LOL-HECO-IR-24

Ref: "The March 3, 2004 Pukele outage incident has accentuated the need to proceed with the project." (Exhibit ST-4, page 12, lines 15-16)

Question(s):

a. Please provide a copy of the HECO March 3, 2004 Pukele outage report filed with the PUC.

b. Please explain how the outage accentuates the need for the line.

HECO Response:

a. See attached pages 3-49.

b. The March 3, 2004 Pukele Substation outage represents a situation HECO was trying to prevent with the proposed East Oahu Transmission Project, as explained in HECO T-4, page 33, line 20, to page 34, line 10. HECO T-4, pages 34-37, explains the various factors involved in trying to look at the possibility of having a situation where both 138kV transmission lines to Pukele could be lost. The loss of two 138kV transmission lines can occur if:

1) one line is out for maintenance and the second line experiences a sudden outage or

2) both lines experience a simultaneous forced outage.

The testimony explains how placing one of the 138kV lines feeding the Pukele Substation from the Koolau Substation on maintenance places the Pukele System at risk if the second 138kV line feeding the Pukele Substation is lost. It explains HECO's maintenance practices for the 138kV transmission lines, for example, conducting quarterly visual inspections on all 138kV transmission lines. Please also refer to the response to LOL-HECO-IR-25.

HECO T-4, page 35, also explains that prior to March 3, 2004, both 138kV transmission lines serving the Pukele Substation had not experienced simultaneous outages, but that there is a possibility that this event could occur. The March 3, 2004 incident occurred, and therefore, accentuates the concern for the reliability of the Pukele Substation, which was described in my testimony.

Hawaiian Electric Company, Inc. • PO Box 2750 • Honolulu, HI 96840-0001

May 11, 2004

William A. Bonnet
Vice President
Government and Community Affairs

The Honorable Chairman and Members of
the Hawaii Public Utilities Commission
Kekuanaoa Building
465 South King Street, 1st Floor
Honolulu, Hawaii 96813

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2004 MAY 11 A 11: 34
PUBLIC UTILITIES
COMMISSION

Dear Commissioners:

Subject: March 3, 2004 Pukele Substation Outage

Attached is HECO's report regarding the Pukele Substation Outage on March 3, 2004. The report details what happened, HECO's efforts to restore the system and measures HECO has taken and will be taking to prevent a recurrence. Included as Appendix A is a report by Power Engineers, Inc., a mainland engineering consulting firm, which was retained to assist in the investigation.

If you have any questions, or require additional information, please call me at 543-5660 or Patsy Nanbu at 543-4702.

Sincerely,

cc: Division of Consumer Advocacy

HECO Report

March 3, 2004

Pukele Substation Outage

Dated May 11, 2004

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Executive Summary

At 7:42 a.m. on March 3, 2004, the HECO system experienced a loss of the Pukele Substation located in upper Palolo Valley. Approximately 40,000 customers in the Waikiki, Manoa, Palolo, St. Louis Heights, McCully, Moiliili, Kaimuki, Diamond Head and Kapahulu areas of urban Honolulu were affected. This represented approximately 14% of the electricity demand on Oahu that morning prior to the outage. Intensive efforts to restore power began as soon as the power was out. Service to approximately 39,000 customers was restored between 8:30 - 9:45 a.m., with the remaining 1,000 customers restored by 11:20 a.m.

The Pukele Substation receives power from two 138-kilovolt transmission lines from the Koolau Substation in Kaneohe. This voltage is converted to 46-kilovolts and distributed throughout the Pukele service area by eight sub-transmission lines.

If the Pukele Substation loses power from both 138-kilovolt transmission lines, there is no power to distribute to the customers in this area.

In non-technical terms, this is what happened:

- One 138-kilovolt transmission line was de-energized as part of on-going work to replace a structure supporting the line. This was performed by opening circuit breakers at each end of the line in Kaneohe and Palolo Valley respectively.

- When the line is de-energized, the microwave communications system continuously transmits an electronic "trip" signal between circuit breakers on both ends of the transmission line to prevent the line from being inadvertently energized. Because of a malfunction of the communications system, this "trip" signal was misrouted from the circuit breaker on the de-energized line to a circuit breaker on the transmission line still in service, causing that breaker to open, the line to be de-energized, and the outage to occur. (page 22, page 25)

The following is a non-technical summary of the events of March 3 on the HECO electrical system and of actions taken by HECO to resolve the problem. A more technical account, plus a consultant's report, follows this summary.

What Happened

As noted, two linked sets of circumstances led to the outage on March 3rd. The linkage was discovered during the investigation and could not have been immediately determined by HECO on the day of the outage.

The first circumstance was that one of the two 138-kilovolt transmission lines that feed power from the Koolau Substation to the Pukele Substation was intentionally removed from service at 6:03 a.m. by opening circuit breakers at each end and de-energizing the line as part of ongoing work to upgrade a structure that supports the line. (Page 13)

Specifically, Koolau-Pukele No. 1 transmission line was de-energized. For this maintenance period, all power was to be carried on the Koolau-Pukele No. 2 138-kilovolt transmission line, the only remaining line feeding the Pukele service area. The electric grid was placed in the same configuration the previous day, without incident, to perform the same work. (Page 13)

One of several protective features automatically initiated when the Koolau-Pukele No. 1 line was de-energized is the continuous transmission over the digital microwave communications system of electronic "trip" signals between the Pukele and Koolau substations to ensure that the circuit breakers on both ends of the line cannot be closed. This feature is designed to protect personnel and equipment while the line is de-energized, and is accepted industry practice. (Page 22)

The microwave communications system serves as the communications link between the Operations Center, the power plants, the transmission substations, and other equipment connected to the electric grid. It transmits power plant and electric grid instrumentation data, which is fed to computers to allow the electric system to be operated efficiently. (Page 17) It also provides mobile radio communications between field crews and the Operations Center.

The second circumstance that morning began at 6:52 a.m. when HECO's Operations Center began to receive alarms indicating problems with a digital link on the microwave communication system at a communications site in Moanalua.

A technician was dispatched to the communications site to assess the problem. The technician reported that the problems indicated a loss of synchronization. Loss of synchronization meant that data being transmitted was being lost or corrupted. (Page 15, 28)

An investigation determined that:

1) The loss of synchronization was due to a problem with the digital microwave communications equipment, manufactured by the Harris Corporation. Several electronic modules were found to be defective. (Page 32)

2) The loss of synchronization eventually caused the continuous electronic trip signal being transmitted for the de-energized transmission line to be momentarily misrouted into the circuit breaker for the Koolau-Pukele No. 2 transmission line, the sole remaining line feeding the Pukele service area. This misrouted signal caused a circuit breaker to trip open, de-energizing that line. (Page 28)

During the investigation it was learned that the loss of synchronization caused data to be momentarily misrouted from their assigned channels in the data stream. Instead of the continuously transmitted electronic trip signal being sent to the de-energized line, it eventually was misrouted to the in-service line. (Page 28)

This event was never before experienced on the HECO system. During HECO's investigation, it was learned that a similar situation previously occurred at the Bonneville Power Authority; however HECO was not alerted to this information. (Page 28)

Restoration

Intensive efforts to restore power began as soon as the power was out. Because the cause of the Koolau-Pukele No. 2 138-kilovolt transmission line outage was not known on the morning of March 3, and the Koolau-Pukele No. 1 line was just de-energized, the decision was made to restore the Koolau-Pukele No. 1 transmission line. Fortunately, crews were not yet at work on this transmission line, and the restoration could be completed promptly with no safety risk.

At 8:30 a.m., restoration of electric service began. Service was restored to most customers by 9:45 a.m., with the remaining customers restored by 11:20 a.m. The restoration effort was conducted in a controlled, methodical, and coordinated manner, notwithstanding the loss of communications due to the microwave system communications problems.

Action Steps

Early in the investigation, HECO contacted Power Engineers, Inc., a mainland consulting company with expertise in transmission issues, to assist HECO with the investigation.

The action steps to be taken based on the HECO and Power Engineers, Inc. investigations are detailed in the main body of this report beginning on page 31. HECO and its consultant are satisfied that once these actions are completed, another failure of the microwave communication system that results in a loss of synchronization will not de-energize a transmission line or substation.

Briefly, the short-term actions are:

a) Defective communications system modules have been replaced and have been sent to the manufacturer. The modules are under warranty, and HECO is working with the manufacturer, the Harris Corporation, to determine the specific cause of failure.

b) To prevent a recurrence of the problem, three technical solutions are being implemented in the specific communications system equipment connected to the microwave communications system that transmits the electronic trip signal. In non-technical terms, (1) the channels for the two Koolau-Pukele lines, which were adjacent, have been separated; (2) the order in which their signals were sent has been reversed; and (3) their frequencies are being changed[1]. HECO found four other instances (for a total of five) on the electric grid where this kind of incident could occur. The first two steps have already been completed for each of the five instances.

c) HECO is working with its subsidiary companies, HELCO and MECO, to determine if a similar potential problem exists on their systems, and has contacted the Kauai Island Utility Cooperative to make assistance available if they also may be affected by this situation.

