction

1.1 Purpose:-

This document outlines the methodology and approach to undertaking Power System Analysis for all QUU facilities. The document generally specifies the assumptions to be made and consistently applied. A standard template for how the information shall be presented in the Arc Flash Analysis Report is outlined as well as a standard template for Arc Flash label formats.

1.2 Abbreviations and Acronyms

AC	Alternating Current
AF	Arc Flash
AFA	Arc Flash Analysis
AS	Australian Standard
CB	Circuit Breaker
CDEGS	Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis
DB	Distribution Board
DC	Direct Current
EF	Earth Fault
EI&C	Electrical Instrumentation and Control
FL	Fault Level
HV	High Voltage
HVAC	Heating Ventilation and Air-Conditioning
IHID	Individual Harmonic Current Distortion
IHVD	Individual Harmonic Voltage Distortion
I_{SC}/I_{load}	Short circuit current value divided by the maximum demand load current at the PCC
kW	Kilo Watts
kVA	Kilo Volt Amps
LV	Low Voltage
O&M	Operations and Maintenance
PCC	Point of Common Coupling
PPE	Personal Protective Equipment
PSA	Power System Analysis
PTW	Power Tools for Windows
QUU	Queensland Urban Utilities
RA	Risk Assessment
SAT	Site Acceptance Test
SLD	Single line Diagram
STP	Sewerage Treatment Plant
TCC	Time Current Curve
TDD	Total Demand Distortion
THDI	Total Harmonic Distortion Current
THDV	Total Harmonic Distortion Voltage
VSD	Variable Speed Drive

1.3 Reference List

Document Number	Title
WI58	Arc Flash Assessment and PPE Selection
TEM337	Terms of Reference - Arc Flash Hazard Risk Assessment Workshop
TMS1200	Electrical Installation – Technical Specification
TMS1621	Typical Pumpstation Maximum Demand Template
TMS1632	PSA Finalisation Procedure
TMS1647	Equipment Tag Naming - Technical Specification
TMS1648	EI&C Design Criteria- Technical Specification
486/1/25-0005-001	Arc Flash & Shock Hazard Sign - Types 1 Standard Detail
486/1/25-0005-002	Arc Flash & Shock Hazard Sign - Types 2 Standard Detail
486/1/25-0005-003	Arc Flash & Shock Hazard Sign - Types 3 Standard Detail
486/1/25-0005-004	Arc Flash & Shock Hazard Sign - Types 4&5 Standard Detail
486/1/25-0005-005	Arc Flash & Shock Hazard Sign - Types 6 Standard Detail
BMS 01607	Energex Supply & Planning Manual (dated 01/03/2013)
03329	Energex Pole Transformer Fusing Standard(dated 15 Nov 2012 (V3 Draft 1))
4920-A4	Energex Overhead Construction Manual Section 2 – Services (dated 15/03/2017)
Manual 00305	Energex Underground Distribution Construction Manual – Section E1 – Assemblies (dated 10/01/2017)
Manual 00305	Energex Underground Distribution Construction Manual – Section E4 –Cable Installation & Testing (dated 29/12/2015)
Manual 00305	Energex Underground Distribution Construction Manual – Section E5 – LV Joints and Terminations (dated 29/12/2015)
RE025800-RPT-001	Arc Flash Risk Assessment Workshop #1 and #2 Report – Network Sites
RO067000-RPT-001	Arc Flash Risk Assessment Workshop #3 Report – STP's and High Category Sites
REF424	PSA Report – Mobile LV Generator Details
REF425	PSA Report – LV Generators Arc Flash Analysis
REP107	PSA Report – Low Risk 230VAC Installations

1.4 Applicable Standards

Document Number	Title
AS 2067:2008	Substations and High Voltage installations exceeding 1 kV a.c
AS 3000:2007	Wiring Rules, Electrical Installations
AS 3007:2013	Electrical equipment in mines and quarries—Surface installations and associated processing plant
AS 3008.1.1:2009	Electrical Installations – Selection of Cables
AS 3851:1991	The Calculation of Short Circuit Currents in Three Phase AC Systems
AS/NZS 61000.3.4	Electromagnetic Compatibility (EMC) Part 3.4 Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 76A.
AS/NZS 61000.3.6	Electromagnetic Compatibility (EMC) Part 3.6 Assessment of emission limits for distorting loads in MV and HV power systems (IEC 61000-3-6:1996, MOD)
AS 61439.1	Low-voltage switchgear and controlgear assemblies Part 1: General rules
IEC 60255	Measuring Relays and Protection Equipment
IEC 60909	Short-circuit currents in three-phase a.c. systems - Part 0: Calculation of currents
IEEE 1584	Guide for Performing Arc-Flash Hazard Calculations
NFPA 70E 2015 Edition	Standard for Electrical Safety in the Workplace
IEEE519	Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems

1.5 Definitions

Project Documentation: Governing technical documents for the specific item(s) for the specific works included or referenced in the Contract

Contractor: The entity bound (including sub-contractors appointed by the contractor) to execute the work having responsibility for design, manufacture and supply, delivery, documentation and other functions as further defined in the documents related to the work.

Contract: The agreement between QUU and the Contractor to which this specification pertains.

QUU:	Representative appointed by QUU and responsible for the management and acceptance of the design works
Extra Low Voltage (ELV):	Not exceeding 50 volts AC or 120 V DC ripple free
Low Voltage (LV):	Exceeding ELV but not exceeding 1,000 volts AC or 1,500 volts DC.
High Voltage (HV):	Exceeding low voltage
Switchboard:	An electrical enclosure containing circuit breakers and other switchgear components.
Distribution Board (DB):	An example of a type of switchboard
Motor Control Centre (MCC):	An example of a type of switchboard
Control Panel:	An example of a switchboard and may contain ELV or LV voltage sources

1.6 Power System Analysis

The Power System Analysis (PSA) for the site generally consists of the following documents:-

- Load Flow and Pump Starting Report
- Load List
- Fault Current Calculation Report
- Maximum Demand Calculation
- Protection Co-ordination Report
- Arc Flash Analysis Report
- HV and LV Cable Sizing Calculations
- Earth Grid Design Report
- Harmonic Design Report
- Power Quality Analysis Report
- Insulation Co-ordination Report
- Site Condition Report

The Project Documentation will define which reports are to be delivered under the Contract. The above reports shall be standalone documents with individual QUU document numbers assigned for large sites such as STP's. QUU may accept to combine several reports under a single QUU document for smaller Network sites and this will be defined in the Project Documentation. Note in the case of combined reports a separate section must be dedicated to each of the report titles above.

The PSA Report for a site shall include all HV and LV equipment connected into the site power network unless specified otherwise in the Project Documentation. This includes miscellaneous control panels with LV supply to the panel. QUU will provide PSA Report templates for a STP(separate reports) and smaller Network sites(combined site report).

The PSA shall be performed by, or under the supervision of, a suitably qualified Electrical RPEQ with the necessary design, operations and maintenance experience and knowledge of power systems and analysis, and particularly experienced in the software tools and computation methods used, as well as aware of the relevancy of data and information that is necessary in order to perform such analysis accurately. The persons performing the modelling shall have extensive experience with latter versions of SKM PTW software.

All PSA reports produced shall be reviewed and checked by an Electrical RPEQ that is experienced in PSA and is independent of the persons who prepared the reports and performed the PTW modelling.

SKM PowerTools for Windows (PTW) version 7.X.X.X or latter shall be used to perform all PSA and the actual version of the PTW software used shall be stated in the PSA Report.

Before issuing the PSA Reports to QUU the Contractor shall ensure the PTW model and libraries have been thoroughly reviewed and checked. Refer to Appendix D of this document for the minimum review process for the PTW model.

The PTW software model including the protective device libraries and other relevant information shall be provided to QUU in native format after QUU has accepted all PSA reports with As Built status. The PTW software model and reports submitted to QUU shall be based on all proposed minor works having been completed. Minor works includes proposed protection setting changes to protective devices and replacement of protective devices where required.

The PTW model and library electronic files and PSA Reports in native and PDF format shall be presented to QUU as outlined in TMS1632 PSA Finalisation Procedure. QUU may at any stage of the Contract seek to review the status and progress of the PTW model, libraries and PSA Report(s) and the Contractor shall provide the requested information within 3 business days of the request.

QUU sites may have existing equipment and cables without tag names assigned. The Contractor shall assign tag names as per TMS1647 Equipment Tag Naming - Technical Specification for new and existing equipment and cables. Single line drawings shall be updated by the Contractor with the assigned tag names as required. The PSA Reports, PTW model and library devices (where applicable) shall match the single line drawings equipment tag names.

The updating to As Built status and re-issue of all PSA Reports required due to site construction or testing works is included under the Contract unless specified otherwise in the Project Documentation.

1.6.1 Load Flow and Motor Starting Report

SKM PTW shall be used to perform load flow and pump starting analysis of the power network.

The operating scenarios that will achieve the maximum and minimum power load for the facility shall be considered as well as the normal operating scenarios. The operating scenarios shall be outlined in detail and all assumptions and estimation stated in the report. The scenarios shall include normal utility supply and emergency generators required to operate the equipment if the utility supply is unavailable. Both permanent installed and temporary mobile generators shall be analysed for the assets feasible operating scenarios.

The starting sequence of large motors and voltage drop to motor terminals shall also be addressed under all scenarios and feasible operating conditions. Interlocking of incomers and bus ties must be considered. For each of the scenarios the report shall include calculations for the bus voltages, branch power factors, currents and power flows throughout the plant electrical system.

The Load Flow report shall document the active and reactive power for each generator, transformer, feeder and busbar. Load Flow diagrams or summary tables shall be produced indicating KW and KVA values, busbar voltage and voltage phase angles. The Load Flow report shall be used to confirm and verify: feeder capacity, system voltage profile and phase angles, Transformer ratings, loadings, power losses and transformer tap settings.

Motor starting assumptions shall be based on the following:-

- DOL starters - 6 X full load current of the motor
- VSD starters - 1.5 X full load current of the motor(unity if non regenerative VSD)
- Soft starters - 3.5 X full load current of the motor

Variation to above are accepted where supported by equipment data sheets or nameplate information which must be provided in the report.

For switchboards with numerous small sized motors on the same bus the motors can be combined into load groups not exceeding 5kW load per group. A motor of each rating must be individually modelled to determine voltage drop at motor terminals and assume longest length of motor cable.

The design of new and modifications to existing assets shall allow for all duty motors on the bus to operate at rated load and the largest motor on the bus to be started cold from standstill. During motor starting the voltage drop at all installed motor terminals shall not exceed 15% of motor rated voltage and the voltage drop at all switchboard bus bars shall not exceed 10%.

The load flow report shall also indicate the minimum power rating for any mobile emergency diesel generators that would be required for the site in event of utility power being unavailable to the site for an unplanned extended period. Refer to REF424 PSA Report – Mobile LV Generator Details for standard generator details to be used for mobile emergency generators. The Contractor shall update the REF424 document with other generator details where the generator required for the site is not already included in the document. The Contractor shall outline in the report where the mobile Emergency Generator(s) will be connected at the site.

It is feasible that the minimum generator size required for the site maximum load (i.e wet weather conditions) exceeds the generator rating required for normal load conditions (i.e dry weather conditions). The PSA report must consider both scenarios and nominate suitable sized generators for all feasible operating conditions. QUU will not accept over sized generators to cover all possible operating scenarios which introduces under loading of the connected generator when site is under low load conditions. When generators are connected the site minimum load shall not be less than 30% of the generator rated load for extended periods (exceeding 8 hours)to prevent engine glazing.

The minimum mobile generator size is determined based on essential and non-essential loads to be continuously operated and the Prime Running Power (PRP) of the generator to get all motors started. Prime Running Power (PRP) is defined as the maximum power which a generator is capable of delivering continuously whilst supplying a variable electrical load when operated for an unlimited number of hours per year. The permissible average power output over 24 hours of operation shall not exceed 70% of the PRP rating.

The PRP rating is required to be specified because it is not known how long the generating set would be retained in service during a mains power outage or how many hours the generator would be expected to support the site's maximum demand load.

The PSA Report must nominate essential and non essential loads powered by both permanent and mobile emergency generators.

All Network sites regardless if generator plug is provided or not shall have the mobile generator supply scenario considered.

1.6.2 Load List

The Load list shall have as minimum the following information and all assumptions clearly nominated for each entry.

- kW rating of all loads
- Full load running current
- Total connected load in kW
- Design spare capacity
- Calculated Maximum Demand Load in kW, kVA and kVAR
- Calculated Power Factor

A load list is required for the design of all new assets and modifications to existing assets. The load list must nominate new and existing loads.

1.6.3 Fault Current Calculation Report

The fault current calculations shall be in compliance with AS3851 and IEC60909.

A Short Circuit Fault Current Study for minimum and maximum three phase and single phase faults shall be calculated at each switchboard bus and electrical enclosure in the power network. The maximum fault current level calculations will determine prospective fault current level which will determine the fault current withstand rating of the switchboards, protective devices and other equipment. The minimum fault levels shall be used to determine the settings for protective devices.

The scenarios and operating conditions to assess the minimum and maximum fault current levels in the power network shall be clearly identified in the report. The emergency generator scenarios shall be considered. All assumptions and estimates shall be stated in the report.

A compliance check of all protective devices against maximum prospective fault current shall also be provided.

1.6.4 Protection Co-ordination Report

The Time Current Curves (TCC's) for each protective device installed at the site shall be included in the Protection Co-ordination Report.

Discrimination by time and current shall be provided between upstream and downstream devices in accordance with AS3000. Changes to existing protection settings and installed equipment shall be proposed to achieve coordination where anomalies are identified. Where discrimination cannot be adequately achieved the Contractor shall advise the reasons why the proposed setting can be accepted and how compliance with AS3000 and Energex requirements are met.

