Session Number: 7

Electrical Arc Flash Hazard Analysis and Mitigation for Taranaki Combined Cycle Power Station

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Abstract

Recent guidelines in NFPA 70E-2009 and IEEE Standards 1584 (2002 & 2004) regarding arc flash hazards have focused safety conscious New Zealand industries to quantify the dangers of potential arc flash events in their energised electrical assets. Contact Energy is no exception with the completion of their second power station to have undertaken an arc flash hazard analysis study. A third power station is currently under investigation. This paper provides an overview of the process undertaken to conduct an arc flash hazard study at the Taranaki Combined Cycle Power Station. The process includes the calculation of the fault current by means of ETAP 7.5, calculation of arc flash, incident energy levels and flash-protection boundaries at the 6.6 kV switchgear bus, and mitigation proposals for reducing the arc flash hazard level. The implemented mitigation method of fast arc flash detection utilises fibre optic light sensors combined with fault current to initiate tripping which is faster than conventional time-graded relaying techniques.

1. Introduction

The driver for the Arc-Flash-Hazard assessment study was an Engineering Risk Assessment Process (ERAP) Report of September 2009 and compiled by RWE Power International. Calculations for these studies are carried out with ETAP® 7.1.0 Arc Flash Analysis software. Similarly, ETAP® 7.1.0 is applied in determining short circuit analysis. These calculations are based on the latest IEEE Standard C37.013, IEEE Standard for AC High-Voltage Generator Circuit Breaker Rated on a Symmetrical Current Basis".

The study calculates a workers potential exposure to arc flash energy, which may be required for the purpose of injury prevention and determination of appropriate levels of Personal Protective Equipment (PPE). The incident energy and flash protection boundaries are determined based on the following two available standards for arc flash analysis: National Fire Protection Agency (NFPA) 70E-2009 and IEEE Standards 1584-2002 & IEEE 1584a 2004.

Of the user-defined categories NFPA 70E-2009 is applied to the studies. The TCC ALSTOM generator is modeled by the sub-transient dynamic model to represent AC and DC decay of short circuit contributions from the generator.

This calculates both system-source and generator source short circuit currents and considers no-load, lagging power factor load, and leading power factor load for pre-fault conditions. ETAP® 7.1.0 is applied in modeling the system network, determining the load flow conditions and carrying out a short circuit analysis. These calculations are based on the IEEE Standard C37.013, IEEE Standard for AC High-Voltage Generator Circuit Breaker Rated on a Symmetrical Current Basis. Figure 1 illustrates the TCC switchboard panel studied for AFHA.

Figure 1: TCC Switchboard Panel

2. Calculation Methodology

2.1 Background

The arc-flash hazard study calculates a workers potential exposure to arc flash energy, which may be required for the purpose of injury prevention and determination of appropriate levels of Personal Protective Equipment (PPE). The incident energy and flash protection boundaries are determined based on the following two available standards for arc flash analysis:

- National Fire Protection Agency (NFPA) 70E-2009
- IEEE Standards 1584-2002 & IEEE 1584a 2004

The program determines the bolted Short-circuit current (3-Phase and 1-phase) and calculates the individual arcing current contributions and arc fault clearing time of all the protective devices involved in the arc fault. The Empirically

Derived Model (EDM) is used for voltages in the range of 0.208-15 kV and for a bolted fault current range of 0.7- 106 kA. The 3-phase and 1-phase fault current are calculated and applied in determining the incident energy. Figure 2 illustrates the single line diagram of the modeled electrical network.