Longer-term solutions include several projects that make improvements to the system:

1. Wide-Area Network (WAN) Project. The WAN project provides more options in routing data to the Operations Center compared to the current fixed routes of the digital microwave communication system's existing multiplexers. This project is planned to be in-service by June 2005. (Page 34)

2. Although the specific problems that occurred on March 3rd have been remedied, the communication problems and outage are a reminder that unplanned events can and do happen on utility systems and can lead to large-scale outages. HECO has proposed the East Oahu Transmission Line Project (EOTP) to provide needed transmission line redundancy to the Pukele

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[1] HECO expects to complete the last technical solution by the end of May.

Substation, the most heavily used substation in its system that is served by only two 138 kV lines.

With the EOTP in place, if one transmission line is de-energized for maintenance and the second transmission line is de-energized for any reason, most customers in the Pukele service area will be unaffected and the remainder will experience at most a 6-second interruption. In short, customers in the Pukele service area generally would not have been impacted by the incident that occurred on March 3.

This project has been submitted to the PUC in Docket No. 03-0417.

1. Overview

At 7:42 a.m. on March 3, 2004, the HECO system experienced a loss of the Pukele Substation. Approximately 40,000 customers in the key areas of urban Honolulu and Waikiki were affected. Intensive efforts to restore power began immediately, with restoration commencing at 8:30 a.m. Service to approximately 39,000 customers was restored between 8:30 - 9:45 a.m., with the remaining 1,000 customers restored by 11:20 a.m.

This report will walk through the sequence of events leading to the outage, the investigation of the outage by HECO and its consultant Power Engineers, Inc., follow-up actions taken, and recommendations.

2. Pukele Service Area Description

Figure 1 Pukele Service Area

The Pukele Substation primarily serves the Waikiki, Manoa, Palolo, St. Louis Heights, McCully, Moiliili, Kaimuki, Diamond Head and Kapahulu areas. The approximately 40,000 customers in this area represented 14% of the total electricity demand of Oahu that morning prior to the outage. The Pukele substation receives its power from two 138-kilovolt transmission lines from the Koolau Substation in Kaneohe. This voltage is converted to 46-kilovolts, and is distributed throughout the Pukele service area by 8 overhead and underground sub-transmission lines.

If the Pukele substation loses power to both 138-kilovolt transmission lines, there is no power to distribute to the customers in this area.

3. Chronology of Events

Table 1 Event Chronology

Time	Event
6:03am	Koolau-Pukele No. 1 138-kilovolt transmission line de-energized to support maintenance on Structure 18. Only Koolau-Pukele No. 2 138-kilovolt transmission line is providing power to the Pukele Substation
6:27am	Pukele No. 7 46-kilovolt subtransmission line de-energized for scheduled maintenance; Pukele No. 8 46-kilovolt subtransmission line in the process of being de-energized for scheduled maintenance
6:29am	Koolau No. 3 48/80 MVA transformer de-energized for maintenance (This scheduled repair had no impact on the outage or restoration of customers)
6:52am	Operations Center receives alarms indicating problems on the digital microwave communications system
7:34am	Intermittent communication failures - communications with transmission substations, power plants, and the Operations Center are erratic and no longer continuous
7:42am	138-kilovolt Breaker No. 146 at the Pukele Substation trips, de-energizing the Koolau-Pukele No. 2 138-kilovolt transmission line. Pukele Substation is without power
8:30am	Koolau-Pukele No. 1 138-kilovolt transmission line is returned to service and restoration of customers commences
9:45am	Service to most customers in the Pukele service area is restored
11:20am	Restoration of service to the remaining (1,000) customers is completed

4. Description/Explanation of Events

a. Chronology

On March 3, 2004, the conditions on HECO's system prior to the unexpected outage event were as follows:

At 6:03 a.m. the Koolau-Pukele No. 1 138-kilovolt transmission line was de-energized by opening circuit breakers 150 and 122 to support planned work (See Figure 2). The scheduled work involved the upgrading of Structure 18 on this line from a wooden pole to a new steel pole. The Pukele Substation is being powered from the remaining Koolau-Pukele No. 2 138-kilovolt transmission line.

At 6:27 a.m., the Pukele No. 7 46-kilovolt subtransmission line was de-energized for planned maintenance. The Pukele No. 8 46-kilovolt subtransmission line was in the process of being de-energized for maintenance when the outage occurred. Because power to these customers was routed to other subtransmission lines, these scheduled repairs had no impact on the outage or restoration of customers.

At 6:29 a.m. the Koolau No. 3 48/80 MVA transformer was de-energized for scheduled repairs. This scheduled repair also had no impact on the outage or restoration of customers.

The electric grid was placed in the same configuration the previous day without incident to perform the same work.

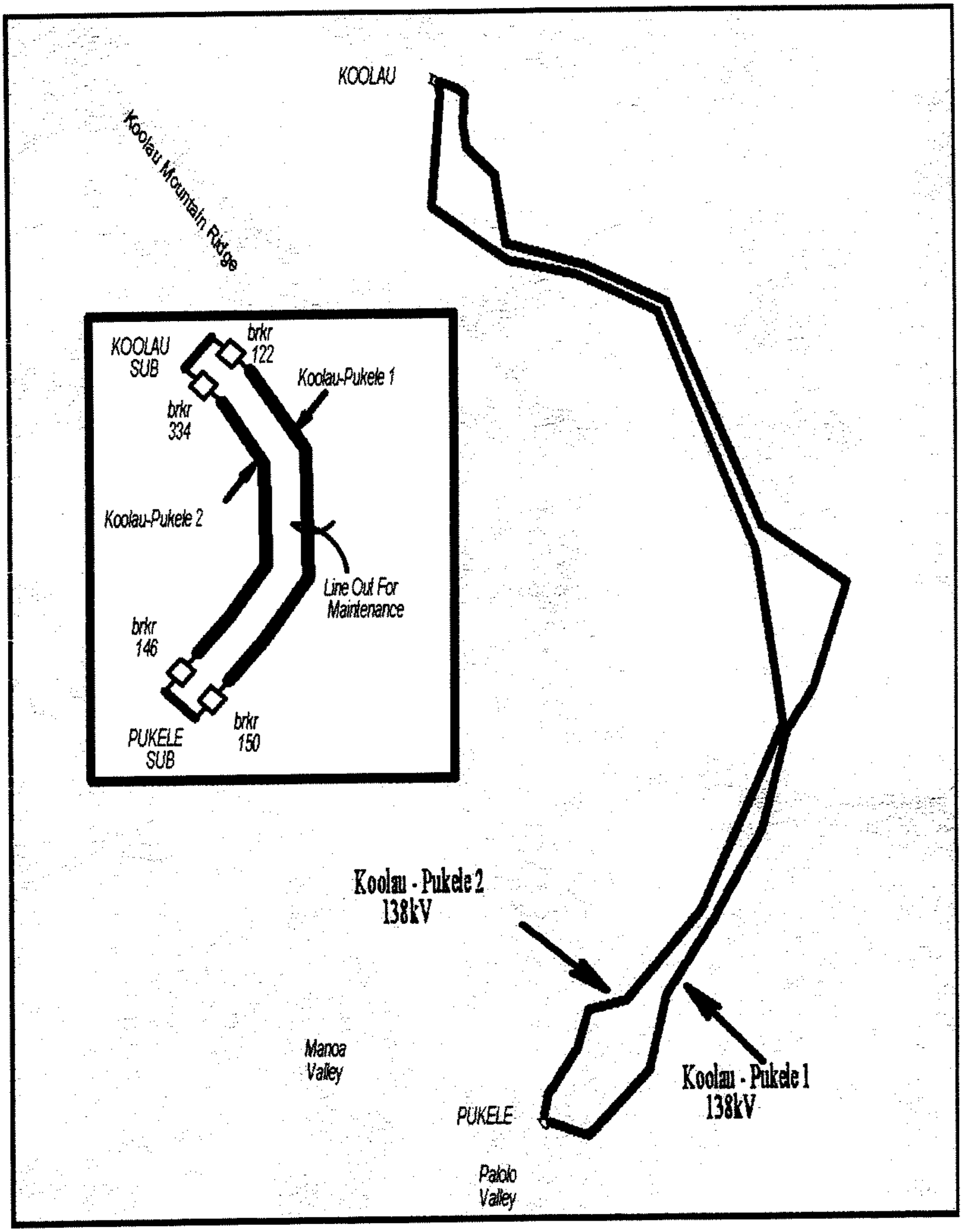

Figure 2 Koolau-Pukele 138kV Transmission Lines

At 6:52 a.m. HECO's Operations Center began receiving alarms indicating problems with a digital link on the microwave communications system at a communications site in Moanalua. A technician was dispatched to the communications site to investigate.