Settings provided for each protective device shall be specific to the model of CB or relay installed. User selectable settings shall be clearly identified in the report. Settings which are not user configurable or factory defaults shall also be identified in the report. Cable damage curves, transformer and generator curves shall be provided to demonstrate equipment is adequately protected from over current and earth fault.

Appropriate settings including LV earth leakage protection devices shall be calculated for each protective device and the characteristics of all protective devices on the circuit under consideration compared, to ensure upstream and downstream discrimination is met. For existing protective devices the as installed TCC's and settings shall be included in the report as well as any recommended modifications to settings. The recommended modifications shall not be implemented until after the Protection Co-ordination Report and Arc Flash Report are accepted by the QUU.

A protective device setting schedule shall be prepared that indicates the settings selected for each device. The utility (Energex) incomer protective device time current curve must be included in the report as well as the protective devices for the emergency generators (permanent and portable). Where applicable the protection coordination report shall include emergency generator CB settings and if any changes must be made to the other protective devices at the site in order to connect a portable emergency generator.

The TCC graphs must use equipment tag names as used in all other documents. All equipment including switchboards, transformers, permanent generators and protective devices shall be uniquely identified. The equipment and cable tag numbers must be verified by the Contractor during site investigations and reconciled with SLD's and cable schedules and other site specific documentation.

Implementation and testing of the revised protection settings shall not be commenced on site until the Contractor has produced a SAT Plan and the plan has been accepted by QUU.

The Protection Co-ordination Report shall not be submitted for QUU review until the Load Flow and Fault Current Reports have been accepted by QUU.

The Protection Co-ordination Report shall be updated and re-issued As Built to QUU after all protection setting changes have been tested. Records of all site tests shall be submitted in a SAT Report.

1.6.5 Maximum Demand Calculation

For new installations only a maximum demand calculation based on the proposed electrical load list shall be provided. The Maximum Demand Calculations shall use Microsoft Excel spread sheets, unless alternative software tool is accepted in writing by QUU prior to Contract award. The Maximum demand calculation for LV distribution boards shall comply with AS3000.

All assumptions and estimations shall be documented in the maximum demand report and clearly defined in the calculation notes. Maximum demand calculations shall be provided for every proposed new distribution board, switchboard, transformer, generator, UPS, power supply etc at the site.

The diversity factors to be used for load list calculations are as follows:

- Circuit capacity of each individual load should be based on its full-load rating.
- For switchboards, use driven plant load, or the following Demand Factors:
    - Pumps, Fans 0.9
    - Lighting 1.0
    - HVAC – 1.0
    - UPS 1.0

A typical maximum demand for an existing two pump station site is shown in Appendix A.

For existing installations the power demand shall be logged over a period of time by the Contractor installing power meters at connection points agreed with QUU in the network. The measured data at the point of supply to the site can also be reconciled with network metering data available from QUU for each site. The metering data will determine the long term minimum and maximum load as well as normal loading for the site. This information shall be used to determine the overall site load factor under various operating conditions. The load factor can be used to estimate the maximum demand of existing equipment.

Refer to section 1.7 for PQA Data Logging requirements.

1.6.6 Arc Flash Analysis Report

The Arc Flash Analysis (AFA) Report shall include but not be limited to:

- The maximum arc flash protection boundary for each switchboard and electrical enclosure at the site containing LV and HV equipment
- The maximum incident energy and nominate the working distance at each switchboard and electrical enclosure at the site containing LV and HV equipment.
- The PPE Category required to access each electrical equipment item

The AFA Report shall refer to the Fault Current Calculation Report, Protection Co-ordination Report and Load Flow Report. The AFA Report shall not be issued for review until the Load Flow, Fault Current Calculation, and Protection Coordination Reports have been accepted by QUU.

The AFA Report cannot be finalised until a formal Arc Flash (AF) Risk Assessment Workshop has been undertaken with QUU for each type of switchboard or electrical enclosure at the site. If required the Contractor shall participate in the AF Risk Assessment Workshop with QUU O&M persons and engineering representatives from the switchboard manufacturer. The Project Documentation will define the scope further on this matter. The AF Risk Assessment Workshop may require updates to be made to the AFA Report before it will be accepted by QUU.

QUU has completed AF Risk Workshops for switchboards installed at Network sites and at STP sites. Refer to the reports listed in section 1.3.

Where the Category of PPE required to undertake any normal O&M task on an item of electrical equipment exceeds Category 0, the Contractor shall discuss with QUU and recommend remedial works to lower the incident energy and achieve a desired Category 0 for all O&M tasks. Where this is not economically feasible a Category 2 for selected O&M tasks will be accepted by QUU. The final AFA Report shall document the incident energy and PPE category for each O&M task after the remedial works have been completed. Refer to WI58 Arc Flash Hazard Assessment and PPE Selection for the categories of AF PPE accepted by QUU.

When an existing switchboard is first identified as Dangerous or Category 4 Arc Flash PPE category the Contractor shall immediately notify the QUU Project Manager. The Contractor shall install temporary arc flash labels to the switchboards. For Category 4 switchboards Type 2 and 3 labels are required. For Dangerous Switchboards Type 6 label is only required. Refer section 3.3 for Arc flash label types.

In addition, for Dangerous existing switchboards the Contractor shall attend a RA workshop with QUU representatives to determine what controls can be introduced immediately to manage the Dangerous Arc flash incident energy level present. The Contractor shall facilitate the RA workshop and provide a report recommending all feasible controls and measures for QUU to implement so as to safely mange the O&M of the asset. The RA workshop shall be allowed as a provisional sum unless specified otherwise in the Project Documentation.

QUU will not accept AF Category 4 PPE and Dangerous switchboards and the Contractor shall provide as part of the AFA Report a budget estimate (+/-30%), equipment lead time, product specification for all technically feasible options to reduce the incident energy at the line side of the switchboard incomer. The options must be adequately defined for QUU to evaluate the most suitable solution.

The AF Analysis Report shall not be submitted for QUU review until the Protection Co-ordination Report for the site has been accepted by QUU.

1.6.7 Power Cable Sizing Calculations Report

Power cable sizing calculations shall be provided by the Contractor for all new cables and existing cables proposed to be retained in service and connected to new equipment.

The sizing calculations for LV and HV cables can be consolidated into one common report for the site. The report shall make reference to the Power Cable Schedule for the site using a QUU document number and all assumptions shall be outlined in the report. The Contractor shall produce a Power Cable schedule from information extracted from the PTW model where QUU is unable to provide an As Built Cable Schedule.

The Earth Fault Loop-Impedance (Zs) of all new LV cables in the network shall be provided in the report. Existing cables where it is proposed to connect new or modified equipment shall also have Earth Loop Impedance Calculation provided.

The calculation of touch potentials throughout the site at all new LV electrical equipment shall also be provided in accordance with AS3000 Appendix B. The calculations shall be presented in an excel spread sheet as an Appendix to the Power Cable Sizing Calculation Report. The excel calculation template to be used is shown in Appendix B of this document.

1.6.7.1 LV Power Cable Sizing

The LV Power Cable Sizing Calculations shall be provided using PowerCAD software. There shall be one calculation sheet provided per power cable. The calculations shall comply with AS3008.1 for current capacity, voltage drop and fault rating. Earth Loop impedance checks shall be as per AS3000. Alternative calculation software or methods are not accepted. Cable sizing calculations are required for all new cables and existing cables proposed to be retained in service and connected to new or modified equipment.

The fully documented PowerCAD native files shall be provided to QUU after the Issued for Use Cable Sizing Calculation Report has been accepted by QUU.

The Cable Calculation Report shall indicate the actual Earth Fault Loop-Impedance (Zs) and maximum Zs max at every LV circuit installed.

LV cable sizing will be determined considering the following criteria:

- Current carrying capacity.
- Voltage drop (between switchboard and the device terminal) typically shall meet the following design criteria:-
    - Switchboard feeders 1.5~2%.
    - Motors – 3~3.5% running and maximum 15% starting at motor terminals.
    - Good engineering practice which may require case by case consideration to alternative voltage drop parameters depending duty, installation features, site conditions etc..
- Fuse or circuit breaker capacity.
- System symmetrical short-circuit fault rating at point of installation.
- Cable installation arrangement (derating).
- Termination and glanding limitations.

An example of a typical Power CAD LV power cable sizing calculation report is as follows:

Standards : AS/NZS 3000:2007/Amdt 1:2009, AS/NZS 3008.1.1:2009/Amdt 1:2011

Generator: **U-700020**
2×500 kVA
400/230V 50Hz

Circuit: **VSD-BM-524002 - P35** (3ø) BM-524002

CABLE DATA - CIRCUIT CABLE

CABLE INPUT DATA

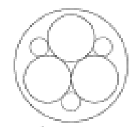
Reference : BM524002-P2
Voltage : 400/231V - 3 Phases
Load Maximum Demand : 50.92 A/phase
Load Power Factor : 0.93 lag
Cable Length : 155 m
Derating Factor : 0.73

Target Voltage Drop : 3.5 %
Air Ambient : 45 °C
Short Circuit Time : 0.053 sec
Fault Level (at load terminals) : 2.13 kA
Max Fault Level (at cable origin) : 10.52 kA

CABLE SIZE

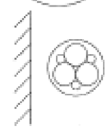
Size Actives (3) : 35mm²
Neutral : No Neutral
Earth : 3×6mm²
Cable Estimated Price : $8,043.12 **Cat No. :** FTDC18AA003
$51.89 /m (No Discount)

CABLE TYPE



Cable Code : 17
VAROLEX TAPE SCREENED VSD CABLE CIRC. 3-CORE 0.6/1 kV INSULATED AND SHEATHED

Cable Configuration : 2
UNENCLOSED, SPACED FROM SURFACE



Cable Insulation : XLPE 90°C
Sheath : PVC
Shield : Cu Tape

Conductor Material : Cu
Earth Conductor Material : Cu

CABLE PROPERTIES

Cable Impedance : 0.092047 Ohms
Cable Resistance : 0.091236 Ohms
Cable Reactance : 0.012183 Ohms
Conductor Operating Temperature : 51.1 °C
Thermal Stress Limit (K² × S²) : 32,969,588 A²s
K : 164.1

CABLE CAPACITY

Current Capacity : 100.9 A
Voltage Drop : 7.879 V (= 1.97%)
Fault Capacity : 25 kA (at 0.053 sec)
Maximum Length : 243.5 m (Based on 51 A/phase)

CABLE SPARE CAPACITY

Current Capacity : 49.9 A (= 98.09%)
Voltage Drop : 1.53 % (Available)
Fault Capacity : 0 kA (at 0.053 sec)
Length : 88.5 m (Remaining)

CABLE PROTECTIVE DEVICE

Manufacturer : NHP
Type :
Model :
Rating : A
Trip : -
(at 10.52 kA 0.298 sec)

An example of a typical Power CAD LV network Earth Loop Impedance report is as follows:-

Designed By :

Transformer: **TX-001-01**

1,500 kVA 400/230V 50Hz **EARTH FAULT LOOP IMPEDANCE - (UNBALANCED LOAD)**

SUPPLY (L.V. Side) : 400/230V 50Hz
Load Maximum Demand : 631.2 kVA (911 A/phase)
Load Power Factor : 0.905 lag
Max. Allowable Site Voltage Drop : 5 %
Actual Site Voltage Drop : 1.62 %

Distribution	Cable Size (mm²)	Cable Length (m)	Max Zs (Ohms)	Zs (Ohms)	Device Model	Curve Type	Trip Unit	Trip Setting (A)	Device Rating (A)
TX-001-01 (1,500 kVA, 11kV/400V)	1,500 kVA (5.9% Impedance [0.001885 + j0.005993 Ohms])								
X MCC-001-01-Bus A (3ø)[1,30]	4×300	5.0	0.0199	0.0069	n.a.	n.a.	n.a.	n.a.	n.a.
VSD X VSD-Blower 7 (3ø)[21]	240	5.0	0.1403	0.0083	NSX630N		Micrologic	500	252-630
VSD X VSD-Blower 8 (3ø)[21]	240	5.0	0.2117	0.0083	NSX630N		Micrologic	500	252-630
VSD X VSD-Blower 9 (3ø)[21]	240	5.0	0.2117	0.0083	NSX630N		Micrologic	500	252-630
VSD X VSD-Blower 10 (3ø)[21]	240	5.0	0.2117	0.0083	NSX630N		Micrologic	500	252-630

[1] Minimum allowed current capacity used in cable calculations.
X This switch board/circuit contains errors. Refer to the footnotes for an explanation.
[21] Cable protective device errors.
[30] There are final sub-circuits on this switch board containing errors.

Note: PowerCAD will model generic VSD's only and this is accepted for LV cable sizing calculations of VSD's.

Where provided on-board earth leakage protection shall be enabled in VSD's and the settings reported in the Protection Co-ordination Report. Therefore PowerCAD Earth Fault Loop impedance calculations for VSD's with integral earth leakage protection can be ignored for VSD motor cables.

Earth leakage calculations are also not required where an earth leakage device is installed at the point of supply for the cable.

1.6.7.2 HV Power Cable Sizing

HV power cable sizing calculations may use manual calculations, PTW, or Microsoft Excel spread sheets. Proprietary software or other alternative methods must be submitted to QUU for review prior to commencing design works.

The proposed template for the HV Cable Sizing Calculation Report must be accepted by QUU before design works commences.

HV cable sizing shall be determined considering the following criteria:-

- Current carrying capacity.
- Voltage drop (between switchboard and the device terminal) using the following basis:
  - Motors – 2~2.5% running, maximum 15% starting at motor terminals
  - Transformer feeders- 2~2.5%.
- Fuse or circuit breaker capacity.

- System symmetrical short-circuits rating at point of installation.
- Cable installation arrangement (derating).
- Termination and glanding limitations.