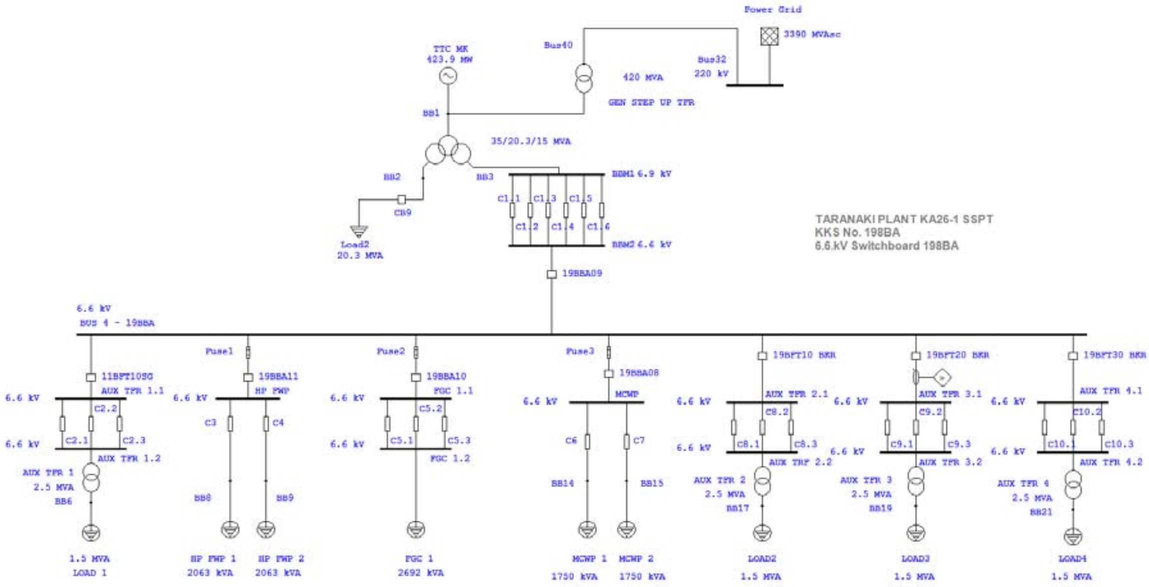

Figure 2: Studied TCC single line diagram

The ETAP Arc Flash Analysis module uses the equations listed in standard IEEE 1584-2002 / IEEE 1584a 2004 and NFPA 70E-2000 and 2004 versions. ETAP does not use the equation listed in sections 5.6 and 5.7 of IEEE 1584-2002 for determining the energy of protective devices (Current Limiting Fuses and Low Voltage Circuit Breakers). These equations are not used since the module takes a more conservative approach by interfacing to the actual TCCs of the devices available in ETAP Star. This is generally considered a more accurate approach and more conservative for current limiting fuses.

Determination of the Arcing Current Contribution (ACC) to a faulted bus is determined using the equations listed in IEEE 1584-2002. The following steps are taken to calculate the individual arcing current contributions:

- The total bus bolted short-circuit current (SCC) is used to calculate the total bus arcing current.
- The individual arcing currents are determined by distributing the arcing current proportionally between all the contributing sources (branches, motor loads, sources, etc.).
- The arcing current contribution ends up being proportional to the calculated bolted short-circuit contribution.

The half cycle current method is applied in determining the ACC. This method utilizes the half-cycle (subtransient) bolted fault current (I_{bf}”) to determine the ACC (I_a”). Typically this method will yield conservative results for fast operating protective devices (i.e. devices which operate in their instantaneous region).

The arcing current determined is assumed to be constant throughout the duration of the arc fault.

2.2 One and a Half to Four Cycle Current Method

This method utilizes the 1½ to 4 cycle (transient) bolted fault current ($I_{bf'}$) to determine the arcing current contributions (Ia'). Typically this method will yield conservative results for longer operating protective devices. The arcing current determined from either IEEE 1584 equations or directly taken as the bolted fault current (Lee method) is assumed to be constant throughout the duration of the arc fault.

2.3 Fault Current Decay Method

This method is very different from the previous two arcing current calculation methods. The program uses a combination of the subtransient, transient and steady-state short-circuit networks to determine the arcing current values which would flow throughout the arc fault duration. The program is taking into consideration the decay in asynchronous and synchronous machine short-circuit current contributions. The program will determine first the subtransient bolted fault current (I_{bf}''). It will also determine the transient bolted fault current (I_{bf}') and finally the steady-state bolted fault current (Ib_f). ETAP manipulates these three values to determine the equivalent I_a'', I_a' and I_a values which flow in the actual arc fault event.

In low voltage systems, the change from I_a'' to I_a' to I_a is not very high and thus the ½ cycle method and the fault current decay methods may yield very similar results for the majority of systems. However in medium voltage systems with a lot of asynchronous (induction) motor contributions and also with large generators contributions, the decay from I_a'' to Ia may be significant. This significant decay in current allows you to model a slower operation of protective devices which in turn may significantly increase the operating time of protective devices. Also, another benefit of the fault current decay method is its removal of arc fault contributions from motors. This allows the estimation of a more accurate amount of incident energy release. This has an impact for the TCC 6.6 kV Switchboard which has a number of motor loads – 6 motors.

The subtransient and transient fault currents are obtained using the typical ½ cycle and 4 cycle networks. The steady-state short-circuit currents are obtained typically at 30 cycles (this is the default value, but this can be user-defined).