The microwave communications system transmits power plant and electric grid instrumentation data to the Operations Center. This data is fed to computers to allow the power plants to be efficiently dispatched. It also provides the Load Dispatcher with the ability to monitor the electric grid and remotely operate equipment on the grid. In addition, the microwave communications system transmits protective system events (short circuits, transmission line outages) and serves as the primary mobile communications between the field crews and the Operations Center. A more comprehensive explanation of the microwave communications system is provided later in this report.

At 7:34 a.m. the system began to experience communication failures that intermittently stopped the flow of instrumentation data from several transmission substations and power plants. Instead of the normal continuous communications, communications was intermittent and erratic. As a result, the ability to remotely operate the electric grid and receive and process equipment status data was hampered. Mobile voice communications became garbled.

At 7:42 a.m. the 138-kilovolt Breaker No. 146 at the Pukele Substation tripped, disconnecting the Koolau-Pukele No. 2 138-kilovolt transmission line from the Pukele Substation. The Pukele Substation was then without power. The system load that morning prior to the outage was 894 MW. The Pukele substation was delivering 126 MW or 14% of Oahu's electrical demand. Later in the day, Pukele Substation provided 176 MW of load at its peak, at 7:15 p.m.

5. Recovery Challenges

Intensive efforts to restore power began immediately. However, problems with the microwave communications system made the restoration effort more challenging. Without the ability to analyze data and to remotely operate equipment from the Operations Center, the Load Dispatcher mobilized personnel to key areas within the Pukele service area to manually operate the equipment. Power plant personnel manually adjusted the loading on the power plants to keep the system stable. Since the primary mobile communications system was ineffective, an alternate means of communications, cellular telephones, was used to communicate with field personnel.

Because the cause of the Koolau-Pukele No. 2 138-kilovolt transmission line outage was still unknown at this time, and the Koolau-Pukele No. 1 transmission line was just de-energized, the decision was made to restore the Koolau-Pukele No. 1 transmission line.

Power to the Pukele service area was restored in a controlled, methodical, and coordinated manner. At 8:30 a.m., the Koolau-Pukele No. 1 138-kilovolt transmission line was manually restored to service. Shortly afterward, the 46-kilovolt subtransmission lines were manually energized one at a time. Concurrently, between 8:45 a.m. and 9:00 a.m., technicians were able to resynchronize the communications system, restoring data flow to the Operations Center. Other remaining 12-kilovolt distribution circuits were then placed in service. By 9:45 a.m., service was restored to approximately 39,000 customers in the Pukele service area with the remaining 1,000 customers restored by 11:20 a.m.

6. Overview of the Communications and Electric Grid Protection Scheme

This overview is intended to be background information for the technical sections of the report that follows. This is a "primer" on a complex technical subject and this summary runs the risk of oversimplification. High-speed data communications and relay protection design are specialty fields within the branch of electrical engineering.

a. Communications System Overview

There are three major components to the communication systems (See Figure 4) that were affected in this incident: (1) the digital microwave communication system (manufactured by the Harris Corporation), (2) the digital multiplexers (Pulsar Technologies, Inc.), and (3) the Transfer Trip Tone Signal Interface (manufactured by RFL Electronics, Inc).

The microwave communications system provides the medium to transmit and receive information from one point in the electric grid to another. The multiplexer takes input signals from numerous sources, merges them into one high-speed data stream (for transmission through the microwave communications system). The receiving end transforms them back to their original signals and sends them to their intended devices. The multiplexers allow for the high-speed transmission of data. The Transfer Trip Tone Signal Interface uses an electronic signal to transmit protective relaying commands from one point to another (e.g., generating a signal to tell a breaker to open).

The microwave communications system serves as the communications link between the Operations Center, the power plants, the transmission substations, and other equipment connected to the electric grid. The microwave communications system transmits power plant and electric grid instrumentation data to the Operations Center. In addition, it provides the Load Dispatcher with the ability to monitor the electric grid and remotely operate equipment on the grid. It also transmits protective system events (short circuits, overload conditions, transmission line outages, etc.) and serves as the primary means of mobile communications between the field crews and the Operations Center.

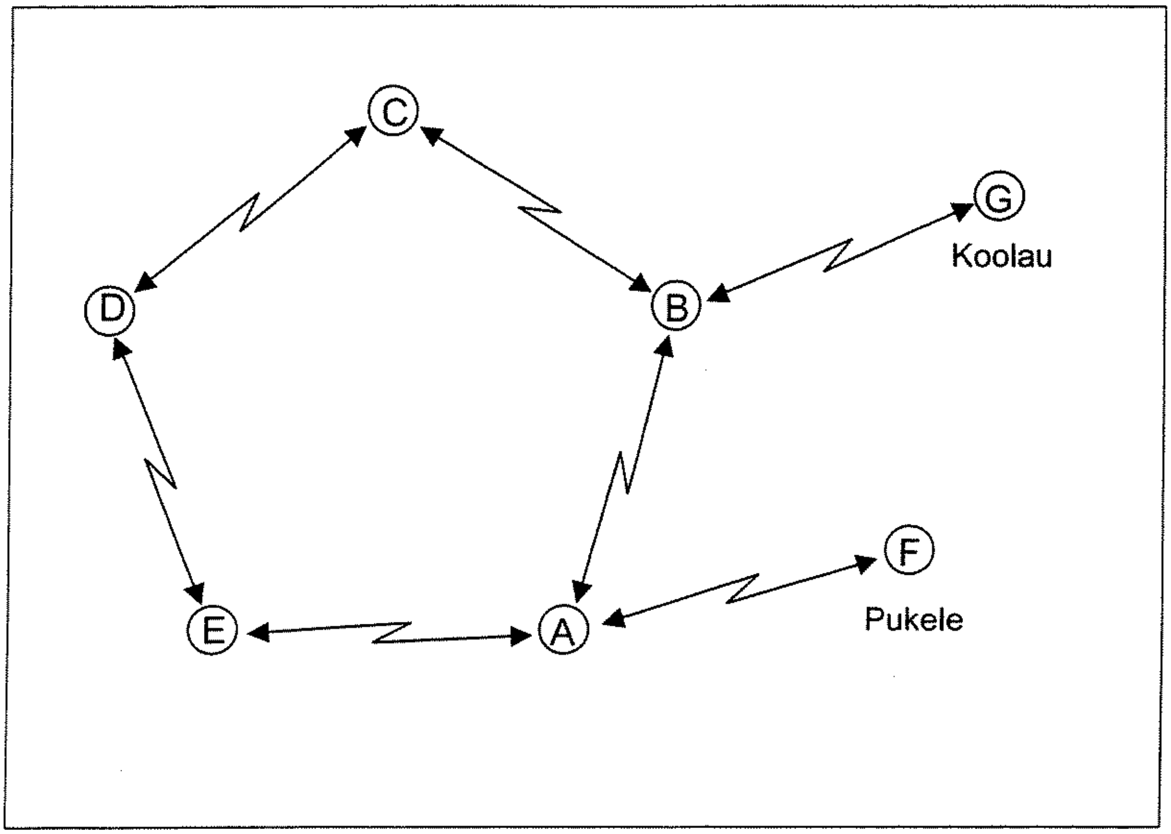

Figure 3 Sample Communications Path

The multiplexers that interface with the microwave communications system are configured in a "ring" topology with several radial legs similar to that shown on Figure 3[2]. The system is designed with several redundant features. For example, if communications flow were to travel counterclockwise along path A-B-C-D-E and a communications link failure were to occur between sites A and B, the communications would automatically switch to an alternate communications system and path; i.e., A-E-D-C-B to ensure all necessary information is communicated. Information at the radial nodes F and G would be communicated as well. This is an industry standard design.

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[2] The specific topology and equipment locations are not shown for security reasons.

