University of Victoria
Engineering & Computer Science Co-op
Work Term Report
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Repair Ground Fault Detection Conflicts With C-Jetty

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April 27, 2020

In partial fulfillment of the academic requirements of this co-op term

Supervisor's Approval: To be completed by Co-op Employer

This report will be handled by UVic Co-op staff and will be read by one assigned report marker who may be a co-op staff member within the Engineering and Computer Science Co-operative Education Program, or a UVic faculty member or teaching assistant. The report will be retained and available to the student or, subject to the student's right to appeal a grade, held for one year after which it will be deleted.

I approve the release of this report to the University of Victoria for evaluation purposes only.

Signature: Digitally signed by Patrick Heintz DN: cn=Patrick Heintz, o=Defence Construction Canada, ou=CFB Esquimalt, email=patrick.heintz@dcc-cdc.gc.ca, c=CA Date: 2020.04.27 11:30:23 -07'00' Position: Team Leader Date: April 27, 2020

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For (Company Name): Defence Construction Canada

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April 27, 2020

Susan Fiddler
Co-op Coordinator
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Dear Susan Fiddler,

As partial fulfillment of Work Term l, please accept the following Work Term Report entitled 'Repair Ground Fault Detection Conflicts With C-Jetty'.

The accompanying report is the result of work completed under employment with Defense Construction Canada during the Spring 2020 semester. DCC is a Crown Corporation that manages construction contracts on behalf of their client partners, the Department of National Defense and the Canadian Forces. Over the course of the spring semester I have worked alongside a team of professionals to support various interdisciplinary projects. My role as a Construction Coordinator required that I help manage these projects under the Real Property Operations team; who is responsible for the support of existing DND infrastructure. The subsequent Work Term Report entails an evaluation of two solutions to be considered for implementation.

I am grateful to have been a part of Defence Construction Canada's team and fortunate to have had the opportunity to develop in a professional workplace. The skills and knowledge I have gained during my time with DCC are instrumental to my development as an engineer. DCC has provided me with a first-hand account of engineering applications in the real world and it has been a vital component in my education as an Electrical Engineering student at the University of Victoria.

It was my pleasure to be a part of such a professional, yet enjoyable and encouraging team at DCC. I owe the entire team a huge thank you for being so welcoming and helpful during my placement. I would also like to extend a thank you to fellow co-ops Brandon Molitwenik and Avalon Shavers for always lending a helping hand. Lastly, thank you to Patrick Heintz whose leadership and professionalism were exemplary.

Sincerely,

Branden Voss
Defence Construction Canada
2B Electrical Engineering Student - University of Victoria

Table of Contents

List of Figures and Tables

Summary

Defence Construction Canada is responsible for all contract management at the Canadian Forces Base located in Esquimalt, British Colombia [1]. In particular, their client partner The Department of National Defense has identified ground fault detection conflicts regarding shore to ship power at C-Jetty. These conflicts have presented system malfunctions and safety hazards that must be addressed. Two potential solutions to this problem are comparatively analyzed prior to selecting one for implementation.

The ground fault conflicts at C-Jetty are attributed to aging electrical equipment, voltage drop issues and inadequate methods for ground fault detection. These deficiencies have posed safety hazards to ship personnel and equipment failure [2]. Therefore, it is required that the shore to ship power system be serviced. DCC has proposed two solutions in response to the identified ground fault issues; the first being the addition of The Three Lamp Method to the existing substation and equipment at C-Jetty. The second suggests that an Insulation Monitoring and Detection System is to be installed with upgrades to C-Jetty's electrical equipment. Since shore to ship power is considered an essential operation for fleet maintenance, the client has specified that functionality should take precedence over cost [2]. After taking into account the needs of the client, option 2 presents itself as a superior choice for effectively combating the ground fault detection conflicts at C-Jetty. It is recommended that the Department of National Defence pursue this design for use.