2.4 Determination of the Fault Clearing Time

The Fault Clearing Time (FCT) is one of the major factors which affect the calculation of the incident energy. The FCT is the time required to clear the fault (arc to get extinguished by an opening protective device). This time is determined from the time current characteristic curves (TCCs) or the definite times of each protective device that is considered to be a source protective device (source PD).

ETAP classifies protective devices (PDs) as two types. The first and most important are the source PDs. These are the devices that energize the faulted bus, and once disconnected, completely isolate the system from any power source. The other type of protective devices is Load PDs. These are the PDs which carry power to the loads or subsystems connected to a faulted bus, but do not provide power from a source (i.e. synchronous generator or power grid).

ETAP takes the most conservative approach when determining the FCT. If there are several parallel source PDs feeding the bus, it will select the longest FCT (or the time at which the last source PD opens). If there is multiple source PDs in series on the same branch, it will take the shortest opening time of such PDs. The FCT is then used to calculate the incident energy for the bus and load PDs. The process of obtaining the fault clearing time is dependent on the method selected to determine the results. For 3-phase and 1-phase calculation methods with the ½ and 1.5 to 4 cycle methods, the process is relatively simple. The program determines the arcing current contribution passing through each source PD and based on its TCC settings, the program automatically determines the estimated fault clearing time of each PD. For these methods, a single current is obtained and plotted on a TCC to determine the trip time or total clearing time (fuses). The arcing fault current obtained using the half cycle method is 24.15 kA. This value is assumed to be held constant over the duration of the arc fault. The same process as shown in the previous image would apply if you were using the 1.5 to 4 cycle fault current method except that the current magnitude would be slightly smaller.

2.5 Determination of Incident Energy

After the fault clearing times have been determined, the incident energy for the fault location is calculated. The fault locations are categorized as follows:

- Fault at the main bus.
- Fault on the source protective devices.
- Fault on load protective devices.
- Fault on load terminals connected through the 6.6 kV cables (at the motors and auxiliary transformers).

Depending on the bus nominal voltage and bolted fault current value either the empirical or theoretical methods are applied.

2.6 Calculating Incident Energy for PDs

The incident energy is calculated once the arcing current, the FCT and the system grounding configurations have been determined. The module yields the incident energy results for the bus and individual protective devices.

The worst possible arc fault at a PD occurs at the input side of the PD (line side or side facing the feeder). In this case, the PD itself cannot clear the fault, and it must be cleared by a typically slower operating feeder PD upstream in the system.

2.7 Hazard/Risk Category Determination

The Hazard/Risk category level is determined by comparing the calculated incident energy in Cal/cm^2 against the ranges specified in the NFPA 70E tables.

3. Study Input Parameters

Study input parameters include data for TCC ALSTOM generator, service transformer, auxiliary transformers, motors and interconnecting cables. Most data has been obtained from Contact Energy's electronic data base. In addition the transmission network was modeled as a grid source.

The 6.6 kV switching equipment consists of metal clad switchgear of Type ABB ZS1/ZVC These are draw-out vacuum circuit breakers and metalclad fuse contactor switchgear Type ZVC. The rated current of busbars is 3150 A and for the tee-offs is 400 A. Instruments and control gear includes combined overcurrent and earth fault relay ABB Type SPAJ 140C, motor protection relay ABB Type SPAM 150C and GEC Type "K" HV fuse links. The ZVC Type Switchgear has withdrawable fused contractor truck. Fuses are of Type 'K" K81SDX 225 and K81SDX250 High Voltage HRC. These are for use on motor starting and general applications. Current ratings are 225 A and 250 A respectively. The breaking capacities of these fuses are 45 kA RMS (symmetrical).

The ALSTOM generator has a rated output of 500 MVA, real power output of 450 MVA and terminal voltage of 21 kV. Rated power factor is 90 % and full load current 12.95 kA. The 21/6.6/220 kV Station Service Transformer (SST) is a HYUNDAI HEAVY INDUSTRIES CO triple winding transformer – primary and two secondary windings. Primary side of the transformer (H) is supplied from the generator – point 11BAA60 on single line diagram HTDA 103233. The following parameters are applied in the calculations:

– <u>Rating (MVA) and voltage (kV)</u>:		
– Primary winding (H)	35.0 MVA	21.0 kV
– Secondary winding (Y)	20.3 MVA	6.2 kV
– Secondary winding (X)	15.0 MVA	6.9 kV
– <u>Short circuit impedance</u>:		
– $Z_{H\text{-}Y}$ to 20.3 / 35 MVA base	8.0 / 13.79 %	
– $Z_{H\text{-}X}$ to 15 / 35 MVA base	8.0 / 18.67 %	
– $Z_{X\text{-}Y}$ to 15/35 MVA base	17.0 / 39.67 %	
– Neutral grounding resistor (NGR):		
– Voltage	6.6/√3 kV	
– Rated current	400 A	
– Resistance	10 Ω	

The total transformer load is verified from available real-time data sourced. Maximum Active Power is 20.92 MW and Reactive Power is 21.73 Mvar. Apparent Power is 30.164 MVA for the 35 MVA SST (86.2%). The Static Starting Device (SSD) has been modeled in ETAP as a lumped load of 20.3 MVA at 6.2 kV.