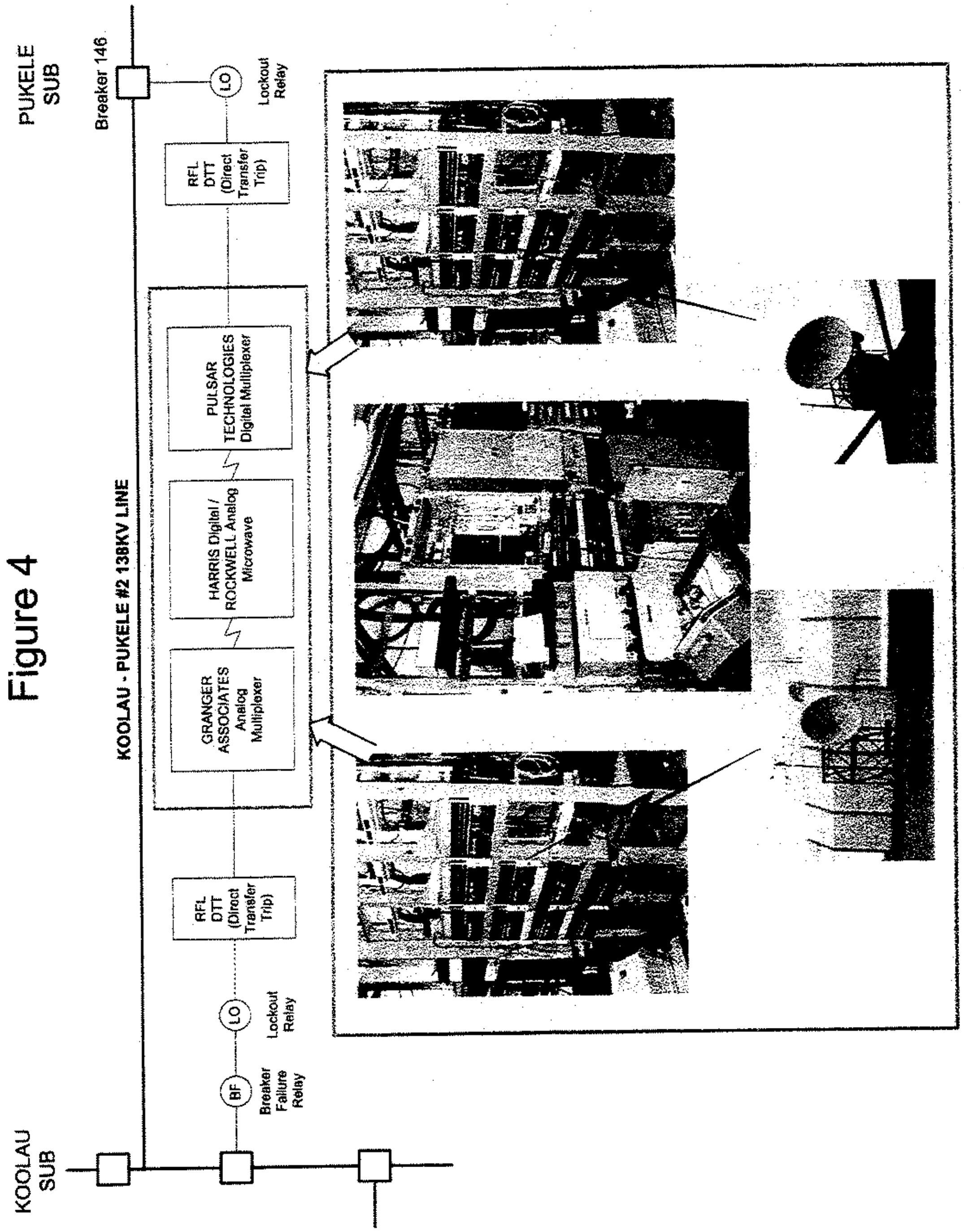


Figure 4 Basic Communications Path for the Koolau-Pukele #2 138 kV line

b. Protection Scheme Overview

The purpose of the electric grid protection scheme is to protect the safety of those personnel working on the electric grid, the public, and to protect the electric grid and equipment from damage due to a severe transient event such a lightning strike, a phase-to-phase or phase-to-ground fault, transmission line overloads, or other major disturbances. Circuit breakers are used to allow or stop current from flowing through transmission lines. The circuit breakers are activated by relays. The relays and logic circuitry used to control them are called the relay protection scheme.

HECO's relay protection scheme is industry standard in design. Using the two Koolau-Pukele 138-kilovolt transmission lines as an example, two scenarios can provide an overview on how the protection scheme is designed to work:

1. Circuit Breaker Failure Scenario

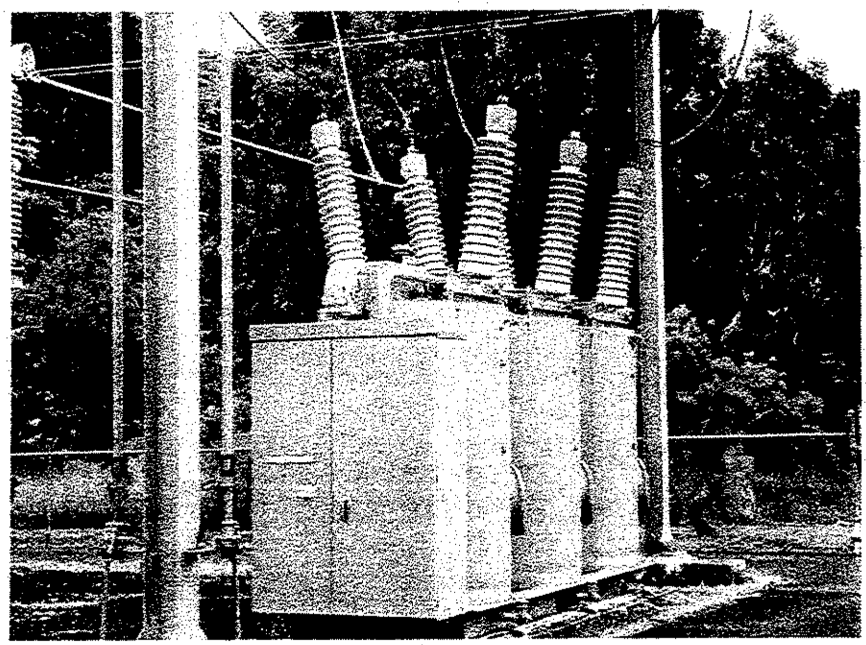
   A breaker failure condition occurs when a 138 kV breaker at a substation fails to open when it is supposed to. Circuit breakers are designed to open to prevent damage to equipment by isolating the area of the electric grid that has a problem without inadvertently shutting down the entire grid.

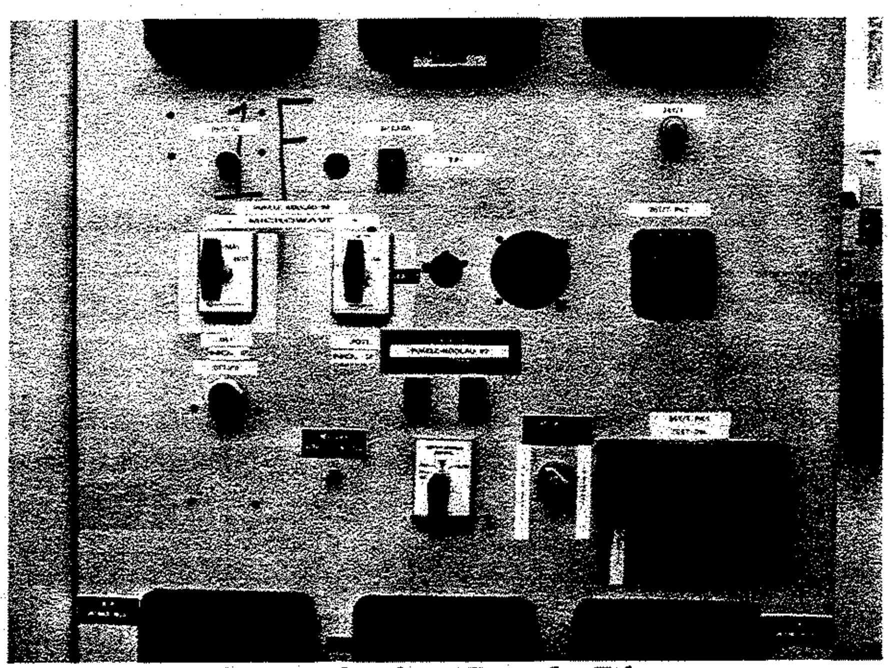
   A breaker failure relay at the Koolau Substation detects a breaker failure condition. The breaker failure relay automatically sends an electronic trip signal to the surrounding 138 kV breakers at the Koolau Substation adjacent to the failed one, directing those breakers to open. The opening of these breakers protects equipment from damage by isolating (i.e. disconnecting) sources of power feeding an electrical fault, such as 138 kV transmission lines into a substation.

   At the same time, the breaker failure relay at the Koolau Substation initiates a trip signal that is directed to the Koolau Direct Transfer Trip (DTT) device, which then sends a trip signal, via the communications system, to the Pukele Substation DTT (See Figure 4 for reference). Figure 5 is a picture of a breaker and DTT.