Sizing and selection of cables must also take into account economic factors and minimum order lengths.

1.6.8 Earth Grid Design Report

The Earth Grid Design Report for sites having HV supply shall be provided using CDEGS or SKM PTW software. Hand calculations for Earth Grid step and touch calculations are not accepted unless agreed otherwise in writing with QUU prior to Contract award.

Refer to TMS1648 EI&C Design Criteria Technical Specification for design requirements and minimum content of an earth grid design report.

1.6.9 Harmonic Design Report

A Harmonic Design Report shall be provided to calculate the level of Total Harmonic Distortion (THD) current and voltage present at the site as well as maximum individual frequencies harmonic distortion for current and voltage. This is applicable to sites where VSD and other non-linear loads such as HVAC inverters, UPS's and battery chargers are proposed to be installed.

The background harmonic levels at the site shall be measured by the Contractor under various plant operating scenarios. Refer section 1.7 PQA Report for how the site measurements will be undertaken and presented to QUU. The site test plan shall be accepted by QUU prior to the site testing works commencing.

The background harmonics are a key design input into the harmonic design report. All other design inputs and assumptions that may affect the THD calculation shall be defined in the Harmonic Design Report. For example THD must be considered when operating under alternative power supplies such as emergency diesel generators.

The equipment proposed by the Contractor shall ensure the THD is minimised under all operating conditions. The magnitude of the THD voltage and current shall be calculated for all main bus bars in the network and at the Point of Common Coupling (PCC) when equipment is operating. The PCC is defined as the location where the utility (Energex) revenue meter is connected at the site as per page 75 of IEEE Std 519-1992. The maximum THD current and voltage shall be calculated for each operating scenario considered. The harmonic spectrum data from actual equipment suppliers for the models of new equipment proposed to be installed shall be used rather than using generic data available in PTW libraries or other software packages.

The thermal ratings of transformers and generators at the site shall be checked against the calculated network harmonic content.

The harmonic analysis shall demonstrate the THD current and voltage limits will not exceed the QUU imposed limits after the new equipment has been commissioned. The equipment installation methods proposed by the

Contractor must ensure that the EMI/RFI is also within the acceptable limits set by equipment manufactures and relevant industry standards. For sites requiring new non-linear loads to be installed the electrical equipment shall not be ordered until the harmonic design report has been accepted by QUU.

The Harmonic Design Report shall contain harmonic mitigation strategies including filters and any other equipment required to meet the THD limits specified by QUU. The report shall document the THD limits with and without the proposed harmonic filters installed. Provisions shall be made in the design by the Contractor to increase the level of harmonic filtering in future if non-linear load growth at the site occurs or if the Contractor's calculations under estimate the actual harmonics measured during commissioning and performance testing.

During commissioning the THD voltage and current and individual frequency harmonic distortion voltages and currents shall be measured to confirm design calculations when the equipment is operated under minimal load, during the starting of large loads and run up to the maximum demand load conditions. The Contractor is responsible for conducting the site measurements and verifying the design calculations. The Contractor shall prepare a SAT Plan before commencing site measurements and provide a SAT Report on completion of site measurements. Any rectification works of the installation to address current and voltage harmonic distortion excursions above the specified design limits shall be the responsibility of and at the cost of the Contractor.

1.6.10 Harmonic Distortion Compliance Requirements

Limits to harmonic emission from LV equipment with rated current greater than 75 A per phase are covered by AS/NZS 61000.3.4. There are also QUU sites with less than 75A load per phase and these would be covered under AS/NZS 61000.3.12 Current greater than 16A and less than 75A. Both these Standards do not specify a harmonic level for LV equipment to comply with and advises a special agreement between the supply authority (Energex) and the consumer (QUU). This consent will depend upon several factors including the expected levels of disturbance caused by the equipment and the actual situation at the connection point to the power supply system. Unless specified otherwise, AS/NZS 61000.3.4 and AS/NZS 610003.12 will not apply in the determination of maximum harmonic distortion current and voltage limits accepted at QUU sites.

The THD at the PCC for modifications to power networks at existing QUU facilities shall be within the values specified in AS/NZS 61000.3.6. An indicative value of planning levels for THDV at an 11kV PCC is given as 6.5% and the compatibility levels for THDV is specified at the PCC as 8% for both LV and 11kV networks. The THDI is typically 16% for both LV and HV PCC's.

TMS1406, for Low Voltage Variable Speed Drives - Technical Specification requires that harmonic filters shall be provided where the calculated harmonic distortion levels at the local LV bus where VSD's are proposed to be connected do not meet any one of the following criteria:-

- THDV exceeds 5%
- THDI exceeds 5%
- Any individual frequency harmonic voltage exceeds 3%
- Any individual frequency harmonic current exceeds 3%.

The IEEE 519 standard has varying THDI limits depending on if the PCC is at LV or HV and depends on the system classification and the I_{SC}/I_{load} value. The maximum THDV is 5% at the PCC for both LV and HV at QUU sites.

The IEEE 519 installation classifications are as follows:

- Special Applications – such as hospitals and airports
- General Systems
- Dedicated Systems – dedicated to the converter load

For the purpose of QUU Harmonic Design Reports the classification of all QUU sites is "General Systems". The PCC shall be taken as the Energex revenue meter connection under normal power supply at the site.

Where a standby generator or provision for an emergency generator is provided at the site, the PCC shall be the connection point of the generator to the site power network. Harmonics produced by generators must be considered in the harmonic design report. The design report shall calculate harmonics distortion for minimum and maximum ratings of mobile emergency generators that can be connected to the site.

11kV is the highest distribution voltage level at the PCC, where QUU owns the HV equipment. The only exception to this is at Eagle Farm SP10 where 33kV is highest voltage level at the PCC.

IEEE 519 specifies maximum 3% for each individual frequency harmonic voltage and the following values for THDI and individual frequency harmonic currents which vary depending on the power network I_{SC}/I_{load} value as shown in the Table 10.3 extracted from IEEE 519.

Table 10.3, p78
Current Distortion Limits for General Distribution Systems
(120 V Through 69,000 V)

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{SC}/I_L	<11	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Where:

I_{SC} = maximum short-circuit current at PCC.
I_L = maximum demand load current (fundamental frequency component) at PCC.
TDD = Total Demand Distortion (Current) as a percentage (equivalent to THDI)
h = order of harmonic frequency

Even current harmonics are limited to 25% of the odd harmonic current limits in above table.

For all QUU sites the I_L maximum demand load is equivalent to the maximum demand current calculated as per section 1.6.4 of this document.

The total harmonic distortion limits for voltage and current as described above are summarised in the following table.

Standard	Description	THDV Limit	THDI Limit	Voltage	Project Scope
AS/NZS 61000.3.6	Planning Level	6.5%	16%	LV	Modification to existing installations
AS/NZS 61000.3.6	Compatibility Level	8%	16%	LV and HV	Modification to existing installations
IEEE 519	General System	5%	As per Table 10.3 of IEEE 519	LV (PCC) and HV(PCC)	New sites
TMS1406	As commissioned	5%	5%	LV(at local LV bus)	All new VSD's

For new QUU sites the Harmonic Design Report shall demonstrate by calculation that the following harmonic emission limits are complied with at the PCC:-

THDV Limit	THDI Limit	Individual THDV Limit	Individual THDI Limit	Voltage at PCC
5%	As per Table 10.3 of IEEE 519	3%	As per Table 10.3 of IEEE 519	LV or HV

It is recognised that when harmonic distortion limits are met at the PCC, they could easily be exceeded downstream in the power network where connected equipment could be affected. Voltage distortion is the result of harmonic currents passing through the impedance of the power system, voltage distortion will always be higher downstream where the harmonic currents are generated and where system impedance is highest. As such the Contractor shall provide harmonic analysis at the main and downstream switchboards in the site power network.

The Harmonic Design Report shall provide the harmonic distortion limits as follows at the PCC and at each major switchboard in the site power network:-

- THDV
- THDI
- Individual harmonic frequencies voltage
- Individual harmonic frequencies current.

1.6.11 Insulation Co-ordination Report

For new and modifications to existing HV installations the Contractor shall provide an Insulation Co-ordination Report. Refer to TMS1648 EI&C Design Criteria for topics to be addressed in the report. The calculations to determine the rating of HV equipment surge arrestors shall also be contained in the report.

1.6.12 Site Condition Report

For existing installed equipment and where specified in the Project Documentation a Site Condition Report shall be provided by the Contractor. The report shall nominate all departures from AS3000 and AS2067 with the existing installation with photographic evidence provided of all defects and all switchboards (internal and external) conditions. The inspection shall include all LV and HV electrical equipment at the site including DB's, control panels, motors and miscellaneous field equipment and interconnecting power cables where visible. Special attention to the installed earthing system condition shall be made.

The budget to rectify defects, equipment supply lead time and risk to QUU shall be identified for each defect so that QUU can determine the priority for the remedial works required. The Contractor shall provide earth loop impedance test at each LV switchboard and LV control panel. The test records for Earth Loop Impedance tests shall be provided in the Site Condition Report. Refer to QUU for a typical template for a Site Condition Report.

1.6.13 PSA Reports Assumptions

Some key assumptions that are to be applicable to all PSA Reports for a site are listed below to ensure consistency in design and reporting approach. This is not an exhaustive list and each site will require to be considered on its own merits and may require additional assumptions. All assumptions must be accepted by QUU, stated in the PSA Reports and consistently applied for the site PSA.

1. Energex LV/HV Transformer fuse ratings is assumed from 03329 Energex Pole Transformer Fusing Standard(dated 15 Nov 2012 (V3 Draft 1)) and page 12 extract provided in Appendix E of this document.
2. A 100A service fuse rating shall be assumed if the supply to a site is direct metered and this is regardless of what fuse is currently installed at the site.
3. At sites that are not direct metered the service fuse rating shall be determined using Energex overhead and underground construction manuals and this is regardless of what fuse is currently installed at the site.
4. Transformer Impedance (%Z) where cannot be confirmed from site inspection due to access restrictions shall be assumed from BMS 01607 Energex Supply & Planning Manual (dated 01/03/2013) and page 145 extract in Appendix F of this document.
5. Mobile LV generator data shall be derived from REF424 Mobile LV Generator Details.
6. When a generator (permanent or mobile) is operating at a site the Arc Flash PPE Category required to access within the arc flash boundary of the generator and all downstream connected switchboards depends on the power rating of the Generator. The incident energy, arc flash boundary and PPE required is contained within WI58 Arc Flash Assessment and PPE Selection and REF425 PSA Report – LV Generator Arc Flash Analysis.
7. This approach to managing the arc flash hazard associated with LV generators is a conservative approach and is required to overcome the need for separate Type 3 arc flash labels on switchboards when a site is

under generator supply. This approach applies to both permanently installed and mobile LV generators.

1.7 Power Quality Analysis Report

The Power Quality Analysis (PQA) Report presents the measured data from power meters connected in the network to measure voltage and current harmonic distortion, power factor, voltages, currents on each phase as well as power demand(kVA, kWH, kVAR) over a specified period. The monitoring period shall be minimum 7 consecutive days and 24 hours per day unless specified otherwise. Individual harmonic frequencies shall be monitored as well as total harmonic distortion for both voltage and current.

Due to the quantity of information to be provided there is a separate PQA Report provided for each power meter connected at the site. The PQA reports make recommendations and provide cost estimate for the supply of harmonic filtering and power factor correction equipment where required at the site.

QUU will provide a template for a typical PQA Report that shows minimum content and an accepted presentation method of the information.

2 Arc Flash Analysis Report Contents

The following sections describe the specific format and typical contents to be included in each section of the AFA Report. A similar structure of the document is required for the PSA Reports.

2.1 Table of Contents

This section shall list all sub section numbers and page numbers in the AFA Report.

2.2 Introduction

This section shall include a definition of the arc flash hazard and why it is required to be analysed, what industry standards are applicable to QUU Facilities and other best industry practices. The section includes discussion on why NFPA-70E and IEEE 1584 are most applicable standards and how these standards are applied in the AFA.

2.3 Purpose of the Report

The intent of the Arc Flash Analysis is to determine the estimated short-circuit and arcing currents, incident energy, and arc-flash boundary (AFB) for all equipment at the site likely to require operation, maintenance, service or inspections while the equipment is energised. The results of the arc-flash study shall be used by the Contractor to make recommendations for changes to the protective device settings and/or other remedial works to limit the level of incident energy down to acceptable levels. Consultation with QUU is required before any recommendations will be accepted.

The results of the arc-flash analysis, based on calculations of the incident energy and AFB at each location, must be presented in a manner which ultimately allows the results to clearly indicate the energy levels, minimum PPE requirements and risks to QUU's operators, as well as to allow QUU's operators to perform the necessary arc flash hazard risk assessments.

2.4 Executive Summary

This section contains a concise summary of the report findings, discusses all Categories of PPE and what remedial tasks required to be addressed to achieve a desired Category 0 PPE for all normal O&M tasks of the equipment. The summary must contain information presented clearly in a table to show for all electrical equipment installed the existing PPE Category before the AFA was undertaken and the modified PPE Category after AFA is complete.

The report shall emphasise the dependency of the study results on accurate and up-to-date data and the collection of such information by the Contractor. The Contractor shall minimise the reliance on estimated or assumed data. This section also outlines why the AFA Report must be updated as modifications are made to the facilities power network.