Glossary

DCC	Defence Construction Canada
DND	Department of National Defence
Crown Corporation	A government owned corporation that is funded by public money and is shielded from constant government intervention and legislative oversight
C-Jetty	A landing stage or pier at which boats can dock or be moored; located at CFB Esquimalt
Ground fault	The unintentional contact between an active conductor and a ground
Ungrounded system	A system in which no conductors are connected to ground
Three phase power	Refer to Appendix B
Three wire system	A three phase power system with three conducting wires and no neutral conductor
Unbalanced system	Refer to Appendix B
CEC	Canadian Electrical Code
RP Ops	Real Property Operations
MCDV	Maritime Coastal Defence Vessel
IMDS	Insulation Monitoring and Detection System
Donut CT	Donut Current Transformer; donut shaped and is used for detecting unbalanced or residual current in a wire
Electrical kiosk	An onshore kiosk used at C-Jetty to house electrical equipment necessary for shore to ship power connection such as ground fault detection system
Substation	Electrical equipment used in transforming, transmitting and distributing power
Transformer	Transforms voltage from high to low or vice versa in order to be purposed (12.5kV – 460V)

Switch gear	An electrical component that directs power to a specified load; used to select path(s) for power delivery
Symmetrical fault	A type of ground fault in which two or more wires in a three-wire system are grounded proportionally
Nuisance tripping	The unwarranted tripping of a circuit breaker; occurs if a fault is detected when one does not exist

1. Introduction

Defence Construction Canada (DCC) is a Crown Corporation that provides innovative contracting for the Department of National Defence (DND) and the Canadian Armed Forces. DCC aims to provide timely, effective, efficient project delivery, full lifecycle support to infrastructure and environmental assets required for the defence of Canada [1]. These projects cover an extensive range of infrastructure; some of which may involve simple everyday maintenance work, while others are more complex and require high levels of security clearance. DCC works closely alongside DND to manage projects from their beginning through to completion. It is DCC's responsibility to manage the procurement process, consult proposals, provide technical advice, and perform quality assurance to guarantee satisfactory completion of work [1]. One such project and the focus of this report is titled 'Ground Fault Detection Conflicts with C-Jetty'.

Figure 1: Overview of C-Jetty [2]

C-Jetty is located on Esquimalt harbour as seen in figure 1 and is used for the maintenance of berthing naval vessels [2]. There is an existing power distribution system installed at C-Jetty for the purpose of supplying shore to ship power while at berth. Shore to ship power is generally ungrounded type, three phase three wire, delta connected [2]. This report focuses on an ungrounded three phase power supply system and the related ground fault detection issues.

2. Project Background

Shore to ship power supply at C-Jetty is ungrounded type, three phase three wire; delta connected and is identical to the power generation on board many modern naval ships [2]. The intent of an ungrounded power configuration is to limit system outage downtime and provide continuity of electrical operation to the load [2]. The shore power supply infrastructure at C-Jetty consists of two substations and fifteen electrical kiosks [2]. This equipment is developing ground fault conflicts due to age, voltage drop issues and incompetent methods for ground detection. Regardless, ungrounded systems are typically unstable in the context of personal safety and fire hazard [2]. Thus, the Canadian Electrical Code means to mitigate these vulnerabilities by implementing a ground fault detection device within the system.

2.1 Canadian Electrical Code

The Canadian Electrical Code (CEC) Rule 10-400(1) and (2) state that ungrounded wiring shall be equipped with a suitable ground fault detection system to indicate the presence of a ground fault [3]. Therefore, a ground fault detection system conforming to CEC is required for shore power supply at C-Jetty as part of a necessary preventative measures against fires and other hazards effecting personal safety [3]. Additionally, CEC Rule 10-400(3) states that ground fault indication activated by the ground fault detection device required by sub rule (1) and (2) shall be clearly labelled as to this purpose and visible to persons monitoring the system status [3].

2.2 C-Jetty Infrastructure

The existing power supply system at C-Jetty is becoming obsolete and, therefore, experiencing ground fault detection conflicts [2]. The system is developing voltage drop issues due to aged equipment and the natural loss over distance [2]. Delivering less voltage than is required by the load is harmful on equipment and contributes to ground fault conditions [2]. Additionally, the current method for ground fault detection is insufficient for C-Jetty's purposes.

2.2.1 Substation

The substation shown in figure 2 contains the current 12.5kV – 480V transformer. Also seen in this visual are the switch gears necessary for distributing power to the electrical kiosks at this jetty. C-Jetty has two separate substations operating off of similar equipment. These substations are divided up to supply C-Jetty East and C-Jetty West respectively.

Figure 2: C-Jetty East Substation

2.2.2 Electrical Kiosk

The electrical kiosk is where the ship is connected to shore power.