The breaker failure DTT is a relay scheme designed to disconnect the far end of

Breaker 146 at Pukele Substation





Relay Panel –Direct Transfer Trip

Figure 5 Relay Panel - Direct Transfer Trip Device

the transmission line in order to de-energize the line quickly. As discussed earlier, the electronic trip signal is sent from the transfer trip tone signal at Koolau to the multiplexer, and through the communications system where it is received at Pukele, routed via a multiplexer and converted back to an electronic trip signal and sent to the DTT. If the DTT recognizes the signal as a valid trip signal, it energizes the lockout relay, which in turn trips Breaker No. 146. See Figure 4 for the flow path.

The lockout relay allows a small signal current to operate the high current relay demand of the 138 kV breaker trip mechanism (See Figure 4). If no relay is used, the large current will damage the DTT electronics.

2. Manual Trip or Protective Action Trip Scenario

The Koolau-Pukele No. 1 138-kilovolt transmission line will be used as an example (refer to Figure 2). Assuming Koolau Breaker No. 122 is tripped due to a protective system action or manual intervention, the relay protection scheme uses a "fast trip" function to immediately trip the corresponding breaker at the Pukele Substation (Breaker No. 150) to de-energize the transmission line.

A Permissive Overreaching Transfer Trip (POTT) relay scheme is used. This is similar to the DTT scheme, except that the POTT scheme requires not just a trip signal, but a reason for the trip signal as well. Once Koolau Breaker No. 122 is tripped, an electronic POTT signal ("trip" signal) is sent continuously through the communications system to the Pukele Substation to fast trip Breaker No. 150 on the other side of the transmission line. This POTT signal will be continuously transmitted as long as the Koolau breaker is open. Once Pukele Breaker No. 150 is open, it also sends a continuously transmitted electronic trip signal to Koolau Breaker No. 122. In summary, electronic trip signals are being sent continuously from each circuit breaker to the corresponding circuit breaker on the other side of the transmission line. This is necessary for safety reasons. For example, if the fault condition on the transmission line is not cleared, and someone attempts to operate either breaker, the continuously transmitted POTT signal will immediately trip that breaker again. This is an accepted industry practice.

c. *Eliminating False Signals to Prevent Spurious Breaker Trips*

In order to avoid false trip signals from initiating inadvertent equipment operations (i.e. breaker trips), a "guard" signal is generated that is normally sent by the transfer trip equipment. A valid trip signal must include 100 milliseconds of a guard signal followed by at least 5 milliseconds of a valid trip signal. It is an extremely unlikely possibility that a spurious signal can duplicate the timing and frequency of the guard signal/trip signal combination. False signals are largely eliminated, and the security and reliability of the protection system is maintained.

7. Investigation

On March 3, 2004, immediately following the outage, HECO assembled a team of in-house professionals to investigate the cause of the outage. Power Engineers, Inc., a mainland engineering consulting firm, was retained to assist with the investigation. HECO transmitted information to them on March 5, and the consultants met with HECO on Monday, March 8.

The overall investigation included the following:

1. An inspection of the Koolau-Pukele No. 2 138 kV transmission line by helicopter on the morning of March 3, 2004, immediately following the outage. In the course of the flying inspection, a broken guy span was discovered on suspension structure #4 in Palolo Valley, but was quickly determined not to be the cause of the outage because of no signs of damage to the conductors.

2. An examination and testing of the control wiring that initiates the tripping operation of the Pukele Breaker No. 146 at Pukele. Hundreds of wires and connections were tested. No abnormal conditions were found.

3. A review and testing of the relay protection scheme, which tripped Breaker No. 146. No abnormal conditions were found.

4. A review of all components in the digital microwave communications system. Information was shared with vendors of the digital equipment (identified earlier) for assessment of possible causes.

5. A review of Weather Bureau reports for atmospheric conditions in the area of the Pukele Substation and the communication site in the Moanalua area where trouble with the digital microwave communication system were focused. Weather was ruled out as a likely cause.

6. A review of videotapes from the security cameras located at the Pukele Substation, and interviews of security personnel posted at the Koolau Substation on the morning of the outage. No personnel were present in either substation at the time of the outage.

8. Findings

a. Summary

Based on the investigation, two linked sets of circumstances led to the outage of March 3rd. The linkage was discovered during the investigation and could not have been immediately determined by HECO on the day of the outage.

The first circumstance was that the Koolau-Pukele No. 1 138-kilovolt transmission line was intentionally removed from service at 6:03 a.m. by opening circuit breakers at each end and de-energizing the line as part of ongoing work to upgrade a structure that supports the line. This left the remaining 138-kilovolt transmission line to carry all power to the Pukele service area. The electric grid was placed in the same configuration the previous day without incident to perform the same work.

One of several protective features automatically initiated when the Koolau-Pukele No. 1 line was de-energized is the continuous transmission of electronic "trip" signals between the Pukele and Koolau substations to ensure that the circuit breakers on both ends of the line cannot be closed[3]. This feature is designed to protect personnel and equipment while the line is de-energized. It is accepted industry practice.

The second circumstance that morning began at 6:52 a.m. when HECO's Operations Center began to receive alarms indicating problems with a digital link on the microwave communication system at a communications site in Moanalua.

A technician was dispatched to the communications site to assess the problem. The technician reported that the problems experienced indicated a loss of synchronization. Loss of synchronization meant that data being transmitted was being lost or corrupted.

During the investigation it was learned that the loss of synchronization caused data to be momentarily misrouted from its assigned channels in the data stream. Instead of the continuously transmitted electronic trip signal being sent to the de-energized line, it eventually was misrouted to the in-service line, resulting in the opening of a breaker and the outage.

b. Detailed Findings

The subsequent investigation ruled out a breaker failure trip at Koolau Substation as the cause of the outage. No breakers at Koolau Substation were tripped and no fault conditions were recorded. However, an electronic trip signal was received at Breaker No. 146 DTT at Pukele Substation and the protection scheme subsequently operated as designed.

Six situations were identified that could cause the breaker failure DTT scheme at Pukele to operate:

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[3] If an attempt is made to close either breaker, it will immediately re-open.

1. The breaker failure protective relay at Koolau Substation operates and the protection scheme operates as designed.

2. The dc (direct current) voltage relay (74 RAW) fails and trips Breaker 146 at Pukele Substation. This relay is intended to ensure there is sufficient voltage at the protective relay to initiate the trip of Breaker 146.

3. The DTT test switch at Koolau Substation is in the test position and the test function initiated. This switch is used by technicians to test the Direct Transfer Trip operation.

4. The relay scheme is incorrectly wired and does not operate as intended.

5. Spurious noise from handheld communication devices in close proximity to the communication equipment causes the equipment to malfunction. For example, a cellular phone used in close proximity to the radio equipment can introduce noise.

6. A false trip signal is transmitted over the communications system to the Pukele Substation.

Situation 1 did not occur as evidenced by no record of a breaker trip at Koolau by the Energy Management System (EMS) log or relay targets.

Situation 2 was initially thought to be a potential cause of the unexpected operation of the DTT scheme at Pukele Substation. Upon replacing the relay, it turned out that the LED indicator lamp was shorted. A bench test of the relay, witnessed by Power Engineers, Inc., indicated that despite the shorted indicator lamp, only 6 milliamps more passed through the device compared to a similar relay. It was within normal specifications. It takes approximately 1 ampere (1000 milliamps) of current to "pick up" or energize the trip coil at Pukele Substation. Situation 2 was therefore ruled out as a possibility (See Figure 6).

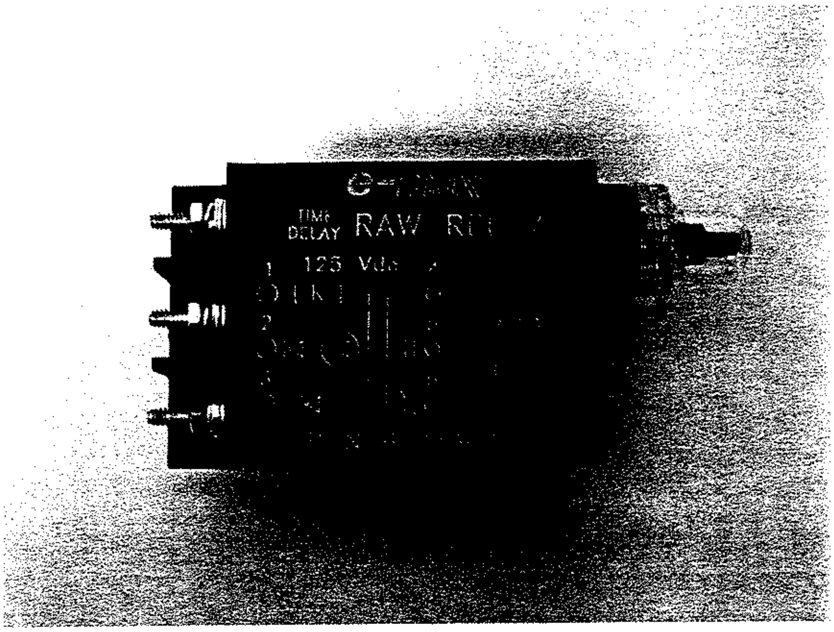

Figure 6 DC Voltage Relay 74 RAW

Situation 3 was ruled out because a person must initiate the test function at the Koolau Substation. The investigation found that no one was present in the Koolau Substation at the time of the outage.