2.5 Assumptions

This section lists and discusses all assumptions made in undertaking the AFA, including the following:-

- The assumptions shall not conflict with those outlined in the Fault Study, Load Flow Report and Protection Co-ordination Reports.
- The worker is stationary for the first 2 seconds of an arc flash incident (constant working distance), and is directly exposed to the arc flash source during this period. It is assumed that the worker would vacate the arc flash zone after a maximum reaction time of 2 seconds;
- To comply with relevant Australian Standards all interrupting devices are rated for the prospective short circuit current (no equipment damage is considered);
- Summarise the minimum and maximum 3ph and 1 ph HV and LV fault levels from the Fault Study Report at each LV switchboard and main HV Switchboard line side of incomers. Briefly describe the operating or switching scenarios for the basis of these minimum and maximum fault level calculations.
- Energex Consumer Mains LV or HV protective device ratings as installed or proposed at the facility shall be considered in all power system analysis.
- Incident Energy is calculated at the line side of the main protective device of each LV switchboard or DB and this is the incident energy assumed for the entire LV switchboard. This is a rather conservative approach and is required because the LV switchboards currently in service at QUU sites are not tested for arc fault containment. An arc produced at the line side of the main incomer may propagate throughout the entire switchboard.
- For HV switchboards if arc fault containment certificates are available from an accredited test facility and the switchboard arrangement has been tested to contain an arc at the main incomer line side, then the incident energy can be calculated on the load side bus of the main incomer circuit breaker or fuse. It is assumed that this is the incident energy level for the entire HV switchboard.
- AFA Calculation is based on IEEE 1584(2002) for arcing fault and NFPA 70E 2015 edition and WI58 for the required PPE equipment.
- The trip setting time for individual protective devices are used from the TCC outlined in the Protection Coordination Report. When no trip time is allocated in the system model, 0.3 seconds maximum disconnection time shall be used.
- The arc flash incident is assumed to be cleared by the protective device in accordance with IEEE 1584.
- The operating time of the circuit breakers were modelled in PTW using the settings and Time Current Curve (TCC) which is shown in Protection Co-ordination Report.
- Motors less than 37kW rating are not considered to contribute to the arc fault current level in compliance with IEE1584.

2.6 Limitations

The report must state that the AFA Report is prepared by the Contractor and if modifications or additions to the power network are made then the PSA must be revised. The Contractor shall nominate other limitations as required and must state explicitly what is excluded from the calculation otherwise it is assumed included.

2.7 Reference Document List

This section contains a table listing all documents by QUU document number and revision number, includes SLD's, cable schedules, load flow report, fault calculation report, protection co-ordination report that are referred to in compiling the AFA Report. Where no QUU document numbers exist the Contractor shall consult QUU to generate document numbers.

2.8 Standards and Regulation

All Australian and International standards relevant to the report i.e. AS3000, IEEE 1584, NFPA-70E, AS4836, AS3439.1 etc must be listed in a table in this section. The version and title must be indicated. All documents such as equipment data sheets and supporting information relevant to the report are included in an Appendix of the AFA Report for future reference.

2.9 Abbreviations List

This section contains a table indicating all abbreviations and acronyms used throughout the report.

2.10 Technical Definitions

This section contains a table that defines all terms used in the AFA report and definition must be must be as per the definitions contained in relevant standards.

2.11 Data Collection

The arc flash analysis must be based on accurate, up to date information. It is the obligation of the Contractor to gather all the relevant available information but not limited to the following:-

- existing SLD's and verify the accuracy of the drawings;
- resolve any equipment labelling issues;
- transformer and generator name plate details,
- equipment past test records,
- CB and relay test reports,
- data sheets for motors, generators, switchboards,
- copies of any previous PSA studies,
- cable schedules showing cable size, type and route length and type,
- Obtain the utility supply nominal voltage, fault current level at point of supply(normal, minimum and maximum) for three phase and single phase to ground faults as well as system X/R ratios if available.
- Obtain relay settings,
- CT ratios,
- CB trip unit settings and sensor sizes,
- fuse types and amp rating,
- HV motor and other equipment characteristics

- Verify nomenclature to be used for all equipment and all devices with QUU. This includes abbreviations etc. The Contractor must ensure proper naming conventions accepted by QUU before creation of any deliverables defined by the PSA scope of work;
- Inspection of the site is mandatory to ascertain the accuracy of all data available
- All site work shall be undertaken in accordance with MP71 QUU Electrical Safety Management Plan where access to electrical equipment is required.

It is assumed the equipment is maintained and in good working order. The Contractor shall report to QUU in writing any concerns with the condition or defects in the equipment inspected during the site investigation.

Where data is not available or readily accessible for protective devices such as relays, CT's, CB's or fuses the Contractor can make reasonable assumptions. The assumptions must be clearly identified in the report and care must be taken so as to not under report the available incident energy at downstream equipment. A conservative alternative is to use the next overcurrent device upstream to define the clearing time where data is unknown.

2.12 Arc Flash Analysis and Calculation Methodology

Adequate detail of the methodology adopted for undertaking the AFA should be provided in this section. This includes outlining the specific steps and methods and the approach should not be significantly different to the following procedures:-

IEEE 1584 -2002/2004a Edition was adapted in PTW for the arc flash study. It should be noted that this standard has been revised in 2008, and the PTW software package may therefore be superseded by the new standard. Also, NFPA 70E (Standard for Electrical Safety in the Workplace), referenced in IEEE 1584, has been amended in 2015. The short circuit studies, estimations of contributing arc fault currents, the estimation of arcing time through contributing branches, incident energy and flash boundary calculations are all carried out using PTW

Protection device characteristics are modelled in PTW. The details such as the settings for relays and circuit breakers, total clearing times and time current curves are included in the Protection Coordination Report.

The branch arc currents were estimated using the IEEE 1584 empirical formulas. The arcing currents, in accordance with IEEE 1584 recommendations, are calculated at 100% and at 85% for each branch contribution to allow for random variation of arc fault current. At these two arcing currents the incident energy is calculated, and the highest incident energy is considered to prescribe risk/hazard categories and PPE requirements.

Note: The minimum fault current could take longer to clear and could result in a higher arc flash incident energy level than the maximum arc fault current condition

The arc flash protection boundary is defined as the distance from the arc source at which the onset of a second degree burn could occur. A second degree burn could occur if the incident energy is greater than 1.2 cal/ cm^2

The following procedures are adopted in PTW in determining the incident energy at the specified equipment:

- Apply 3-phase fault to each bus/equipment in the power system
- Calculate:
  - Bolted fault current at the bus;
  - Bolted fault current through each protective device;
- Calculate the arcing fault current at the bus and through each protective device;
- Determine the trip/delay time for fuses and relays from TCCs;
- Determine circuit breaker opening times, using the following industry standard values shown:-
  - 1.5 cycle <1000 V moulded case
  - 3.0 cycle <1000 V power circuit
  - 5.0 cycle 1 – 35 kV
  - 8.0 cycle >35 kV
  -

  Note: For heavy current LV switchboards and MCC's were current rating exceeds 800A, the compliance with AS3000 clause 2.5.5.3 shall be demonstrated and calculation included for circuit breaker clearing time.
- Determine the arcing duration by summing the trip/delay time and breaker opening time;
- Determine the type of equipment from four choices (either specified or set to default):
  - Switchgear (default for equipment ≤35 kV);
  - Panel (default for equipment ≤1 kV);
  - Cable;
  - Open Air (default for equipment >35 kV);
- Determine the bus gap with the following default values:
  - ≤1 kV Switchgear: 32 mm;
  - ≤1 kV MCCs and panel boards: 25 mm;
  - 1 – 5 kV Switchgear: 104 mm;
  - >5 kV Switchgear: 152 mm;
  - All Cables: 13 mm;
  - 1 – 5 kV Open Air: 104 mm;
  - >5 kV Open Air 152 mm;
- Determine the working distance with the following default values:
  - Switchgear ≤1 kV 610 mm;
  - Panel, DB's, Switchboards ≤1 kV 455 mm;
  - Switchgear >1 kV, <35 kV 910 mm;
  - Switchgear >35 kV 1829 mm;
  - Others 455 mm;
- Determine if equipment is earthed by searching all branches connected to a bus:

  - o If transformer is found with an earth (but with no neutral impedance) at the bus end, it is set as "Earthed";
  - o All other cases, default status will be used as follows:
    - ▪ ≤1 kV: Unearthed;
    - ▪ >1 kV: Earthed;

- Calculate the Incident Energy using the IEEE 1584 empirical equations. All incident energies shall be reported in units of cal/ cm^2

- Calculate the arc flash boundary;

- Determine the PPE requirements based on NFPA 70E version 2015 and WI58.

2.13 Arc Flash Analysis Parameters, Options and Tolerances

For each voltage level and equipment type define all parameters used and indicate reason why selected i.e., bus bar gap, working distance, voltage level Hi/Lo tolerances.

2.14 Operating Conditions

This section contains a discussion on normal and possibly abnormal operating conditions and typically considers the number of large motors operating, HV Ringmain open or closed etc and other factors that can have significant effect on plant loading. The operating conditions should be the same as those outlined in the Load Flow and Fault Study Reports. Similar as per the Fault Current report all large inductive loads (motors greater than equal to 37kW) must be considered to contribute to the fault. If there is nil contribution to the fault current at the upstream busses from VSD starters for example, then this should be mentioned in this section of the report.

2.15 Summary of Results

Provide a table summarising all results at all bus voltages and is standard table extracted from PTW. Only the operating scenario that produces the highest incident energy level are summarised in the table. Typical summary table column header as follow:-

Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (J/cm2)	PPE Level	Label #	Cable Length From Trip Device (m)

2.16 Analysis

Describe in detail the scenarios that give the highest incident energy. The ultimate aim is to achieve Category 0 PPE for all O&M tasks on electrical equipment that is not a tested design by a certifying body for arc fault containment. If any O&M tasks on the equipment exceed Category 0 PPE, then the Contractor must revisit the protection co-ordination study and consider other methods to reduce the incident energy level.

As per WI58 the AFA report shall indicate that QUU has specified three types of PPE Categories 0, 2 or 4 to simplify the PPE requirements across all sites. PPE Category 4 will only be accepted where all other options to lower the incident energy to Category 2 have been exhausted and modification to the installation is not practical or economically feasible.

When the calculated incident energy at a switchboard exceeds 40 cal/ cm^2 the entire switchboard is declared Dangerous. No access is permitted to Dangerous switchboards while energised regardless of PPE worn. Access means opening doors or removing covers to the switchboard. Control and monitoring of switchboard equipment with all doors locked closed and covers securely in place is permitted with QUU standard PPE.

2.17 Recommendations and Conclusion

Summarise what operating scenarios causes the highest incident energy in each switchboard or enclosure in the power network. This section shall define the categories of PPE required for the site and what O&M tasks require which category level of PPE. The section should also include a summary of any economically feasible remedial works that can be considered for each equipment item to lower the incident energy levels further. The recommendation must be categorised into three groups based on risk to QUU, complexity and cost as follows:-

- Simple: Low cost options such as modification to overcurrent device settings or fuse size/type change out.
- Moderate: Slightly higher cost solutions such as additional overcurrent protection
- Detailed: Higher cost options such as installing new equipment or retrofitting CB's with new trip units or implement speciality protection schemes to reduce the incident energy levels.

Recommendations do not need to be detailed designed, however any solutions proposed shall have adequate details provided and be considered technically and economically feasible. Budget estimates of +/-30% accuracy must be provided for all recommendations. Where installed equipment does not comply with AS3000, AS2067 or other relevant standards the recommendation must disclose the departures and specifically what is required to rectify the defect.

Note Dangerous and Category 4 switchboards pose high risk to O&M persons and are a high priority for QUU in order to reduce the arc flash hazard.

3 Arc Flash Hazard Analysis Report Appendices

The following sections outline the required content to be included in the AFA Report where relevant to the site.

3.1 Arc Flash Mitigation Strategies

Aside from PPE requirements, there are some other countermeasures that can be specified under the hierarchy of controls that has been commonly used in Australia to minimise arc flash hazards and damage to equipment. The Contractor shall describe what arc flash hazard mitigation strategies are applicable to the site and some possible strategies are as follows:-

3.1.1 Elimination

Get rid of the hazard out of the workplace. Elimination of the hazard is the most effective means of hazard control. It involves the physical removal of the hazard. For example can the existing equipment that contributes to the arc flash hazard be decommissioned and removed from the site or can the equipment be modified so that operation is done from a remote location where arc flash hazard is eliminated or reduced.

3.1.2 Substitution

Is there any opportunity to replace or change equipment or materials to lower the risk from the arc flash hazard. Substitution is the second most effective way to control hazards, which involves removing something that produces a hazard (similar to elimination) and replacing with something that does not produce or lowers the likelihood of the hazard event occurring. For example would replacing an existing switchboard with a high arc flash hazard with an arc fault contained switchboard that poses little or no arc flash hazard risk be feasible and cost effective.

3.1.3 Engineering

Some typical engineering controls are as follows:-

- Design and install equipment to counteract the hazard. Engineering controls do not eliminate hazards, but rather keep people isolated from hazards.
- In addition to PPE requirements, the replacement of switchboards with fully arc fault contained switchboards should be considered as part of the overall arc flash hazard mitigation strategy for new and proposed sites to be refurbished.
- The project documentation would specify the LV switchboard to be constructed in accordance with TMS60 LV Switchboard Technical Specification. This specifies an arc fault contained switchboard enclosure, fully type tested arrangement to a specified fault level in accordance to AS 61439.1.
- For existing switchboards temporary protection setting maybe considered to lower the incident energy when switchboard is accessed for O&M tasks. The protection settings would be selectable by the user and when selected the temporary settings may compromise protection co-ordination with upstream

and downstream devices. An alarm must be produced if protection settings are not returned to normal settings within a specified time frame.