This kiosk contains switch gears required for routing power to a desired ship and also houses the mechanism for detecting ground faults. The current method for ground fault detection has limited capability; some faults such as symmetrical faults, have gone undetected [2]. According to RP Ops this has been a contributing factor to electrical fires resulting in personnel injury [2]. Since the shore ground detection system is not compatible with the ship system, what is known as nuisance tripping has occurred. This means that the ship system is detecting the shore systems ground and causing an outage [2]. Other ships such as Maritime Coastal Defence Vessels (MCDVs) were equipped with Insulation Monitoring and Detection System (IMDS) which will be discussed in this report.

3. Discussion

In response to the ground fault detection conflicts at C-Jetty, DND has been presented with two design options. Each design addresses the issue differently but provides a viable solution to the problem. Option 1 and option 2 are expanded in detail through this section of the report.

3.1 Option 1: Three Lamp Method

The Three Lamp Method is an older technique for detecting ground faults [2]. This method consists of three lamps; L1-ground, L2-ground and L3-ground [2]. Recall that shore to ship power is three phase and three wire. This means there is one lamp per wire

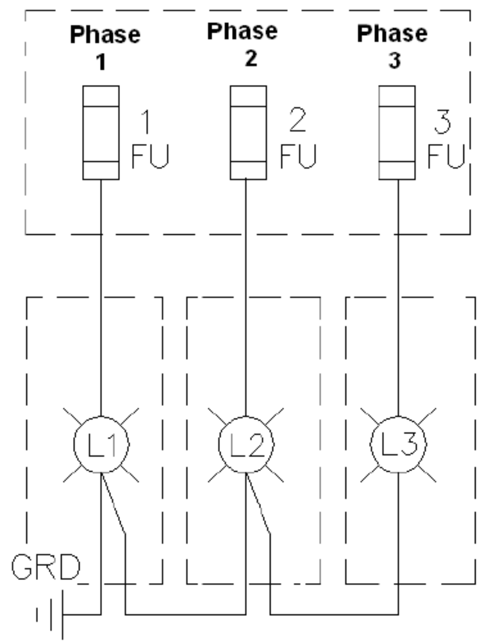

Figure 3: Three Lamp Method Schematic [2]

to monitor its individual status between a conductor and ground. This is represented by the visual labelled figure 3. Under normal circumstances all three lights will be dimly lit. If the system were to experience a ground fault, one of the three lamps will no longer emit light while the other two will become brighter [2]. The light that has gone out indicates a ground fault somewhere on its corresponding wire. The design is in place to notify personnel that a fault exists and must be promptly repaired. Refer to Appendix B of this report for a brief overview on the behaviour of three phase power for a better understanding in this context. Note that there is no function in place to halt the power delivered to the load thus, equipment will continue operation and may be hazardous [2]. Trouble shooting can be time consuming and difficult as the location of the fault could be at any point in the identified line. Due to this lack of insight it is often required that equipment be shut down during the process of trouble shooting [2]. To implement this option the existing 12.5kV – 480V transformer and other electrical equipment does not need to be replaced. Rather, the current equipment can be re-routed and re-used [2].

Table 1: Pros and Cons of Option 1

Pros		Cons	
Criteria	Explanation	Criteria	Explanation
Simplicity	Design is simple and easily implemented [2]	Troubleshooting	No mechanism to pinpoint fault location [2]

Low Cost	The estimated cost for applying this option at C-Jetty is around $3.8 million [2]	Capability	Not capable of detecting symmetrical faults
Substation / Equipment	Existing substation to be re-routed and re-used. New switch gears are not necessary	Functionality	Requires shutdown of important services in the event of a ground fault

3.2 Option 2: Insulation Monitoring and Detection System (IMDS)

An Insulation Monitoring and Detection System (IMDS) monitors the ungrounded system between an active phase conductor and a ground as depicted in Figure 4 [4]. The IMDS is a tool that will expose a ground fault through insulation resistance [4]. This means that the device will measure in Ohms and a ground fault will be indicated as an “insulation breakdown” [4]. The IMDS is designed to issue an alert through light and sound or disconnect the power supply if the resistance between the two conductors drops below a certain threshold value [2]. One notable advantage of this method is that the ungrounded system is allowed continuous operation of important services regardless of a fault condition [5]. It is important to remember it is assumed that all naval ships will be retrofitted with an IMDS system and future vessels will be manufactured using this system [2].