There are four ABB Trafo – BB LV dry type auxiliary transformers (UAT) with the following technical data applied in the calculations:

– Rated Power:	2.5 MVA
– Rated Voltage:	6.6 / 0.42 kV
– Rated Current:	218.7 / 3,436 A
– Vector Group:	Dyn 1

Each transformer is modeled with a % Z of 6% and a typical X/R of 10.67. Similar to the SST, the loadings for each UAT are verified from available real-time data sourced between 25/06/2010 and 30/06/2010.

The loadings are as follows:

Source 01	109.1 A	1.239 MW	1.304 MVA
Source 02	0.5 A	0.006 MW	0.007 MVA
Source 03	27.03 A	0.263 MW	0.309 MVA
Source 03	72.00 A	0.700 MW	0.823 MVA

All of the above loadings are modeled at a minimum of 0.007 MVA and a maximum of 1.25 MVA. Power factor varied between 85 and 95 %. Motors operate the HP Feedwater Pump, Fuel Gas Compressor (FGC) and Main Cooling Water Pump (MCWP). The following parameters are applied in the calculations:

Feed water Pump:

- Real Power Rating: 1,650 kW
- Motor Current: 170 A
- Power factor: 85 %
- Fuse rating: 250 A

Fuel Gas Compressor Motor:

- Real Power Rating: 2,450 kW
- Motor Current: 236 A
- Power factor: 91 %
- Fuse rating: 405 A

Main Cooling Water Pump:

- Real Power Rating: 1,400 kW
- Motor Current: 145 A
- Power Factor: 85 %
- Fuse Rating: 250 A

All of the above have been modeled in ETAP as lumped loads.

Protection relays modeled in ETAP 7.1.0 are according to the ABB Technical Specification. The final protection relay settings applied in the calculations are from the most recent protection tests.

4. Results of Arc Flash Hazard Analysis

4.1 Short-Circuit Current

The 3-phase bolt currents are calculated for ANSI Duty, maximum 0.5 cycle, 4 cycle and the minimum 30 cycle. Both the ANSI Duty and the maximum 0.5 cycle calculations provide the same results as they are both at 0.5 cycles. The minimum bolt current occurs at the 30 cycles which represents the decayed asymmetrical peak amplitude.

The results of the above three phase short circuit current at each respective location are illustrated in Table 1. The maximum bolt current of 26.21 kA occurs at the 6.6 kV switchboard. It is evident that in the short term (0.5 cycle) there is reactive fault current contribution from the reactive motor load.

Table 1: Summary of calculated 3-Phase short-circuit currents

Location	Short-Circuit Current (kA)		
	Max (0.5 Cycle)	4 Cycle	Min (30 Cycles)
6.6 kV SWB	26.20	23.43	18.62
SST	19.06	19.03	18.62
Aux Tfr 1	0.43	0.18	0
HP FW	2.33	1.55	0
FGC	1.22	0.81	0
MCWP	1.97	1.32	0
Aux Tfr 2	0.43	0.18	0
Aux Tfr 3	0.43	0.18	0
Aux Tfr 4	0.43	0.18	0

4.2 Incident Energy & Flash-protection Boundary Limits

With the existing protection operating scheme, the maximum Incident Energy (E) calculated is 177.60 J/cm^2 (42.45 cal/cm^2) with a Flash-protection boundary (D_B) of 35.69 m and the PPE NFPA70E Category of "4" is exceeded. This is calculated at a 3-phase fault on the 6.6 kV switchboard incomer and a clearance time of 0.94 second. Due to the existing current transformer specifications and protection multiplying factor, the current instantaneous overcurrent scheme will not operate in an expected time of 0.2 s. In addition to the former studies, faults are simulated at 6.6 kV switchboard busbars and all outgoing 6.6 kV feeders from the switchboard.