Situation 4 was ruled out because the control wiring was checked thoroughly by HECO technicians and test engineers and confirmed by Power Engineers.

Situation 5 was ruled out as unlikely because no personnel were present in either Koolau or Pukele Substations (with the exception of the security guard at the gate of Koolau Substation) at the time of the outage. A source of noise in close proximity to the equipment is necessary for situation 5 to cause a malfunction; and additionally, the noise must mimic a precise pattern (guard signal/trip signal) in order to be interpreted as a valid signal.

After this process of elimination, the investigation focused on Situation 6 - how an inadvertent trip signal could have been sent over the communication system.

HECO's investigation discovered that a similar incident was experienced by the Bonneville Power Authority ("BPA"). Through discussions with RFL Electronics, Inc., (RFL), RFL referred HECO to a presentation on their website that was made at a telecommunications conference that described the potential problem. HECO was not aware of this problem or presentation prior to the investigation; nor was HECO notified of this problem by equipment vendors or BPA. This presentation helped HECO to understand how Situation 6 could occur. HECO provided the presentation to Power Engineers for their assessment of the likelihood of the occurrence.

Based on discussion with the digital equipment manufacturers, HECO and Power Engineers, Inc. have concluded that the following events led to an electronic trip signal being sent to the energized transmission line at Pukele Substation:

1. Breaker No. 122 was opened at Koolau Substation as part of the process to de-energize the Koolau-Pukele No. 1 138 kV transmission line for scheduled maintenance work. This initiated the POTT signal that is continuously transmitted to Breaker No. 150 at Pukele Substation as long as Breaker No. 122 is open (described on page 20).

2. The digital microwave communications system lost synchronization.

3. Because the digital microwave communications system lost synchronization, the digital multiplexers also lost synchronization. Each multiplexer contains 24 channels of data. When the multiplexer lost synchronization, data were being lost or corrupted. It was also learned that data were no longer being sent to their assigned channel (misrouted).

4. It is believed that the continuously transmitted POTT trip signal emanating from Koolau breaker No. 122, and which was assigned to multiplexer channel 14, was misrouted or "hopped" to channel 13 when synchronization was lost. Channel 13 is assigned to the Koolau-Pukele No. 2 breaker failure DTT (direct transfer trip). When the DTT received this trip signal, it immediately tripped open Breaker No. 146, removing

power from Pukele Substation. Figure 7 is a schematic diagram of the channel locations. This is the first time this type of failure was experienced on the HECO system.

Makalapa DA RTU	1	Koolau-Pukele #2 DTT	13
Makalapa SS RTU	2	Koolau-Pukele #1 POTT	14
Koolau SS RTU #1	3	Mokuleia F2	15
Koolau SS RTU #2	4	Mokuleia F1	16
Wahiawa DA RTU	5	Tripler F2	17
Wahiawa SS RTU #3	6	Tripler F1	18
Halawa SS RTU	7	Pohakapu DA RTU	19
Halawa-School POTT	8	Halawa Fault Recorder	20
Malae F2	9	Halawa-Iwilei POTT	21
Malae F1	10	Halawa-Makalapa POTT	22
Laie F2	11	Halawa Tel Ext 7xxx	23
Laie F1	12	Spare	24

Trip Signal from Koolau Substation (channels 13 and 14)

Figure 7 T-1 Bank 1 Multiplexer Channel Assignments

5. Based on discussions with Harris Corp. and Pulsar Technologies, Inc., it is possible for data to "sit" in the wrong channel for longer than 5 milliseconds while the multiplexer is processing all 24 channels and waiting for the digital microwave and multiplexer to synchronize.

6. Both transfer trip equipment for the Koolau-Pukele No. 1 line (POTT) and Koolau-Pukele No. 2 breaker failure scheme (DTT) reside on the same multiplexer. The two trip schemes are differentiated only by their location (or channel) on the multiplexer.

7. Both transfer trip equipment for the Koolau-Pukele No. 1 line (POTT) and Koolau-Pukele No. 2 breaker failure scheme (DTT) use the same frequency for their trip signals.

c. *Power Engineers, Inc. Report Summary and Recommendations*

Power Engineers, Inc. (Consultant) was requested to provide a second opinion on the cause of the outage. HECO sent outage data to the consultant for review on March 5, and met with them at HECO's offices on Monday, March 8. The consultant reviewed several drawings with HECO and jointly developed the six possible scenarios that could cause Breaker No. 146 DTT to operate (see page 26).

HECO provided the RFL Electronics, Inc. presentation made at the East Coast regional telecommunications conference, "The Effect of Digital Frame Loss on Audio Protection" to the consultant. The consultant noted that while the digital multiplexer equipment is similar to HECO's, it is not the same model as the HECO equipment. The report stated that under a loss of synchronization situation channel-hopping and subsequent inadvertent breaker tripping can occur.

The consultant noted that before HECO began migrating its analog communications system to digital, there was no possibility of channel-hopping in an all-analog system. The consultant also reported that, "(t)he possibility of frame loss and channel-hopping is not a well-known or published aspect of the digital microwave and multiplexing equipment."[4,5]

The consultant noted that HECO had similar POTT and DTT protection configurations on other transmission lines.

In the end, the consultant recommended the following:

1. Replace RFL modules for the DTT channels with different frequency groups from the POTT channels so that if channel-hopping does occur, the POTT

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[4] Consultant report, page 4.
[5] HECO began the migration from an analog to digital system for two reasons: (1) a digital microwave system has significant advantages in increased bandwidth and was becoming the industry standard; and (2) the analog system was obsolete.

permissive frequencies will be on the wrong frequencies to trip breakers on DTT.

2. Re-arrange the POTT and DTT channels such that the POTT channels precede the DTT channels to prevent a POTT channel from hopping into a DTT channel[6].

3. Wire alarm contacts for RFL output operation to the EMS system to allow more detailed analysis of events.

The status of the recommendations is discussed in the next section.

9. Immediate Actions

The following actions are being implemented to prevent the recurrence of a channel-hopping-induced breaker trip during a subsequent loss of synchronization:

1. The POTT signal for the Koolau-Pukele No. 1 138 kV transmission line was separated from the breaker failure DTT signal for the Koolau- Pukele No. 2 138 kV transmission line in the digital multiplexer channels. This work, which is consultant recommendation #2, was completed on April 6, 2004. The POTT signal for Koolau-Pukele No. 1 line precedes the breaker failure DTT signal for Koolau-Pukele No. 2 line, and the two channel assignments have been separated so they are no longer adjacent. As stated earlier, with POTT preceding DTT, any future channel-hopping event will not cause an inadvertent breaker trip. In addition, by placing the POTT signal on channel 3 and leaving the DTT signal on channel 13, this eliminates any possibility channel-hopping creating a repeat occurrence. Figure 8 shows the new channel configuration.

[6] If a DTT channel inadvertently hops into a POTT channel, no trip will occur because the POTT channel requires an additional supervisory action to generate a trip signal.

Makalapa DA RTU	1	Koolau-Pukele #2 DTT	13
Makalapa SS RTU	2	Koolau SS RTU #1	14
Koolau-Pukele #1 POTT	3	Mokuleia F2	15
Koolau SS RTU #2	4	Mokuleia F1	16
Wahiawa DA RTU	5	Tripler F2	17
Wahiawa SS RTU #3	6	Tripler F1	18
Halawa SS RTU	7	Pohakapu DA RTU	19
Halawa-School POTT	8	Halawa Fault Recorder	20
Malae F2	9	Halawa-Iwilei POTT	21
Malae F1	10	Halawa-Makalapa POTT	22
Laie F2	11	Halawa Tel Ext 7xxx	23
Laie F1	12	Spare	24

Figure 8 Modified multiplexer channel assignments

2. Work is underway to place the breaker failure DTT equipment on a different frequency from the POTT permissive signal (consultant recommendation #1). By using different frequencies, the transfer trip equipment for either POTT or DTT protection scheme will not recognize a trip signal from the other scheme should the communications system coincidentally experience a loss of synchronization and a possible misrouted trip signal to other transfer trip equipment. This is to ensure that a channel-hop event will not cause a repeat occurrence. The crystals have been received from the vendor and this work will be completed by the end of May 2004.

3. HECO is working closely with the Harris Corporation and has sent the defective digital microwave system modules to them to determine the cause of failure.

4. Four other POTT/DTT configurations have been identified (5 total) and they have all been or will be re-configured as in number 1 and 2 above.