Figure 4 below represents a three phase three wire power system that delivers to two separate loads. The IMDS provides a more precise method for identifying the location of a ground fault [5]. Each line L1, L2 and L3 are polled by the IMDS close to the source. In the event of a ground fault, the device will specify which line has been grounded.

Furthermore, this option differentiates itself from the first by introducing a donut CT. The device will impose a signal down the line to be measured by the donut CT [5]. The CT

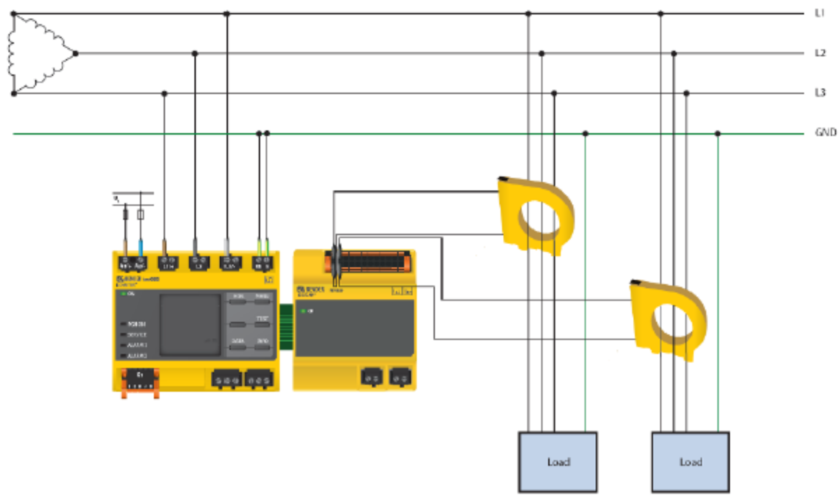

Figure 4: IMDS Schematic [2]

will sense an unbalanced condition and a location of the ground fault can be identified. The existing 12.5kV – 480V transformers will need to be replaced by new 12.5kV – 460V transformers [2]. The current 480V distribution board and all jetty kiosks will need to be deconstructed [2]. Each jetty kiosk will be capable to handle 2 berthing ships simultaneously after replacement [2]. Again, refer to Appendix B for information on three phase power under this context.

Table 2: Pros and Cons of Option 2

Pros		Cons	
Criteria	Explanation	Criteria	Explanation
Compatibility	Identical to system used on board Canadian Forces Naval Ships	High Cost	The estimated cost for applying this option at C-Jetty is around $9.5 million [2]
Trouble Shooting	Provides a method for better locating a ground fault	Substation	Existing substation to be replaced with new

Functionality	Allows continuous operation of important services even if a ground fault occurs
Capability	Capable of detecting symmetrical faults [5]

4. Comparative Analysis

DCC has been led to the two previous design options; The Three Lamp Method and The Insulation Monitoring and Detection System. As part of the process in determining the best option to proceed with, it is important to compare the ability and features of each design. In summary, Table 3: Weighted Objectives Chart included in this section effectively highlights the key decision-making factors behind this project. Refer to Appendix A to better understand the criteria for Table 3.

4.1 Design Reliability and Functionality

Upon review it can be seen that each design provides a viable solution to the existing ground fault detection conflicts previously outlined. Option 1: The Three Lamp Method implements a simple more cost-effective design to meet the objectives of this project. Option 1 utilizes a basic design that relies on lamps to measure the voltage across an active phase conductor and a ground through bulb brightness. This solution is also compatible with the existing substation and power distribution system at C-Jetty. Unfortunately, this design is deficient in its ability to detect symmetrical faults and competently troubleshoot ground faults. However, this system provides a low cost, practical solution to the achieve the client's objectives.

Option 2: IMDS approaches the solution by measuring resistance within the system in order to identify potential faults. This solution uses a monitoring device between an active phase conductor and a ground to measure potential resistance created by a fault condition. Option 2 also makes use of a donut CT as a method for analyzing and finding the location of a ground. Despite being more expensive, this solution provides effective troubleshooting and adequate capabilities to meet the needs of the client partner.