3.1.4 Administration

Some typical administration controls are as follows:-

- Arrange work so people spend less time around the hazard and monitor their understanding of the hazard and the controls. Administrative controls do not remove hazards, rather limit or prevent people's exposure to the hazards, such as.
- Restricting access to switch rooms and switchboards to Authorised Personnel only;
- Apply signage and arc flash labels to electrical equipment advising personnel of the arc flash energy levels and PPE recommendations.
- Authorised Personnel to have training in the hazards and procedures associated with working within an electrical switchroom.
- All personnel not directly involved in switching operations to vacate area when switching occurs.
- Formal risk assessments shall be conducted prior to conducting work on or near electrical equipment.
- Removal of non-essential furniture and equipment from locations in front or adjacent to switchgear; and
- Electrical maintenance regime shall include regular inspection of the condition and security of hinges, locking mechanisms, mechanical interlocks and door fasteners, and electrical equipment and protective device condition and operation.

3.1.5 PPE

The use of PPE to protect the wearer's body while near the hazard. PPE is the least effective means of controlling hazards because of the high potential for the PPE to become ineffective due to damage. The arc flash PPE items accepted by QUU are outlined in WI58 Arc Flash Assessment and PPE Selection and section 3.3.2.

3.1.6 Upstream Equipment and Protection Settings

Upstream protective device settings for the main incomer power supply will have a significant impact on the arc flash hazard risk level present at the equipment. Protection Coordination must ensure the arc flash incident energy levels are as low as possible and still maintain adequate discrimination throughout the facility while meeting safe touch voltage limits. Adjustments of upstream protective device, if practical, to instantaneous trip settings of the breaker and or relays can be used to lower the trip time response which will lower incident energy and arcing fault currents.

3.1.7 Arc Suppression Technology

Arc fault suppression technologies are designed exclusively to offer protection against the negative consequences of an internal arc in HV switchboards functional units, cable ways and bus bar compartments. The arc suppression methods effectively help to avoid the negative effects if an arc fault does occur.

All new HV switchboards should be considered with arc fault suppression technology, however only if is a type tested solution.

3.2 Arc Flash Hazard Prevention Methods

The Contractor shall describe what Arc Flash Hazard Prevention methods are feasible for the particular site if any and typical discussion as follows.

Aside from arc flash mitigation strategies, there are other hierarchy of techniques designed to reduce the risk of arc initiation or reducing the potential damage caused by an arc fault within a switchboard and below are AF prevention methods:

3.2.1 Active Arc Fault Suppression

Achieved by using the appropriate settings on protective devices, or by using optically triggered arc detect technology.

3.2.2 Passive Arc Prevention

Separation of assemblies in accordance with AS/NZS 61439.1 may be achieved by the insulation of bus bars, the use of barriers or by insulated housings. One or more of the following conditions can be attained by dividing assemblies by means of partitions or barriers (metallic or non-metallic) into separate compartments or enclosed protected spaces:

- Protection against contact with hazardous parts belonging to the adjacent functional units. The degree of protection shall be at least IP2X;
- Protection against the passage of solid foreign bodies from one unit of an assembly to an adjacent unit. The degree of protection shall be at least IP2X.

The following are typical forms of separation by barriers or partitions

Main criteria	Sub criteria	Form
No separation.		Form 1
Separation of busbars from the functional units.	Terminals for external conductors are not separated from busbars.	Form 2a
	Terminals for external conductors are separated from busbars.	Form 2b
Separation of busbars from the functional units and separation of all functional units from one another. Separation of the terminals for external conductors from the functional units, but not from each other.	Terminals for external conductors are not separated from busbars	Form 3a
	Terminals for external conductors are separated from busbars.	Form 3b
Separation of busbars from the functional units and terminals for external conductors and separation of all functional units from one another, including the terminals for external conductors which are an integral part of the functional unit.	Terminals for external conductors in the same compartment as the associated functional unit.	Form 4a
	Terminals for external conductors not in the same compartment as the associated functional unit, but in individual, separate, enclosed protected spaces or compartments.	Form 4b

Table: Forms of internal separation

The Contractor shall nominate what form of separation is applicable to each switchboard and electrical enclosure and clearly state what the basis for the assessment is.

3.2.3 Arc Fault Containment

Switchboards can be constructed to withstand internal arcing-faults by segregating sections of the board and venting each section to release the pressure caused by an arcing-fault. The inclusion of these features on a switchboard may reduce the arc-flash hazard to personnel while the switchboard is fully closed, but not while the switchboard is opened and energised under maintenance.

Furthermore, the standard tests listed in AS/NZS 3439.1 for LV switchboards only prescribe testing on the load side of outgoing circuits (limited arc-fault) and not the less frequent bus, incomer fault or protection device fault (unlimited arc-fault).

IEEE 1584 does not, at present, recognise any improvement in safety as a result of limited or unlimited arc-fault containment, possibly because the tradition in North America is to construct switchboards without strong arc containment. The IEEE standards committee is currently working to include arc-fault testing as part of the consideration of arc-flash hazard. In the meantime, it is left to individual workplaces to interpret the IEEE 1584 arc-flash results and to reconcile these with the arc-containment ratings of the switchboards under consideration.

At present most of QUU's LV switchboards are not designed and tested for arc fault containment. Several arc flash risk assessment workshop have been undertaken to thoroughly assess all O&M tasks on various types of LV and HV switchboards currently installed at QUU network facilities. Refer to the AF Risk Assessment Reports listed in section 1.3

QUU has assessed the arc flash hazard as negligible risk where LV switchboards are energised and all doors and covers are locked closed and switchboard is well maintained and was originally installed by licenced electrical contractors. Refer to Arc Flash Risk Assessment Workshop Reports listed in section 1.3 for details of the risk assessment and recommendations for PPE required.

This determination of negligible arc flash hazard risk is based on NFPA 70E 2015 Section 130.7 Informational Note No.2 extract as follow:-

> *It is the collective experience of the Technical Committee on Electrical Safety in the Workplace that normal operation of enclosed electrical equipment, operating at 600 volts or less, that has been properly installed and maintained by qualified persons is not likely to expose the employee to an electrical hazard.*

The risk assessment of negligible arc flash hazard risk allows a person to access LV switchboards and LV generators with standard PPE to perform control and monitoring tasks and this is strictly based on all the following conditions for the energised LV switchboard being met:-

- LV switchboards and LV generators were originally installed and tested by licensed electrical contractors and
- LV switchboards and LV generators are routinely inspected and maintained by licensed electrical contractors and
- Main control compartment escutcheon panel locked closed(front door to escutcheon can be open) and
- all other access doors locked closed and,
- all covers screwed or bolted in place.

This determination of negligible arc flash hazard risk does not extend to HV switchboards. When HV switchboards are energised and all access doors are locked closed and covers in place the PPE as per the Type 3 arc flash labels shall be worn to access within the arc flash boundary of the switchboard.

As per WI58 there are three arc flash PPE categories for access to electrical equipment to help mitigate injuries that could be sustained to a person during an arc flash incident. The PPE categories and items included in each category are generally based on NFPA 70E: 2015. The PPE category is determined based on the calculated maximum incident energy at the equipment.

Incident Energy Level	PPE Category
<= 1.2 Cal/ cm^2	0
<=8 Cal/ cm^2	2
<=40 Cal/ cm^2	4
>40 Cal/ cm^2	Dangerous

For incident energy level exceeding 40 Cal/cm^2 there is no PPE Category defined as all access to the live equipment must be done with all sources of power supply isolated from the equipment to be accessed.

At an LV switchboard the maximum incident energy is generally at the line side of the main incomer and this incident energy is assumed for the entire switchboard. This is a conservative assumption because if an arc occurs at the line side of the main incomer it can propagate throughout the entire switchboard. The arc can propagate because the LV switchboard is not an arc fault contained enclosure, performance tested by an accredited independent laboratory.

The PPE items in each category of PPE are outlined in QUU WI58 Arc Flash Assessment and PPE Selection and section 3.3.2 Arc Flash label Type 2.

3.2.4 LV Control Panels and Distribution Boards

The calculated incident energy level is very low for a single phase 240VAC control panel, switchboard or DB where supplied from a 32A or lesser rated CB. QUU has assessed the incident energy level as negligible. Refer to REF426 PSA Report – Low Risk 230VAC Installations.

A person is only required to wear minimum standard QUU PPE and safety glasses to protect them from arc flash hazard while accessing the live equipment with doors open. They must also follow all other QUU procedures for testing or working on live equipment.

3.3 Electrical Equipment Arc Flash Labels

This section shall contain the arc flash labels for each switchboard, Distribution Board and all other electrical equipment at the facility containing LV or HV power sources.

The arc flash labels are in addition to other mandatory labelling required by Australian Standards on electrical equipment and QUU typical design for switchboards.

3.3.1 Arc Flash Label - Type 1

At QUU facilities with indoor HV equipment or LV equipment (excluding LV switchboards), the Arc Flash Label Type 1 shall be fixed to the building access doors. The Type 1 label shall also be fixed to the access gates where security fencing is provided to HV or LV electrical equipment (excludes LV switchboards). The label indicates the PPE items that must be worn by all persons accessing the switchroom or secured fenced area. The person must remain 300mm clear of the electrical equipment at all times.

The PPE outlined on the Type 1 label is typically applicable to cleaners and O&M persons undertaking non electrical works in the switchroom or fenced area and remaining outside the arc flash boundary of all equipment enclosures. If access is required inside the arc flash boundary distance including touching or access to any of the electrical enclosures, the PPE required to be worn by all person is as per the Arc Flash Type 2 and 3 labels.

ARC FLASH AND SHOCK HAZARD SIGN – TYPE 1

Notes: Type 1 label is not applicable to equipment installed outdoors where security fence is not provided.

Type 1 label is not required to be installed at LV switchroom access doors and fenced compound access gates that only contain LV switchboards.

3.3.2 Arc Flash Label - Type 2

QUU has standardised on Category 0, 2 and 4 PPE as per NFPA – 70E 2015 and QUU Work Instruction 58 Arc Flash Assessment and PPE Selection. A Type 2 label shall be provided describing the PPE items contained in each category. The PPE components specified on the label are not optional and all items must be worn to comply with QUU requirements when performing certain activities on the equipment.

A Type 2 label shall be fixed to electrical equipment generally including:-

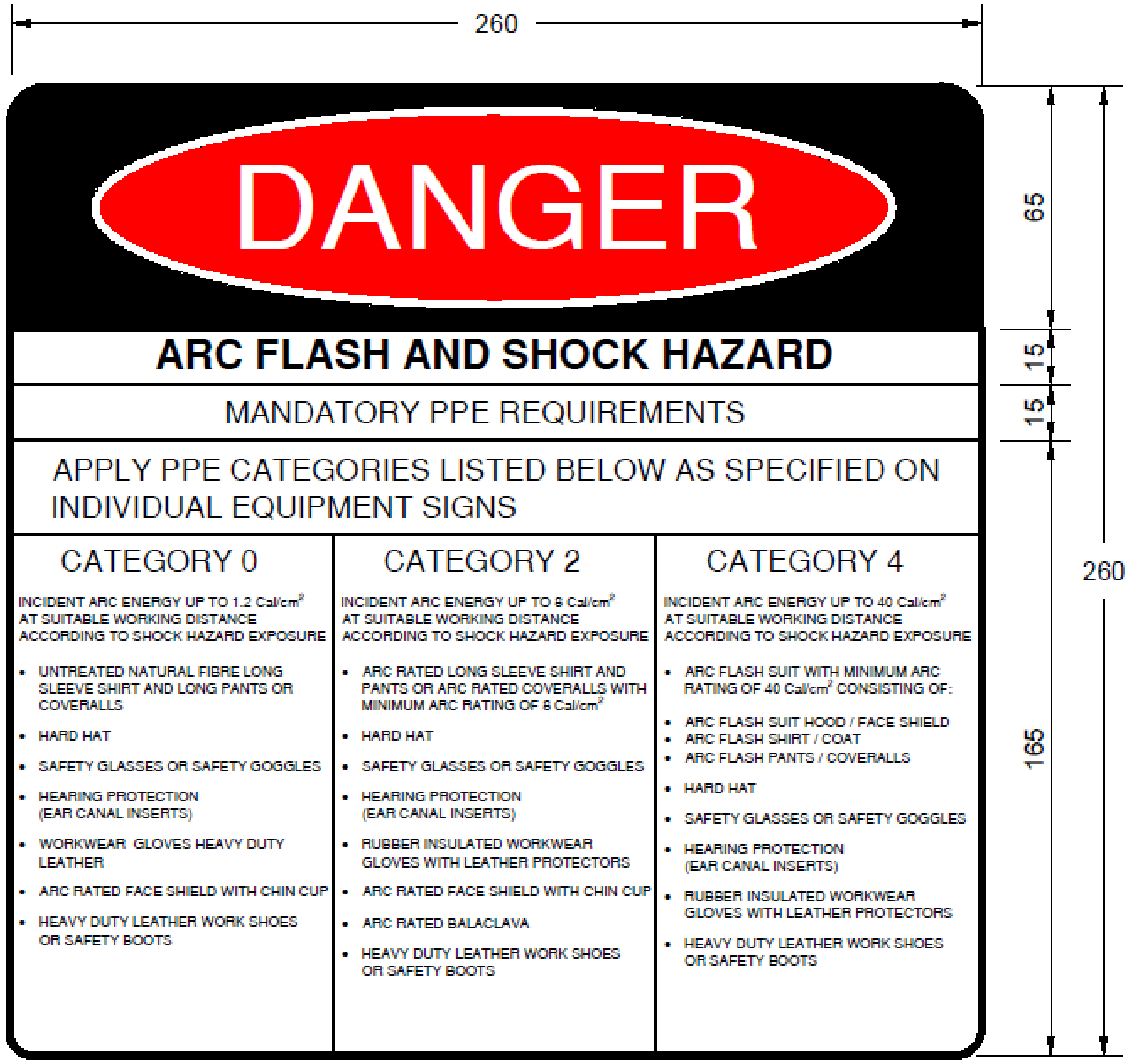
- Switchboards,
- Distribution Boards,
- MCC's,
- LV Control Panels and
- Generators

For indoor switchboards a Type 2 label shall be fixed to the external of the front access door to the main control compartment of the switchboard.