5. Mitigation of Arc Flash Hazards

When instantaneous overcurrent protection is the sole protection provided, no additional Arc-Flash-Hazard mitigation is required. However, overcurrent protection is only applied to the incomer and auxiliary transformer feeders and not to the other feeders (FGC, MCWP and HP FWP). Another factor to consider is the detection of the arc-flash during an incident and as close to the source of the fault as possible and the protection of all potential supply feeders. Lastly, it is advisable that the existing overcurrent protection have a "back-up" protection system installed that is specifically for Arc-Flash-Hazards. For these reasons mitigation should be considered. There are three basic concepts for arc flash mitigation. These are:

- By reducing the exposure to indoor switchgear.
- Increasing the distance of the arc from the arc to the worker.

- Reducing the total amp-cycles of the arcing fault.

As the incident energy is directly proportional to the total arcing time, strategies for arc flash hazard mitigation focus on faster detection and clearing of the arc flash – thereby reducing the total amp-cycles of the arcing current (I^2t). The two main components of the total arcing time are the protection relay and the circuit breaker interrupting times. The total arcing time is the sum of the relay operating time and the breaker interrupting time. As the incident energy is directly proportional to the total arcing time, strategies for arc flash hazard mitigation focus on faster detection and clearing of the arc flash. The two main components of the total arcing time are the protection relay and the circuit breaker interrupting times. In addition to the former considerations, mitigation should always include basic low capital investment practices such as safety Awareness programs which comprise Arc-Flash-Hazard courses, posters and "awareness days/weeks".

The exposure to indoor switchgear can be reduced by allowing restricted and controlled access to switchrooms. This can be achieved by considering the following: Restricting access to switch rooms by rerouting traffic by alternative routes, eliminating the use of switchgear room as storage facilities, and restricting the minimum number of personnel for operating or inspections.

The safest practice to prevent arc-flash injuries is for operators to avoid the danger zone. Since the incident energy is proportional to the square of the distance (in open air), increasing the working distance will significantly reduce the incident energy. Working distance can be increased by using remote racking devices, remote controlled switchgear racking mechanisms, operating devices, and extension tools (i.e. hot sticks).

Reducing the total amp-cycles of the arcing fault can be achieved by installing faster relaying. This is a more cost-effective approach to reducing arc flash hazards than replacing costly circuit breakers. The most commonly used protective relays today are bus differential, instantaneous overcurrent and time-overcurrent relays.

Bus differential protection is reasonably fast with a typical operating time of 1 – 2 cycles but the cost of implementation is expensive due to the dependence on dedicated current transformers which will need to be installed on every circuit connected to the bus. It must be considered that bus differential protection does not protect against arc flashes in the feeder cable compartments because faults in these areas are usually outside the bus differential zone. Instantaneous overcurrent protection operates with no intentional time delay and with a typical operating time of 1 – 2 cycles.

Instantaneous overcurrent protection is relatively inexpensive. It is usually difficult to set instantaneous values low enough to provide meaningful arc flash protection without compromising coordination with downstream relays.

Time-overcurrent protection is inexpensive but slow as it intentionally adds time delay to coordinate with downstream feeder protection. Operating times can range from a few cycles to more than a second depending on system coordination requirements.

The fastest arc flash detection system currently available is based on optical arc flash detection. The optical arc flash detection relay has a typical operating time of 2.5 milliseconds (0.15 cycle), making it far faster than any of the conventional current-based schemes described above. Its operating time is largely independent of the fault current magnitude since the low-level fault detector elements are only used to supervise the optical system. With optical arc flash protection installed, the relay operating time is essentially negligible compared to the circuit breaker operating time. Cost is fairly low since current transformers are only needed on the main breaker(s). In addition, the feeder cable compartments can also be protected, providing complete coverage of all switchgear compartments.

This type of system consists of light detecting relays that are connected by fibre optic cables to light sensor(s). Combining arc-flash detection and high-speed overcurrent from a protective relay provides fast tripping and security, using both instantaneous overcurrent and light from the arc flash. In order to prevent false trips due to flash bulbs, arcs from circuit breakers performing switching, strong sunlight, etc., an optional current sensing relay is available to supervise the optical relay. Including trip times for the circuit breaker and the current sensing relay the total system will trip the main circuit breaker in about 40 milliseconds.