Table 3: Weighted Objectives Chart

Objective	**Weight**	**Criteria**	**Three Lamp Method**		**IMDS**	
			Score	Value	Score	Value
Reliability	0.4	Will the system effectively detect and locate ground faults	3/5	0.8	4/5	1.6
Functionality	0.3	Does the system as a whole operate correctly, efficiently and safely	2/5	0.6	4/5	1.2
Compatibility	0.25	Does the system work with other systems used by the navy	2/5	0.5	5/5	1.25
Cost	0.05	$	5/5	0.25	3/5	0.15
Overall Score (out of 5)				**2.15**		**4.20**

5. Conclusion

The comparison of the two ground fault detection methods determined that the Insulation Monitoring and Detection System most effectively fits the needs of the client. Despite the additional cost of replacing the electrical kiosk and existing substation, the benefits reveal the IMDS as the most effective means of ground fault detection at C-Jetty. This system presents an overall superior functionality to its competition. Notably, the IMDS supersedes its competition in ground fault detection, ground fault location, compatibility and its troubleshooting process. The lack of functionality and capability to The Three Lamp Method proves it to be antiquated and unsatisfactory for the client's needs at C-Jetty. It is also important to recall that it is the client's intent to incorporate the IMDS design on their ships. This includes the existing Canadian Forces Naval ships being retrofitted with IMDS, and also anticipating all new ships are to be built with the latest IMDS [2].

6. Recommendation

This report recommends with confidence that the Department of National Defence should pursue the implementation of an IMDS in response to the ground fault detection conflicts at C-Jetty. Ultimately the functionality and capability of the IMDS should be prioritized over the cost effectiveness of the first option [2]. This option effectively provides a safe and reliable system for shore to ship power. To install this system at C-Jetty, the existing 12.5kV – 480V transformer, distribution board and electrical kiosks must be dismantled and replaced with a 12.5kV – 460V transformer, new distribution system and new kiosks capable of supplying two berthing ships simultaneously [2]. The IMDS can then be connected to the system in order to solve future issues related to ground fault detection. The IMDS in conjunction with adequate equipment is easily distinguished as the best option to provide a trustworthy and secure method for ground fault detection at C-Jetty.

References

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Appendix A - Weighted Objectives Chart Criteria

The following table outlines the criteria for scores from 1-5 on each objective covered in Table 3, the Weighted Objectives Chart of this report.

Objective	**1 - Poor**	**2 - Bad**	**3 - Average**	**4 - Good**	**5 - Excellent**
Reliability	Unreliable (i.e. the system only sometimes detects ground fault)	Somewhat reliable (i.e. the system can detect ground fault)	Mostly reliable (i.e. the system can detect ground fault and rough location)	Reliable (i.e. the system can detect ground fault and location)	Very reliable (i.e. the system consistently detects ground fault and accurate location)
Functionality	Not functional	Intermittent functionality and is not safe	Functions safely	Functions safely and mostly efficient	Functions safely and efficiently
Compatibility	Not compatible (i.e. system doesn't match ship experiences nuisance tripping)	Somewhat compatible (i.e. may trip but equipment is still insufficient)	Mostly Compatible (i.e. delivers appropriate voltage and mostly avoids tripping)	Compatible (i.e. system closely resembles ships and is consistent)	Very compatible (i.e. system matches ship and runs smoothly and effectively)
Cost	> $12 million	$12 million - $10 million	$10 million - $8 million	$8 million - $6 million	< $6 million

Appendix B - Three Phase Power and Related Calculations [6]

Three phase circuits generate, transmit, distribute and consume large blocks of electric power. A set of balanced three phase voltages consists of three sinusoidal voltages that have identical amplitudes and frequencies but are out of phase with each other by exactly 120°. The three voltages can be referred to as a-phase voltage, b-phase voltage and c-phase voltage. Using the a-phase voltage as the reference voltage there are only two possibilities for the remaining voltages. They will either lead ($+120°$) or lag ($-120°$) the a-phase voltage. This is represented by the following equations:

$$V_a = V_m \angle 0° \quad [6]$$

$$V_b = V_m \angle + 120° \quad [6]$$

$$V_c = V_m \angle - 120° \quad [6]$$

Where V_{abc} is the respective phase voltage, V_m is voltage max and $\angle$ is a mathematical operator used to represent each voltage as its complex number value.

According to the above equations, the following also holds true:

$$0 = V_a + V_b + V_c \quad [6]$$

Thus, an unbalanced set of three phase voltages would not cancel out. This means each of the three phase voltages are not exactly $120°$ out of phase with one another. As a result, we give the equation:

$$0 \neq V_a + V_b + V_c \quad [6]$$