Public accessed switchboards are located on sites that do not have a site security perimeter fence with permanently locked access gates. For outdoor switchboards that can be accessed by the public the Type 2 label shall be fixed to the escutcheon panel at the common control compartment and label is not visible with main access doors closed.

For outdoor switchboards that cannot be accessed by the public a Type 2 label shall be fixed to the external surface of the front access door to the main control compartment of the switchboard.

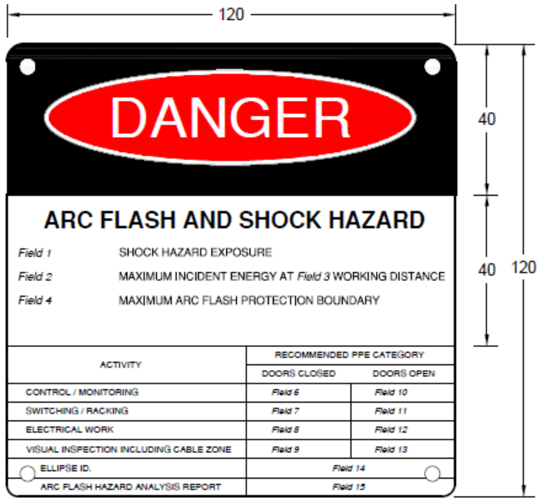
A Type 2 label shall be fixed to the exterior door of a permanently installed generator main control compartment. The label shall be in a clearly visible position when approaching the generator.



ARC FLASH AND SHOCK HAZARD SIGN – TYPE 2

3.3.3 Arc Flash Label - Type 3

The rules for fixing of type 3 labels are the same as type 2 labels.



ARC FLASH AND SHOCK HAZARD SIGN – TYPE 3
REFER NOTE 1

ARC FLASH AND SHOCK HAZARD SIGN
TYPICAL ARRANGEMENT

A Type 3 label for each LV and HV switchboard at a site shall be produced and each label to be shown in the AFA Report. Motor terminal boxes, local isolators, and transformers do not require Type 2 and 3 arc flash labels to be provided and these equipment items shall not normally be accessed while energised.

Type 3 labels are not required for 240VAC single phase switchboards where fed from a CB less than or equal to 32A upstream.

The information displayed on the switchboard Type 3 labels is only applicable when the switchboard is fed from the normal utility (Energex) supply.

When the switchboard is fed from a mobile (temporary installed) generator the O&M persons shall refer to WI58 to determine the arc flash PPE category and arc flash boundary to access the generator and all downstream connected equipment including LV switchboards etc.

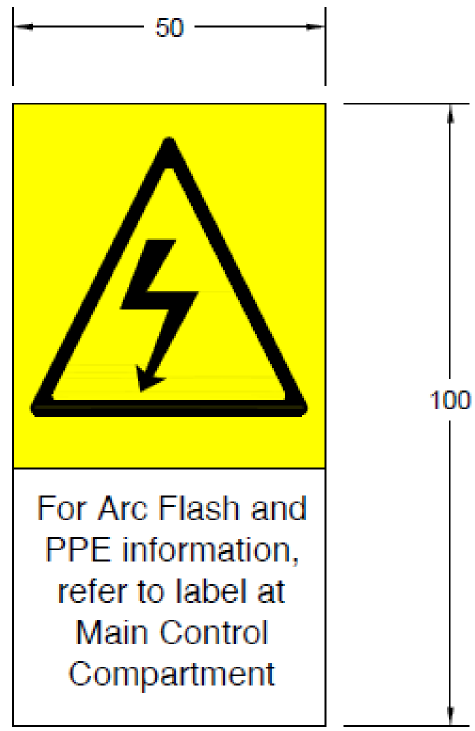
A Type 3 label shall be fixed to the exterior door of a permanently installed generator main control compartment and the label shall be clearly visible when approaching the generator. The incident energy, arc flash boundary and PPE nominated on the generator's Type 3 label is also applicable to all switchboards connected to the generator (only when generator is operating).

3.3.4 Arc Flash Label - Type 4

All public accessible switchboards shall have a type 4 label provided on the external surface of the main control compartment front door.

Switchboards installed on sites with restricted public access do not require a Type 4 label.

The Type 4 label fitted to a switchboard generally signifies that the Type 2 and 3 arc flash labels are installed on the escutcheon behind the front door where Type 4 label is fitted.

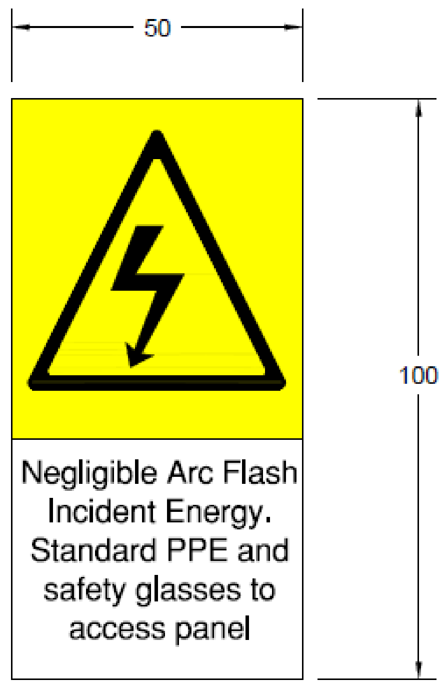


ARC FLASH AND SHOCK HAZARD SIGN TYPE 4

3.3.5 Arc Flash Label - Type 5

A Type 5 label is the only arc flash label required for an LV control panel or an LV switchboard that is fed from a single phase 240VAC supply protected by a 32A or less CB.

An enclosure with a single phase 240VAC, 32A CB or RCBO rated less than or equal to 32A as the main isolator is deemed to comply and shall be provided with a Type 5 label.

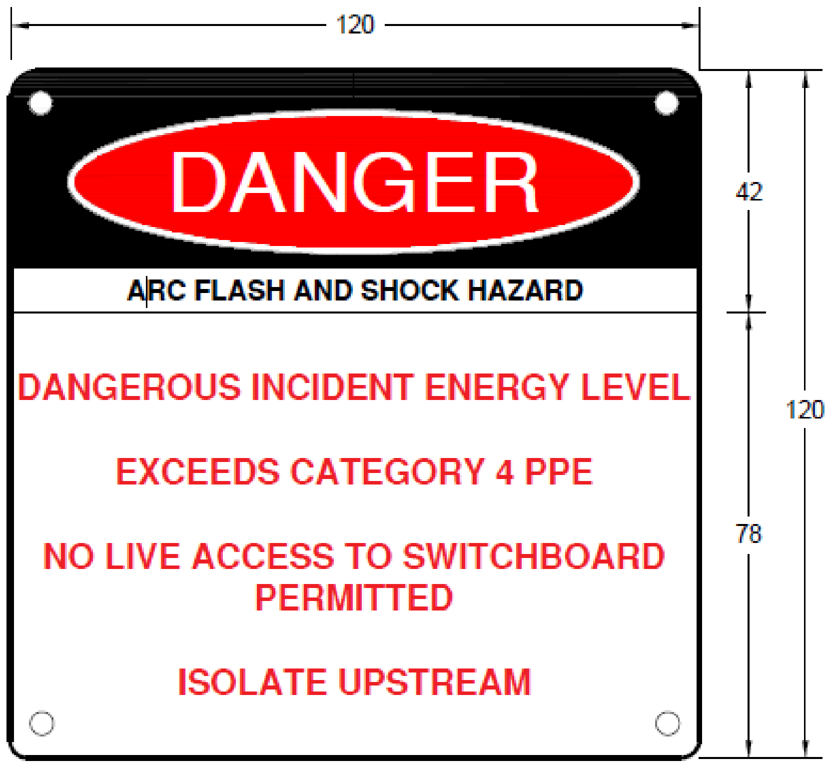


ARC FLASH AND
SHOCK HAZARD SIGN
TYPE 5

3.3.6 Arc Flash Label - Type 6

A Type 6 label shall be installed to a switchboard that has been determined to have Dangerous Incident energy level exceeding 40 Cal/cm². The Type 6 label must be installed in a prominent location on the external door of a switchboard by the Contractor. The label must be installed as soon as an existing switchboard is determined to have Dangerous incident energy level.

For large switchboards with multiple incomers and control compartments there may be need for multiple Type 6 labels on each control compartment.



ARC FLASH AND SHOCK HAZARD SIGN – TYPE 6

3.4 PowerTools for Windows – Single Line Diagrams

The Contractor shall provide a print out of the single line diagrams (SLD's) from the PTW model in the report. The SLD's must show voltage drop, power loads (kW, kVA kVAR), fault currents and cable details for all busses in the PTW model. All text must be legible in A4 page print of the SLD's.

There may be a requirement to provide multiple SLD's to indicate operating scenarios that generate the highest incident energy at each bus in the PTW model.

Note: All the SLD's must be provided with QUU Equipment tag numbers for switchboards and transformers and all cables uniquely identified. The tag numbers must match exactly the tag numbers as installed or proposed to be installed. The tag numbers must be verified during site investigations and reconciled with SLD's and cable schedules.

3.5 Reference Data

The Contractor shall include equipment data sheets and any other documents without QUU document numbers that were used to generate the AFA report and these documents are not listed in section 2.7. This includes relevant records produced and data gathered at any site investigations undertaken by the Contractor. The switchboard Arc Flash Containment Test certificates where available and any relevant correspondence from the equipment manufacturers would be provided in the Appendix of the AF Analysis Report.

Appendix A – Typical Maximum Demand Template

TMS1621 Typical Pumpstation Maximum Demand Calculation Template Spread sheet will be provided to the Contractor and shows the minimum typical details required to be provided for a pump station maximum demand calculation.

QUEENSLAND UrbanUtilities

SP130 Villiers St - Sewage Pump Station Switchboard

Maximum Demand calculation:

		Red	White	Blue	NOTES	
Sewage Pumps:	2 x 6.9kW 13A (Duty/Assist/Standby)					
	1st pump (100%)	13.00	13.00	13.00		
	2nd Pump (75%)	9.75	9.75	9.75		
Interlocked	~~3rd Pump (50%)~~	-	-	-		
	SUB TOTAL	22.75	22.75	22.75		Amps

		Red	White	Blue	NOTES	
Vacuum Pumps:	2 x 4kW 13A (Duty/Standby)					
	1st pump (100%)	-	-	-		
Interlocked	2nd Pump (0%)	-	-	-		
	SUB TOTAL	-	-	-		Amps

		Red	White	Blue	NOTES	
Dry Well Equipment						
	Sump Pump <<XX>> kW	-	-	-		
	Vent Fan <<XX>> kW	-	-	-		
	Dry Well Lights (5X <<xx>> w)	-	-	-		
	SUB TOTAL	-	-	-		Amps

		Red	White	Blue	NOTES	
Pump Control CCTs:						
	SS/VSD Loads 2 off		0.50	0.50		
	Pump Control CCTs - 2 pumps		0.75	0.75		
	SUB TOTAL	-	1.25	1.25		Amps

		Red	White	Blue	NOTES	
Switchboard DB (Standard):						
	Common Control			0.50		
	Laptop GPO		2.00			
	External Switchboard Light					
	24vDC Power Supply :-			0.63		
	SUB TOTAL	-	2.00	1.13		Amps

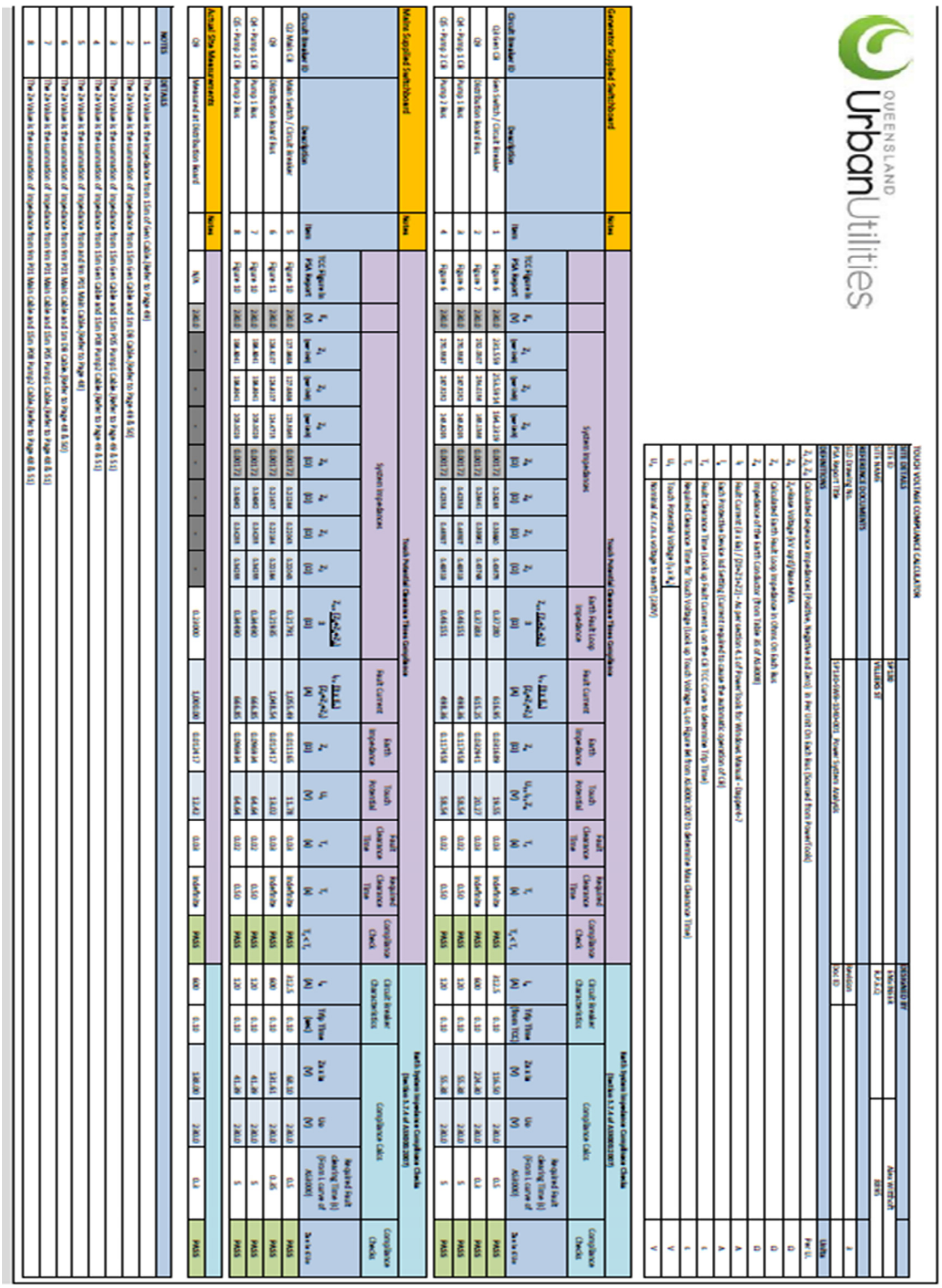
PLC/RTU	1.00	@24V DC
Card Field Load	2.00	@24V DC
Flowmeter	0.00	@24V DC
Wet Well Level Relay	0.12	@24V DC
Dry Well Level Relay	0.00	@24V DC
Radio	0.50	@24V DC
PSTN	0.00	@24V DC
Modem	1.00	@24V DC
HMI	1.00	@24V DC
Well Washer	0.00	@24V DC
Manhole Level Relay	0.00	@24V DC
Em Storage Level Relay	0.00	@24V DC
Generator Controls	0.00	@24V DC
Switchboard Lights (6)	0.72	@24V DC
Total 24V DC Loads:	**6.34**	**@24V DC**