6. Final Protection Proposal

6.1 TCC 6.6 kV Switchboard Arc Flash Protection Scheme

The existing 6.6 kV switchboard at TCC complies with the IEC 62271-200 standard for internal arc withstand safety and with this requirement Contact Energy does not need to implement costly switchboard replacement strategies. However Contact Energy has taken further safety initiatives by installing SEL-751 A feeder protection relays and retroffiting optical arc flash detection system on the existing equipment. The intention is to isolate the arcing fault current as fast as possible and to ensure the energy levels do not exceed the PPE NFPA70E Category of “2”.

Based on the arc flash hazard calculation, a tripping time of less than 190 ms is required to be within the energy level of category “2”. The arc flash protection system monitors the arc flash level and supervise with an instantaneous arc flash overcurrent element to provide fast selective/ multiple tripping of the 6.6 kV breakers. The arc flash overcurrent element is set to pick up for a current well above the maximum anticipated current for normal operation, such a current is defined as a fault current as distinct from a normal load. It is recommended that the element is set to greater than twice the maximum load current.

SEL-751A relays replaced the existing ABB Type SPAJ 140C feeder protection relays which were installed on an incoming feeder and 4 outgoing auxiliary transformer feeders. Each SEL-751A relay is designated to monitor upto 4 optical sensors where each sensor can be fitted either at a switchgear compartment or a different feeder breaker, at TCC the 5 relays were required to provide enough optical sensors for cable, breaker and fuse compartments Mirrored bits were used for relay communications for bus tripping, local breaker tripping, transmission of bus arc flash and circuit breaker failure protection functions as shown in Figure 3. Overcurrent and earth fault protection for each breaker is retained and re-applied in the SEL-751A relays, and supplemented with trip circuit supervision. Relay, trip circuit/communications and arc flash optical sensors are continuously monitored and alarmed to the site control room allowing us to ensure that the protection is fully operational at all times.

TCC is normally in continuous operation, the mirrored bits communications allowed us to simplify wiring of the installation which occurred during a 7-day electrical outage as part of a larger 3-yearly plant survey/inspection.

Arc flash optical sensors are fitted in the different switchgear compartments as illustrated in Figure 4 and listed as follows:

- Arc flash bare-fiber loop sensor is located within the 6.6kV switchgear busbar compartment and connected to the incomer SEL751A relay.
- Arc flash point sensor is located within each circuit breaker/ motor contactor compartment. The busbar measuring compartment with a busbar earthing facility also has a point sensor.
- Arc flash point sensor is also located within each circuit breaker cable compartment.