		Red	White	Blue	NOTES	
Switchboard DB - Optional Equipment						
	Odour Unit	-	-	-		
	Chemical Dosing	-	-	-		
	Genset Aux Supply	-	1.00	-		
	Cathodic Protection	-	-	3.00		
	Em Storage Tank Sump (1.7kW)	-	-	-		
	Valve Pit Sump Pump (0.55kW)	-	-	-		
	Flowmeter (240vAC)	-	-	-		
	F/meter Pit Sump Pump (0.55kW)	-	-	-		
	SUB TOTAL	-	1.00	3.00		Amps

		Red	White	Blue	NOTES	
Sw/Bd DB Building –						
	Internal Building 3ph 10A Outlet	10.00	10.00	10.00		
	Crane (Hoist)	-	-	-		
	Internal Building Lighting	-	-	-		
	External Building Lighting	-	-	-		
	Internal Building 1ph 15A GPO	7.50	-	-		
	Internal Building 1ph 10A GPO's	-	-	-		
	Air Conditioning	-	-	-		
	SUB TOTAL	17.50	10.00	10.00		Amps
	TOTAL PER PHASE	40.25	37.00	38.13		Amps

	Max Demand	Rating	Spare Capacity	
Distroutin Board	17.50	32.00	14.50	AMPS
Switchboard	40.25	63.00	22.75	AMPS

Appendix B – Typical LV Touch Voltage Calculation Template



QUU will provide the Touch Voltage Calculation Template upon request by the Contractor.

Appendix C – Direct Current Arc Flash Analysis

An arc flash analysis shall be undertaken on all equipment including large battery banks operating at all DC voltage levels. The DC incident energy calculation shall be undertaken as per Section D.5.1 of NFPA 70E 2015 using the Maximum Power Method. The Maximum power method is based on the concept that the maximum power possible in a DC circuit will occur when arcing voltage is half of the system voltage and only applied to voltages levels less than 1000V DC. The DC arc flash incident energy shall then be used to determine the Category of PPE required to access the battery panel.

The DC Arc Flash Boundary distance shall be determined from NFPA 70E 2015 Section D.5.3 Short Circuit Current Method and look-up Table 130.7(C)(15)(B).

Note that this method also nominates the PPE Category and the PPE nominated in the Table 130.7(C)(15)(B) shall be ignored. The PPE nominated in WI58 shall be complied with.

An example of a DC Arc Flash Analysis using the Maximum Power Method for a typical battery bank is as follows:-.

Battery bank consisits of 1 x string of 53 cells in series.

				Input		
System Voltage	$V_{sys}\,(V)$			110		
Internal Resistance per cell	$R_{cell}\,(m\Omega)$			0.15		
Number of cells	N_C			53		
Working Distance	$D(cm)$			45.5		
Arcing time(outgoing feeder MCCB)	$T_{arc}\,(sec)$			0.015		
Total Battery Bank Resistance	$R_b\,(m\Omega)$	=	R_{cell} x N_C	7.95		
Maximum system bolted fault current	$I_{bf}\,(kA)$	=	V_{sys}/R_b	13.84		
Arcing current	$I_{arc}\,(kA)$	=	0.5 x I_{bf}	6.92		
DC Arc flash Incident Energy	$I_{EM1}\,(cal/cm^2)$	=	0.01 x V_{sys} x I_{arc} x T_{arc}/D^2	**0.06**		
DC Arc flash Incident Energy (Arc in a box or enclosure)	$I_{EM2}\,(cal/cm^2)$	=	3 x I_{EM1}	**0.17**	**Category**	**0**

Appendix D – Validation Checks of PSA Using PTW

QUU or others will undertake a review of PTW model and libraries as outlined in this section. It is the Contractor's obligation to ensure that the checks are completed to at least the minimum standard nominated in this section. Any departures or concerns shall be brought to QUU's attention. It is the Contractor's obligation to rectify any anomalies, errors or inaccuracies etc that maybe identified by QUU or others at any time during project execution and after Contract practical completion.

D1. Data Integrity – General Checks:

a. Check PTW options and general settings – look under project options for things like Standards (IEC), units (metric), Wiring (mm^2), Frequency (50Hz), etc.
b. Check paths for reference library and miscellaneous files (will point to your previous project opened in PTW, and needs to be directed to the particular project instead).
c. Check incoming supply / Utility / Energex POS details – has max and min FL's been modelled properly reflecting actual conditions for the site, e.g. 3-Ph, L-G, X/R ratio's, voltage levels, etc?
d. Check if alternate source of supply is model (e.g. Generator), it's also modelled correctly with machine specific data (e.g. Sub transient, transient impedances, ratings, etc.). Check also that generator not set as a swing bus (if operating in parallel with utility) – instead, set to PQ operating mode.
e. Check the project's referenced data libraries (obtained from the project back-up) – are there any new elements created by the consultant for the relays, protective devices, elements (cable, load, motor), etc? – If yes, then the checks are more exhaustive as the level of new component modelling will depend entirely on the diligence of the consultant in defining the relay models, settings parameters, etc.
f. Check site SLD and compare against the number of circuits as modelled in the project one-line … is there a good match? If not, then likely not all loads have been modelled, and/or lumped loads used.
g. Produce a cable schedule from the project file, and compare the cable lengths against the site cable schedule (if one exists) – if not, review the project cable lengths - are they all conveniently the same lengths or just rounded up to nearest 10 or 50 metres? (will affect accuracy of voltage drop and earth fault loop impedance calculations, especially for borderline circuits).
h. Check cable ampacity of the cables modelled – has consultant modelled the method of installation, deratings, etc? – should be evident in the ampacity values.
i. Check for 'hidden' buses or 'hidden elements' (an impedance is required between any two buses, but not necessarily shown on one-line).
j. Also check for buses by 'expanding them' to reveal if there are any elements still in-service but not visible (yet affecting the PSA results). Use PTW's search and go-to functions, or run custom Query's.
k. Check all protective devices are modelled in each circuit – HV relays, LV ACB's, EF relays, etc.
l. For EF relays, check that the 'Function' of that relay is set to Sensor type being "neutral" instead of "phase", otherwise that relay will be used in the AF calculations and will show a faster clearing time for the same arcing current (and hence a lower Incident Energy Level, which is inaccurate).
m. Check each protective element – ensure that under 'Function' that the correct O/C element is ticked for 'Used in Arc Flash' calculations, otherwise it will be bypassed altogether irrespective of whether that element is properly graded with and lower in the TCC than the upstream protection element.

n. O/C LV Protection elements that are not selected in Arc Flash studies are likely entered as 'Ground Fault' CB's in the library, and should instead be in the Static Trip section.
o. Check project has no lumped loads or modelling methods which could cause inaccurate PSA results – e.g. motor contribution generally ignored for motors < 37kW but if many are lumped together as one, can affect S.C and A.F values.

D2. Load Flow:
a. Perform a load flow analysis – are there any fatal errors or errors reported by PTW? – Typically, bus voltage levels not set, or more than one swing bus defined, etc.
b. Check load flow results against the site's metered maximum demand – is the site demand as modelled overly excessive? – this would indicate careless modelling of the loads, and not taking into account load diversity, mode of operation (e.g. 2 x pumps, duty-standby), running load of motors (which typically only run at 60-80% of their NPR due to conservative motor sizing to be higher than the pump size), etc.
c. An excessive load model will indicate overloaded transformers, overloaded cables, etc. Check primary plant ratings and loading & incoming power supply load draw – compare against rating or connection agreement capacity.
d. In the Load Flow Study 'set-up' section, check that the 'Load Specification' is set to "1st Level Demand or Energy Audit Load" (and not "Connected Load"), otherwise, all loads will be used in the LF calculation with no diversity.
e. Set the voltage drop tolerances (e.g. 5%) and branch VD tolerance (e.g. 3%) in the LF solution criteria. This is used to flag and report on buses with low voltage levels.
f. Check voltage drop report – any buses exceeding limits?
g. Check branches – are there any ampacity issues, exceedance of cable rating, excessive branch losses?
h. For motors, check the starting PF, LRA.FLA ratio, running PF, etc. Check also the 'Diversity' and 'Load Factor' … are they all set to 1.0?
i. Also check all motors – are they modelled as "running" or "starting" in the LF? Some motors could still be left in "starting" mode – use the correct data-block to identify this.
j. Use the appropriate data-block to display the PSA results to audit the study – chose a data-block that's appropriate to what you want to see.
k. If performing Transient Motor Starting (TMS) studies, check if there are any Starters, VSD's, DOL's – are they modelled correctly? (for both motors and the connected loads to the motor's – e.g. torque-speed curves, load and motor moment of inertia, etc.). Has the consultant linked these to a custom motor and load library? If yes, check it.

D3. Short Circuit:
a. Perform a SC analysis – understand the difference between "Comprehensive" and "IEC 60909" options. Comprehensive takes into account current shifts in parallel paths (e.g. two transformers supplying same downstream bus) in the TCC. QUU only accept comprehensive for the arc flash analysis and AS3851(IEC60909) for the fault study.
b. For IEC 60909, check for Meshed network X/R adjustment method, use "C".
c. For "Comprehensive", check Pre-Fault voltage settings – some will result in a more conservative SC result (e.g. PU voltage if set to 1.03 for all buses). Also, check if motor contributions are checked.
d. Under the SC study setup, check for faulted bus … is "All buses" chosen or "selected buses" only?
e. Check if the prospective FL's from the SC study exceed any plant rating – e.g. HV CB or switchgear rating, LV MCC rating, etc.
f. Check transient models of generators and motors – is the impedance data reasonable and accurate (not just typical and generic).

g. Check motor contributions, and verify motor contribution paths. Are they reasonable? Are you getting large contributions from small motors?
h. Check study conditions that motors < 37kW (50 HP) are ignored in the study – this is in the Arc-Flash study setup dialog box.

D4. Protection Coordination:
a. Visually check the protection coordination – select the PD's you want to see, then select 'go-to TCC drawing' … do the TCC's appear to all coordinate properly?
b. Show device TCC's up to the fault rating at the bus to ensure full coordination.
c. Check the protection margins between devices – both in the 'time domain' as well as the 'current domain'.
d. For current-domain margins, need to ensure there's adequate margin to account for additional loads from other parts of plant if the upstream device carries more load.
e. When visualising the TCC for coordination, do it in small steps – first, for primary plant & incoming supply. Then add more + more downstream devices to the TCC to confirm coordination.
f. When checking coordination of parallel paths (e.g. 2 x TX's supplying one downstream bus), ensure the TX curve is shifted by the current axis scaling to account for the current division. Also, for Ph-Ph faults on secondary side of Dyn transformer, need to shift TX curve to the left by 0.866 factor.
g. Focus on the larger loaded circuits or circuits with large motors and transformers.
h. Check against the motor starting curves, starting times, inrush factor, asymmetrical inrush, etc. For high efficiency motors, LRA/FLA ratio can be as high as 19x, instead of usual 7-8x.
i. Check transformer inrush factor and time is not overly conservative (~8x , instead of 12x FLC ; 0.1 sec). Also check the X/R ratio has been set properly.
j. For any generators modelled, check that subtransient and transient impedance values used are "saturated" values, not "unsaturated" values from the generator data-sheets. If only one Xd" value is shown, assume it's is un-saturated, and hence apply a factor of 0.85 to it.