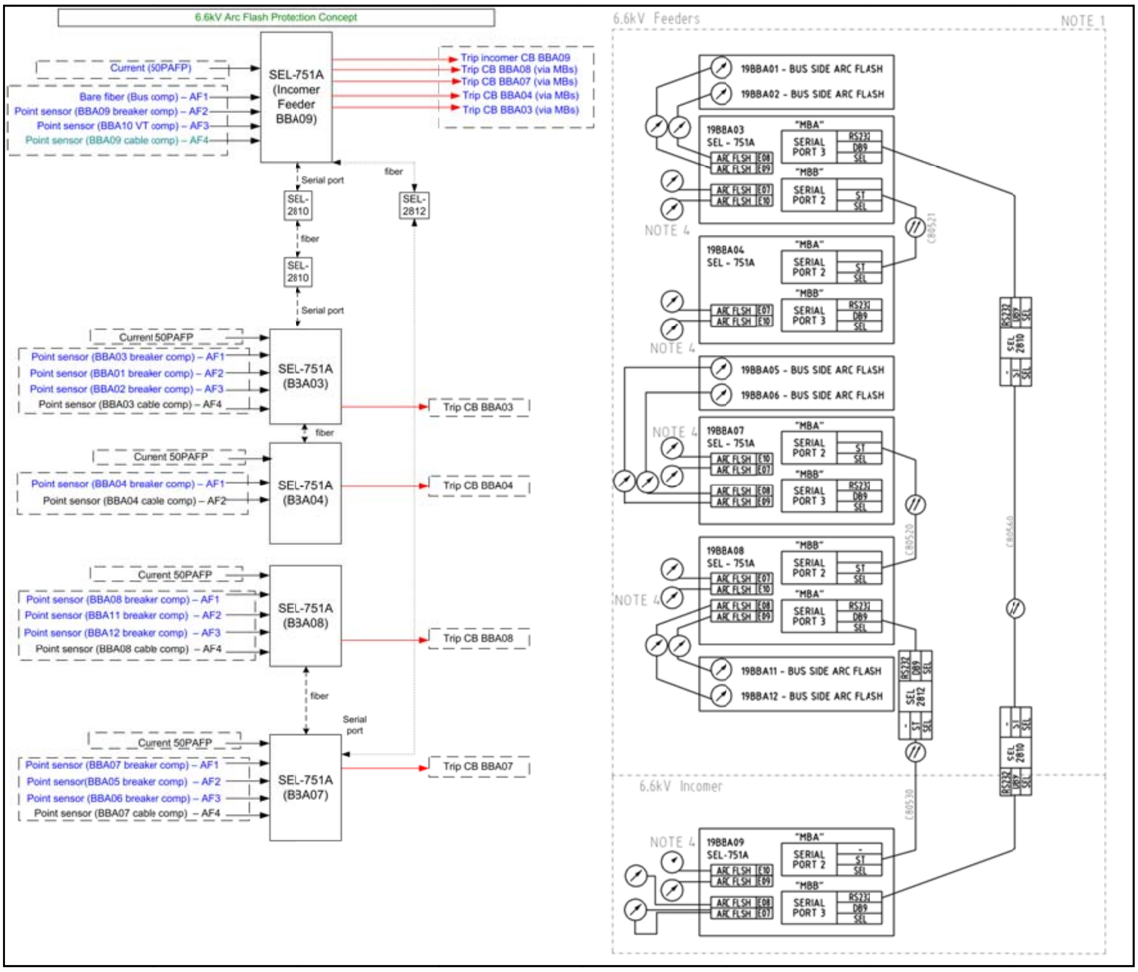

Figure 3 Communications connection diagram

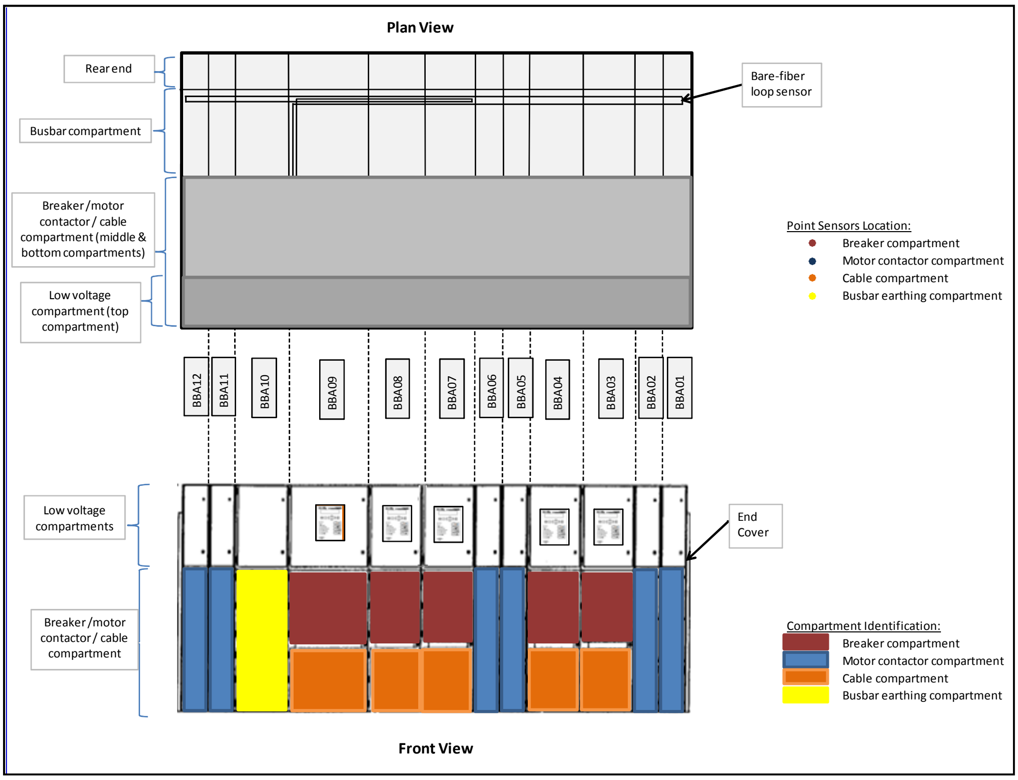

Figure 4: Switchgear layout and optical arc flash sensors arrangement

6.2 Electrical Safe Work Practices

6.2.1 Switchgear Operation

The 6.6kV switchgear at TCC can be racked out and in with the door closed. Based on IEC 62271-200 requirement, the Internal Arc Classification (IAC) for this switchboard is AFLR, which is designed for safe working around the switchgear (i.e. front, lateral and rear) in case of internal arc fault as long as the doors are all closed. The conditions when the worker is exposed to the hazard is when a selected circuit breaker is manually racked out completely from the cubicle whilst the board is still energised. This exposes the workers to the hazard risk of an arc flash during a fault finding in the vicinity of the breaker with the door opened. One example is to rack out a particular motor feeder breaker from the compartment in order to replace the blown fuses with the board is still energised.