D5. Arc Flash:
a. Check AF study options – what standards are they referring to (i.e. NFPA 70E 2015 D4). Check also Units (metric) and Incident Energy (cal/cm²) and distance (mm).
b. Check global max arcing time set to 2.0 secs
c. Exclude contributions from motors < 50 HP; but include motor contributions for 2.5 cycles
d. Check also "fixed or movable" options for each bus.
e. Check if Fuses are used – that the minimum melt curve is not used, but 'total clearing time' curve instead.
f. Under Report Options, check IE and Flash Boundary definition tables used (70E 2015).
g. Do an AF study, compare arcing current against the TCC's visually – is the device which is reported by PTW as having operated for the fault 'intuitively correct'? If not, investigate further.
h. Has HV CB opening time been entered in the HV relays definition (if not, then AF results will be better than actual due to shorter clearing time in the calcs). LV CB clearing times are accounted for in the CB clearance tolerances.
i. Check the AF report / spread-sheet – are LV devices set properly (e.g. bus spacings)?
j. Check the AF report / spread-sheet – what levels are reported for the Incident Energy Levels at the faulted buses? Do any appear to not be intuitively correct? (Higher Levels / Cat's are generally higher upstream due to both higher fault current and longer clearance times, for the same bus voltage).

k. Check if device operate times are reasonable. For MCC's > 800A, AS3000 requires instantaneous setting pick up at 30% of prospective fault current to ensure fast clearance times.
l. Check protective device libraries – have any custom protective elements been created specifically for the project by the consultant? Has consultant used the correct PD / relay (and not just conveniently selected from what's only in the LIB_AS?) e.g. Terasaki vs Hawker Siddley
m. Review the settings 'segments' in each PD created – are they 'feature rich'? – e.g. SI, VI, EI curves, Instantaneous, time delays, I^2t shoulder options, etc. have been defined?
n. For relays, do all settings appear to be "continuously" adjustable? (some relays plug or pick-up or time-multiplier settings are only available in discrete steps).
o. For new elements (e.g. cables, transformers, drives, etc.) – check if master data LIB_AS library is matched to project library. May need to import elements from the project library to the master library (once the PD data accuracy has been validated).
p. Check AF results spread-sheet for N5 errors – e.g. mal-grading, etc.
q. Also check if 85% if Arcing Current has been used in the IE levels (N3) and visually check on TCC – presents an opportunity to move the instantaneous further to the left to reduce clearing times and IE levels.

D6. Harmonics:
a. Check has there been any harmonic producing loads modelled in the project? Are they modelled properly with harmonic sources from a library?
b. Check Harmonic Distortion levels – do they appear to be reasonable?
c. If PFC is modelled, do an impedance frequency scan to see if there are any susceptible resonant frequencies to certain order harmonics.

D7. Study Conditions / Scenarios:
a. Examine the no. of scenarios created – if more than 3 or 4, ask why and what for? – understand each scenario's details and conditions of the model, and reference back to the PSA report for explanation of the scenario's considered.
b. Use data-visualiser to examine differences between each scenario - changes against the 'base case' will appear to be pink (e.g. setting changes).

D8. Transient Motor Starting:
a. Has there been any motor starting modelled in the project (e.g. for larger motors > 100kW).
b. Is the motor taking too long to start? Check slip, motor accelerating torque, bus voltage, staggered start times, etc.
c. TMS requires accurate modelling of the starter, starting conditions, motor models, motor and load torque-speed and moment of inertia values, etc.

Appendix E – Energex Standard Transformer and Fuse Ratings

Energex Limited Standard — No: 03329 - 15 Nov 2012 (V3 Draft 1)

Appendix 4 - Overhead Distribution Transformer Overcurrent Protection

OVERHEAD DISTRIBUTION TRANSFORMER OVERCURRENT PROTECTION

energex

11kV HIGH VOLTAGE

3 Phase Transformer HV Protection — Expulsion Dropout Fuses

Transformer Rating [kVA]		LV Circuit: Open wire/ LVABC	HV Current: Full Load [A]	with TRX LV fuse: HV Fuse Link	with TRX LV fuse: Stock Code	without LV fuse: HV Fuse Link	without LV fuse: Stock Code
3 ph	15[3]	LVABC	0.8	8T	14228	-	-
3 ph	25	LVABC	1.3	8T	14228	-	-
3 ph	50[3]/63	Open	2.6/3.3	8T	14228	-	-
		LVABC		8T	14228	-	-
3 ph	100	Open	5.2	16K	14231	8T	14228
		LVABC		16K	14231	-	-
3 ph	200	Open	10.5	20K	13405	20K	13405
		LVABC		20K	13405	-	-
3 ph	315	Open	16.5	25K	13730	25K	13730
		LVABC		25K	13730	-	-
3 ph	500	Open	26.2	40K	13731	40K	13731
		LVABC		40K	13731	-	-

1 Phase Transformer HV Protection — Expulsion Dropout Fuses

Transformer Rating [kVA]		LV Circuit: Open wire/ LVABC	HV Current: Full Load [A]	with TRX LV fuse: HV Fuse Link	with TRX LV fuse: Stock Code	without LV fuse: HV Fuse Link	without LV fuse: Stock Code
1 ph	10[3]	LVABC	0.9	8T	14228	-	-
1ph	25	Open	2.3	8T	14228	-	-
		LVABC				-	-

LOW VOLTAGE

3 Phase Transformer LV Protection — HRC Fuses

Transformer Rating [kVA]		LV Circuit: Open wire/ LVABC	LV Current: Full Load [A]	LV Current: Circuit Load [A]	LV Fuse Link: LV Fuse [A]	LV Fuse Link: Description	LV Fuse Link: Stock Code	LV Fuse Holder: Max Rating [A]	LV Fuse Holder: Stock Code
3 ph	15[3]	LVABC	20	13.5	50/80[4]	Ferrule Ended 57mm x 22.2mm HRC	4442 / 4451[4]	100	19910
3 ph	25	LVABC	33	21.5	80	Ferrule Ended 57mm x 22.2mm HRC	4451	100	19910
3 ph	50[3]/63	Open	67/84	44/55	100	Ferrule Ended 57mm x 22.2mm HRC	12454	100	19910
		LVABC			100	Bolt in Type HRC, 111mm	4458	630	2822
3 ph	100	Open	133	88	160	Bolt in Type HRC, 111mm	4465	630	2822
		LVABC			160	Bolt in Type HRC, 111mm	4465	630	2822
3 ph	200	Open	267	174	200	Bolt in Type HRC, 111mm[4]	4471	630	2822
		LVABC			200	DIN Size 2 HRC (per circuit)[5]	13898	400	20146
3 ph	315	Open	420	273	315	Bolt in Type HRC, 111mm[4]	4477	630	2822
		LVABC			200	DIN Size 2 HRC (per circuit)[5]	13898	400	20146
3 ph	500	Open	667	434	500	Bolt in Type HRC, 133/184mm (per cct)[6]	4485	630	2822
		LVABC			315	DIN Size 2 HRC (per circuit)[5]	15118	400	20146

1 Phase Transformer LV Protection — HRC Fuses

Transformer Rating [kVA]		LV Circuit: Open wire/ LVABC	LV Current: Full Load [A]	LV Fuse Link: LV Fuse [A]	LV Fuse Link: Description	LV Fuse Link: Stock Code	LV Fuse Holder: Max Rating [A]	LV Fuse Holder: Stock Code
1 ph	10[3]	LVABC	40	50/80[4]	Ferrule Ended 57mm x 22.2mm HRC	4442 / 4451[4]	100	19910
1 ph	25	Open	100	100	Ferrule Ended 57mm x 22.2mm HRC	12454	100	19910
		LVABC		80	Ferrule Ended 57mm x 22.2mm HRC	4451	100	19910

11/12.7kV SWER

SWER Isolating Transformer

Voltage	Transformer Rating [kVA]		Full Load [A]	HV Fuse Link	Stock Code
11kV		100	9.1	25K	13730

SWER Distribution Transformer

Voltage	Transformer Rating [kVA]		Full Load [A]	HV Fuse Link	Stock Code
12.7kV	1ph	10[3]	0.8	3K	13401
12.7kV	1ph	25	2.0	3K	13401

LOW VOLTAGE (SWER)

Transformer Rating [kVA]		LV Circuit: Open wire/ LVABC	LV Current: Full Load [A]	LV Fuse Link: LV Fuse [A]	LV Fuse Link: Description	LV Fuse Link: Stock Code	LV Fuse Holder: Max Rating [A]	LV Fuse Holder: Stock Code
1 ph	10[3]	LVABC	40	50/80[4]	Ferrule Ended 57mm x 22.2mm HRC	4442 / 4451[4]	100	19910
1 ph	25	Open	100	100	Ferrule Ended 57mm x 22.2mm HRC	12454	100	19910
		LVABC		80	Ferrule Ended 57mm x 22.2mm HRC	4451	100	19910

NOTES:

1. The fuse sizes listed are the recommended maximum.
2. Coordination between the HV and the LV fuses listed above is not guaranteed for all fault levels.
3. 10 kVA, 15kVA and 50kVA are no longer Energex standard transformer sizes, but are included as there are still some in service.
4. Depends on low voltage conductor/service cable size. If used as a combination LV and service fuse, the smaller rating should be used.
5. Where 2 circuits are fused separately, sizing is based on max 65/35 split between 2 circuits (This is assumed max circuit load).
6. Where 2 circuits are fused separately, refer to the Overhead Construction Manual, Section 7 for details.

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Appendix F – Energex Standard Transformer Impedance Values

3.7 FAULT LEVELS AT DISTRIBUTION SUBSTATIONS

3.7.1 Background

This section revised impedances for 11kV/433-250 V transformers and the maximum fault level at Distribution Substations for both the existing distribution transformers and new distribution transformers (available under current contract (CK18) with ABB and Wilson transformers). This data may be used for determining LV fuse sizing and the fault rating of the LV switchboard.

3.7.2 Revised Typical Fault Levels At Distribution Substations

Table 3.7.1 details the revised impedances of 11kV/433-250 V transformers and the maximum LV fault current for a 3 phase fault at Distribution Substations for distribution transformers available under recent and current contracts.

These fault levels are the maximum three phase fault currents that can be expected on the LV terminals of a distribution transformer. The fault currents correspond to a worst case transformer impedance of 90% of nominal, as transformer standards allow a ±10% tolerance on nominal impedance. These values assume an 11kV fault level of 250MVA (13.1 kA).

TABLE 3.7.1 – Revised Impedances and Maximum Fault Levels

Name Plate Rating (kVA)	Transformer Type	Trans. Nominal Impedance (%)	Maximum LV 3 Phase Fault Current (kA)		
			Single Trans.	2 in Parallel	3 in Parallel
25	POLE MOUNT	3.30%	1.1	2.2	3.3
63	POLE MOUNT	4.00%	2.3	4.6	6.9
100	POLE MOUNT	4.00%	3.7	7.2	10.8
200	POLE MOUNT	4.00%	7.2	14.2	20.8
315	POLE MOUNT, DRY and PADMOUNT	4.00%	11.3	21.8	31.7
500	POLE MOUNT, DRY and PADMOUNT	4.00%	17.5	33.3	47.6
750	PADMOUNT and GROUND	5.00%	20.8	39.2	55.6
750	DRY	6.00%	17.5	33.3	47.6
1000	PADMOUNT and GROUND	5.00%	27.2	50.3	70.2
1000	DRY	6.00%	23.0	43.0	60.6
1500	DRY	6.00%	33.3	60.6	83.3
1500	GROUND	6.25%	32.1	58.6	80.8

Appendix 3.7.A - Table 3.7.A.1 gives the current maximum LV fault current for a three phase fault for transformers purchased prior to 1989 (with a higher impedance) and transformers purchased after 1989 (with a lower impedance). This table is an extract from the Distribution Planning Manual – Table 9.21.

APPENDIX 3.7.A - Maximum LV Fault Current for High Impedance and Low Impedance Transformers

Table 3.7.A.1 gives the current maximum LV fault current for a three phase fault for transformers purchased prior to 1989 (with a higher impedance) and transformers purchased after 1989 (with a lower impedance). This table is an extract from the Distribution Planning Manual – Table 9.21.

Table 3.7.A.1: EXTRACT FROM DISTRIBUTION PLANNING MANUAL – Section 9.5

Table 9.21

MAXIMUM LV FAULT LEVELS

Transf. Rating (kVA)	Transformer Nominal Impedance (%)		Maximum LV Fault Current (kA)					
			Old Impedances			New Impedances		
	Old	New	Single Transf.	2 in Parallel	3 in Parallel	Single Transf.	2 in Parallel	3 in Parallel
200	4.0	-	7.2	14.2	20.8	No longer purchased - use old values		
300	4.0	4.0*	10.8	20.8	30.3	10.8*	20.8*	30.3*
500	4.5 (Also 5.0%)	4.5*	15.7	30.0	43.0	15.7*	30.0*	43.0*
750	5.0 (Also 6.25%)	5.0	20.8	39.2	55.6	20.8	39.2	55.6
1000	6.0 (Also 7.5%)	5.0	23.0	43.0	60.6	27.2	50.3	70.2
1500	9.0 (Also 9.75%)	6.25	23.0	43.0	60.6	32.1	58.6	80.8

* No impedance change from previous purchase contract
( ) Other impedances stocked

Note that these fault levels are the maximum three phase fault currents that can be expected on the LV terminals of a distribution transformer. The old impedance fault currents are based on the lowest old impedance stocked, not necessarily the most common or most recent purchases. The fault currents correspond to a worst case transformer impedance of 90% of nominal, as transformer standards allow a ±10% tolerance on nominal impedance. These values assume an 11 kV fault level of 250 MV.A.

3.7.3 Reach of Single and Dual LV Fuses

The ENA Low Voltage Protection Guidelines state that *"Overhead distributors shall be designed and incorporate electrical protection designed to clear a bolted fault, such as, wires twisted or firmly held together by fallen tree branches.*

The guidelines also stipulate the reach of an LV fuse to clear a bolted phase to ground fault at a minimum of 3 x fuse rated current. For the pole top transformers supplying open wire and

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