Under normal operational conditions the switchgear must only be operated or racked in/ out with doors closed to prevent direct exposure to energised conductors. In addition close pushbuttons on the SEL751A relay front panels are configured with a 30 second delay to allow a local operator to carefully leave the room before circuit breaker closure occurs. During this period the LED next to the close pushbutton will flash to indicate the close command is enabled and the timer is counting down.

6.2.2 Restricted and Controlled Access to Switchroom

Personnel will have a restricted and controlled access to switchrooms especially during the switching operations and inspections. The switchgear room is not to be used as a storage facility and this can help prevent any unnecessary visits to switchroom.

6.2.3 Personnel Protective Equipment (PPE) Minimum Requirement

For working around the switchgear with switchgear conductor still energised and with the door opened, all personnel is required to put on a minimum PPE level 2. This requires a flame retardant shirt & pants, cotton underwear, eye and face protection, leather-over-voltage-rated gloves and safety boots.

7. Conclusion

With the proposed Arc-Flash-Hazard mitigation, is possible to reduce the maximum Incident Energy (E) originally calculated at 177.60 J/cm^2 (42.45 cal/cm^2) to 28.34 J/cm^2 (6.77 cal/cm^2). This corresponds to a decrease in Flash-protection boundary (D_B) of 35.69 m to a 5.41 m. The final PPE NFPA70E Category achieved is “2”. These results are calculated at the same 3-phase fault on the 6.6 kV switchboard incomer and at a clearance time of 0.15 second. The application of ETAP 7.5 has been applied in calculating the short circuit current. These calculations are for the maximum (0.5 cycle), 4 cycle and minimum (30 cycles) short circuit values.

8. References

1. Measurements of the effects of smoke on active circuits; Dr Tina J. Tanaka; Sandia National Laboratories, Accident and Consequence Analysis Department, Albuquerque, NM 87185-0748, USA February 1999.
2. Application of Existing Technologies to Reduce Arc-Flash Hazards; Jim Buff and Karl Zimmerman, *Schweitzer Engineering Laboratories;* SEL; 2006.
3. Practical Solution Guide to Arc Flash Hazards; Chet Davis, P.E., Conrad St. Pierre, David Castor, P.E., Robert Luo, PhD, Satish Shrestha; ESA, Inc; 2003.
4. IEEE 1584^{TM} Guide for Performing Arc-Flash Hazard Calculations.
5. NFPA 70E 2009 Standard for Electrical Safety in the Workplace.
6. Critical Incident Energy Reduction through Arc Flash Hazard Mitigation by Norman E. Reifsnyder, WorleyParsons, Inc. and Robert A. Wilson, ABB, Inc.
7. Arc Flash Mitigation – Distance is Safety Finley Ledbetter – Group CBS Inc. Scott Peterson – CBS Nuclear Services Inc.
8. ARC FLASH HAZARD ANALYSIS AND MITIGATION; Christopher Inshaw, Emerson Process Management Electrical Reliability Services Inc. Brea, CA Robert A. Wilson ABB Inc Houston, TX Western Protective Relay Conference Spokane, WA October 20th, 2004.
9. INTERNATIONAL STANDARD IEC 62271-200 First edition 2003-11High-voltage switchgear and control gear – Part 200: AC metal-enclosed switchgear and control gear for rated voltages above 1 kV and up to and including 52 kV.
10. ANSI/IEEE Standard C37.20.7-2007, “IEEE Guide for Testing Metal-Enclosed Switchgear Rated Up to 38 kV for Internal Arcing Faults,” IEEE.
11. EEMAC G14-1 (1987), “Procedure for Testing the Resistance of Metal-Clad Switchgear Under Conditions of Arcing Due to an Internal Fault,” EEMAC.
12. “Strategies for Mitigating the Effects of Internal Arcing Faults in Medium-Voltage Metal-Enclosed Switchgear;” Wactor, Olsen, Ball, Lemmerman,

Puckett, Zawadzki; presented at 2003 IEEE PCIC conference, (PCIC-3-09) IEEE.

13. Draft Standard C22.2 No. 261, "Evaluation Methods for Arc-Resistant Ratings for Enclosed Electrical Equipment."
14. SIEMENS TechTopics Publication No. 70 2009.