5. HECO's equipment does not have the capability of meeting consultant recommendation #3; this requirement will be fulfilled when the time comes to upgrade/replace this equipment.

10. Follow-up Actions

HECO is also working with its subsidiary companies MECO and HELCO to determine if any similar configurations exist.

In addition, HECO placed a courtesy call to the Kauai Island Utility Cooperative to inform them of the situation and make assistance available should they need it.

11. Conclusions

A loss of synchronization of the Harris digital microwave communications equipment created a loss of synchronization of the Pulsar digital multiplexer, allowing the continuously transmitted POTT (permissive overreaching transfer trip) signal from the Koolau No. 1 138 kV Breaker No. 122 to be misrouted (channel-hopped) into the Pukele No. 2 138 kV Breaker No. 146 breaker failure DTT (direct transfer trip) channel. This immediately tripped Breaker No. 146 and resulted in the loss of power to the Pukele Substation.

This event was never before experienced on the HECO system. And the possibility of such an occurrence is very remote. Because two or more138-kilovolt transmission lines feed each major substation, a risk of outage due to a loss of synchronization exists only if all but one of the transmission lines feeding the substation is out for any reason, the remaining energized line is vulnerable to the loss of synchronization/channel-hopping scenario (of which only 5 transmission lines were identified), and the loss of synchronization actually does occur. Yet it serves to demonstrate that such an event, despite being very remote and at the time unforeseeable, can result in a large-scale outage.

The restoration effort was conducted in a controlled, methodical, and coordinated manner, notwithstanding the loss of mobile verbal communications and the loss of EMS supervisory control.

HECO will continue to vigorously pursue the immediate and follow-up actions identified above.

HECO and its consultant are satisfied that once the above actions are completed, another failure of the communications system that results in a loss of synchronization will not de-energize a transmission line or substation.

Going forward, HECO has been working on several projects that make incremental improvements to the system. Two of them are discussed here.

a. Communications

HECO is proposing a Wide-Area Network (WAN) project for RTU communications. This project, when completed, will provide a network of links and nodes that will enable addressable RTUs to communicate back to the Operations Center. This network will allow for various routing options that would permit dynamic switching of the communications paths from those RTUs to the Operations Center as compared to the fixed routes established with the existing multiplexers. The WAN project is planned to be in-service by June 2005.

An additional benefit of the RTU WAN project is to allow for a seamless transition of RTU data to the new Energy Management System (EMS) and its backup system. Currently, all RTU connections are individually "wired" to the EMS. The RTU WAN would be the new interface between the EMS and the RTUs. When the new EMS is installed, the RTU data can be redirected by software.

b. Transmission Line

Although the specific problems that occurred on March 3rd are being remedied, the communication problems and outage are a reminder that unplanned and unforeseen events can and do happen on utility systems that can lead to large-scale outages.

HECO has proposed the East Oahu Transmission Line Project (EOTP) to provide needed transmission line redundancy to the Pukele Substation, the most heavily used substation on its system that is served by only two 138 kV lines.

With the EOTP in place, if one transmission line is de-energized for maintenance and the second transmission line is de-energized for any reason, most customers in the Pukele service area will be unaffected, and some will experience at most a 6-second interruption. Customers in the Pukele service area generally would not have been impacted by the incident that occurred on March 3.

This project has been submitted to the PUC in Docket No. 03-0417.

Appendix A Power Engineers, Inc. Report

--INVESTIGATION FINDING--
POWER ENGINEERS, INC.

EXECUTIVE SUMMARY

POWER Engineers, Inc. was requested to provide a second opinion on the potential causes of the Ko'olau-Pukele Line # 2 trip on March 3, 2004 at 7:42:43 am.

On March 3, 2004, beginning at 6:03:16 am the HECO line crews and dispatch took Ko'olau-Pukele Line #1 out of service to perform line maintenance. One hour, thirty nine minutes, and 27 seconds after Line #1 was opened and cleared for maintenance Pukele Breaker 146 tripped taking Ko'olau-Pukele Line #2 out of service on an 86TT (transfer trip) operation. This resulted in an outage of the Pukele 138 kV and 46 kV substation buses with associated loads. Operations personnel indicated there was no apparent reason for the Pukele 86TT LOR (lock out relay) to have operated. Normal operation of the Pukele 86TT device is for a 50BF relay to trip the 86BF (breaker failure) at Ko'olau to operate and send a signal over the communication network to trip the Pukele 86TT and trip breaker 146.

Protective relays that could have caused the trip and associated wiring were checked at Ko'olau and Pukele. No relays were found to have operated and the wiring was according to the design prints. Tripping due to radio frequency (RF) noise from cell phones or hand held radios was considered and discounted, as personnel were not in any of the equipment locations at the time of the trip. The only RF source not ruled out completely is from Camp Smith. This RF source, although the makeup is unknown, is extremely unlikely to be the cause of the communication failures and breaker trip based on the coincidence of other factors.

The factors that coincide are:

1. The POTT uses an approved scheme that constantly keys the permissive signal when the breaker is open.
2. HECO uses RFL cards for the DTT and POTT schemes with identical frequencies.
3. The Ko'olau-Pukele Line #1 breakers were opened that morning for maintenance keying the permissive signal.
4. The digital microwave communication system lost synchronization to the point that even the voice channels were garbled.

The most likely explanation is a loss of synchronization of the digital microwave communications system that resulted in a loss of synchronization of the Pulsar Focus multiplexer allowing data from the POTT permissive channel to be put into the DTT channel. This could only happen in a situation where transmission lines are out for maintenance and power to the substation is being fed by the remaining transmission line. RFL has posted a presentation on their web site that addresses a similar problem brought to light by a major utility on the mainland. Based on our investigation and the other items ruled out, we believe channel hopping is the most probable cause of the trip.

We recommend the following to prevent this from recurring:

1. Replace RFL cards for the DTT channels with different frequency groups than the POTT so that if channel-hopping occurs the data from the POTT permissive signals will not be recognized as frequencies to trip the breakers on DTT. This is recommended system wide.
2. Rearrange the POTT and DTT channels such that the POTT channels precede the DTT channels to prevent a POTT signal hopping into a DTT channel. This is recommended system wide.
3. Wire alarm contacts for RFL output operation to the EMS system to allow more detailed analysis of events.

INVESTIGATION

HECO engineers provided the following information prior to travel:

1. One lines for Ko'olau & Pukele substations
2. Schematics & wiring diagrams for Ko'olau & Pukele substations
3. Relay Settings
4. Communication diagrams & equipment lists
5. Maintenance records for relays and RFL6745's
6. Summary of pertinent sequence of events

Monday March 8, a meeting was held in HECO's offices with HECO and POWER to discuss the Pukele substation outage event. In this meeting the data previously provided and requested additional data to include the full Sequence of Events Report and relay schematic drawings for the Pukele and Ko'olau substations were reviewed. During this meeting HECO explained that it learned of a similar incident experienced by Bonneville Power Authority ("BPA"). Through discussions with RFL Electronics, Inc., RFL referred HECO to a presentation on their website that was made at a telecommunications conference that described the potential problem. HECO was not aware of this problem or presentation prior to the outage; nor was HECO notified of this problem by equipment vendors or BPA. HECO provided the presentation to Power Engineers for their assessment of the likelihood of the occurrence. The meeting then focused on the relay and communication systems. Drawings discussed were:

- 72633 Electrical – Ko'olau-Pukele #1 138 kV DC Schematic – Ko'olau Substation
- 72636 Electrical – Ko'olau-Pukele #2 138 kV DC Schematic – Ko'olau Substation
- 72640 Electrical - Breaker Failure GCB 331, 332 & OCB 122 DC Schematic – Ko'olau Substation
- 14668 Electrical – Ko'olau #2 Line Elementary Diagram DC Circuits - Pukele 138 kV Substation
- 14670 Electrical – Ko'olau #1 Line Elementary Diagram DC Circuits - Pukele 138 kV Substation
- 75254 Ko'olau #1 138 KV Line DTT DC Elementary Diagram - Pukele 138 kV Substation

- 75255 Ko'olau #2 138 KV Line DTT DC Elementary Diagram - Pukele 138 kV Substation

Analysis of the DTT schematics for breaker failure for the Pukele and Ko'olau substations provided six possible scenarios for the Pukele Substation Ko'olau Line #2 86TT to trip:

1. The 86BF for Ko'olau-Pukele No. 2 138 kV transmission line circuit breaker located at the Ko'olau substation ("Ko'olau") tripped on breaker failure and sent the transfer trip signal over the RFL 6745 tone gear to trip the Pukele 86TT for Ko'olau Line #2. This was ruled out, as there were no indications of 50BF or 86BF relay targets or EMS alarms at Ko'olau that this operation occurred. Also, operation of the Ko'olau 86BF would trip additional Ko'olau breakers resulting in indications to operation staff and the EMS. No breakers tripped at Ko'olau.
2. The 74 RAW DC voltage relay at the Pukele substation ("Pukele") had a burned out LED. If this relay had failed and allowed enough current to pass, it could have tripped the 86TT without any other indication. This was ruled out by testing the 74 RAW relay and the 86TT relay and confirming that the 74 RAW relay would only transmit 6 milliamps while the 86TT requires 1 ampere to trip.
3. The DTT test switch at Ko'olau could have been set to the test position and the test function operated which would trip the Pukele 86TT if the DTT test switch at Pukele remained in the Normal position. This operation requires a person to switch the DTT Test Switch into the test position and then push a button to initiate the test signal to the RFL. This was ruled out, as this would require a person actively operating the equipment (not accidental contact) to operate the device. Security tapes indicated that no people were in the control houses at the time the Pukele 86TT operated. Security at Pukele consists of video cameras and motion sensors. Ko'olau has video recordings and security guards.
4. The Pukele Substation Ko'olau Line #2 86TT, Ko'olau 86BF or DTT transmitter or related devices could have been miss-wired and another operation could have asserted voltage to the relay/DTT transmitter causing it to operate. The wiring was verified at the Pukele and Ko'olau substations first by the HECO engineers and technicians and then by POWER. All wiring was correct according to the schematic diagrams.
5. Spurious noise could be introduced to the RFL transmitters/receivers by cell phone, radio or other means triggering the communications gear to operate and trip the Pukele 86TT. In most known cases this requires a person to operate a cell phone or radio in close proximity to the relays or communication gear. No one was present at either substation or in the Moanalua communications site. It was noted that Camp Smith could be a source for significant radio frequency or microwave signals of unknown strength. For a spurious signal to attach to the microwave system and result in a trip it would have to mimic a DTT signal for a frequency shift both up and down at the right frequencies for a duration of 5.4 milliseconds to affect a trip. This is extremely unlikely and was ruled out as a cause.
6. The communication system could lose "Synchronization" and divert a standing POTT permissive signal from the POTT channel to the DTT channel resulting in a trip. This seems to be the most likely possibility and is discussed in more detail below.

Communication System Channel-Hopping

It was noted that the Pukele and Ko'olau protection schemes use a "Fast Trip" function such that when a breaker opens (say Ko'olau 122), the breaker auxiliary switch 152b contacts initiate a permissive overreaching transfer trip (POTT) signal that remains set as long as the breaker is open. Thus, if a fault occurs on the line while the breaker is open, the relaying will trip on the communication based POTT scheme with no intentional delay rather than on the time delayed elements. In the case of a dead line where the POTT signal is enabled, closing into a line fault at the opposite end would also trip instantly. This is an established POTT scheme illustrated in ANSI/IEEE C37.113, 1999 section 5.2.4.3 and the Westinghouse TT-8 relay application guide. The essential part of this finding is that with breakers open for maintenance, the POTT permissive trip signal is continuously transmitted on T1-bank 1, channel 14. Reference RFLs website at www.rflelect.com for this presentation.

The EMS/Badger log and the Harris microwave log shows communication loss of synch alarms and A1 power supply alarms beginning at 6:52/6:54 am on March 3rd approximately 50 minutes before the Pukele Breaker 146 trip. A HECO communications technician was traveling to the Moanalua communications site to troubleshoot the problem when Pukele Breaker 146 tripped and found that the A1 radio transmitter assembly was bad and dropping the power supply voltage, resulting in the system switching to the hot standby A2 radio. Throughout the morning the microwave at the Moanalua site and Ward showed "Major Alarms", "Synch Loss". The T1 multiplexer switched from the primary signal path to the backup signal path and back numerous times, which causes loss of synch on the T1 multiplexer, during the morning of March 3rd. Conversations with HECO employees indicated that around this time, the voice channels began to experience significant noise and messages were garbled.

The Pukele-Ko'olau Line #1 POTT is set to T1-bank 1-channel 14 and the Ko'olau-Pukele Line #2 DTT is set to T1-bank 1-channel 13. All HECO POTT and DTT signals use the same RFL Group 9 guard and trip frequencies. RFL Group 9 transmits on two sub-channels, with both signals required to be received at the opposite end to trip. Sub-channel A has a guard frequency of 1765Hz that switches to a trip frequency of 1465Hz (guard high, trip low), while sub-channel B has a guard frequency of 2145Hz and a trip frequency of 2445Hz (guard low, trip high). The protocol is that the guard signal must be recognized at the receiving end for at least 100 milliseconds and then the trip tone received for 5.4 milliseconds to be a valid trip signal. With the DTT in normal mode, the receiving end would have had both continuous guard tones on T1-bank 1 channel 13. With the POTT scheme constantly transmitting the low and high trip tones of 1465Hz and 2445Hz respectively on T1-bank 1 channel 14, if this signal hopped into channel 13 for 5.4ms, then the DTT would recognize a valid trip signal and operate the 86TT at Pukele. The system was originally designed with analog equipment where there is no possibility of channel- hop, so that the choice at that time of using the same frequencies for all equipment reduced spare stock and maintenance. In the late 1990s, HECO began to upgrade the analog communication system with more modern digital microwave equipment to increase the capability of the communication system. The possibility of frame loss and channel-hopping is not a well-known or published aspect of the digital microwave and multiplexing equipment.

The RFL presentation called "The Effect of Digital Frame Loss on Audio Teleprotection" discusses tests performed by RFL on RFL and digital multiplexer equipment similar in nature but not identical to the HECO equipment. Their published results indicate that channel-hopping was reproduced during bench tests for loss of synch and frame misalignment. Their test consisted of 23 channels set with trip tones and one with guard tone and resulted in one trip output approximately every 20 minutes of the test. The RFL presentation indicates that the digital framing loss with serial data may result in just losing one or more bits and the remaining bits moving forward in the same increment as the lost bits. The garbled data would be unlikely to result in a valid word (tone). Loss of 8 bits would result in a complete channel-hop with possibly valid tones and all channels beyond the lost word would move forward one channel. If the multiplexer did not lose synch, the data would be replaced in approximately 125 microseconds, which is well below the 5.4ms threshold of the RFL to trip. If the multiplexer lost synch at the same time the frame misaligned by 8 bits, then the data would not be overwritten until synch was reestablished. To meet the 100ms guard and 5.4ms trip tone requirement for the RFL gear, during times when the multiplexer was losing framing, channel 13 would have to receive valid guard tones for at least 100ms and then sequentially receive valid trip tones. If a garbled word hopped into channel 13 during communication failures, then the guard tone would have to reestablish for 100ms prior to the trip tone hopping into channel 13 and remaining for 5.4ms.

Questions were presented to Harris Corporation (the digital microwave manufacture) and Pulsar Technologies, Inc. (the T1 multiplexer manufacturer).
Pulsar questions:

1. "What would be the longest time the Focus Mux would take to detect a loss of synch" - This is very hard to predict. If the loss of sync were due to lost communications, the detection of sync loss would be around 3 milliseconds (mS). If the sync loss was due to a slowly deteriorating or high BER line, then it could a few seconds to a few minutes.

2. "What is the resynchronization time for a Focus T1 multiplexer?" - 13 to 30 mS, based on a probability. The higher the one's density, (i.e. the greater the number of 1s versus 0s in the data) the faster the resync algorithm will be.

3. "When the T1 is resynchronizing, is the data in each channel frozen? No. The data is never frozen. After sync has been lost for 2.5 seconds, all 1's are written in place of the data from the loss of sync direction - this is the "squelch".

4. "If the Focus T1 multiplexer misses one frame, will the data for the next channel be put into the previous channel? (i.e. if the frame for Channel 5 is missed, will the data for Channel 6 be put into Channel 5?" - The straight answer is probably no, however, we do not have a clear understanding of how the resync algorithm in FOCUS works to find the synch bits and lock in the channels. It does seem highly unlikely that it could get temporarily stuck being exactly 8 bits off (i.e. a 1 DS0 shift) for more than a

few frames at 125 us a frame. We are defining a series of tests to investigate this, but it may take a couple of weeks more. We can update you on what is found.

Subsequent responses on these tests from Pulsar are as follows:
"Our technician has finished the following tests that I asked him to run. Basically it was with three PRIs, set with minimum security, in chassis top and bottom. One PRI sending trip and the other 2 sending guard. The two chassis in between top and bottom chassis are full of V4W modules mapped to fill up the DS1 stream. Electrical XCVRs in all chassis with APM armed. A "break" was initiated and reconnected repeatedly between the two middle chassis. He then filled up the event buffer with data. I see no false trips in the test results."

The channel-hopping is illustrated in Figure 1.

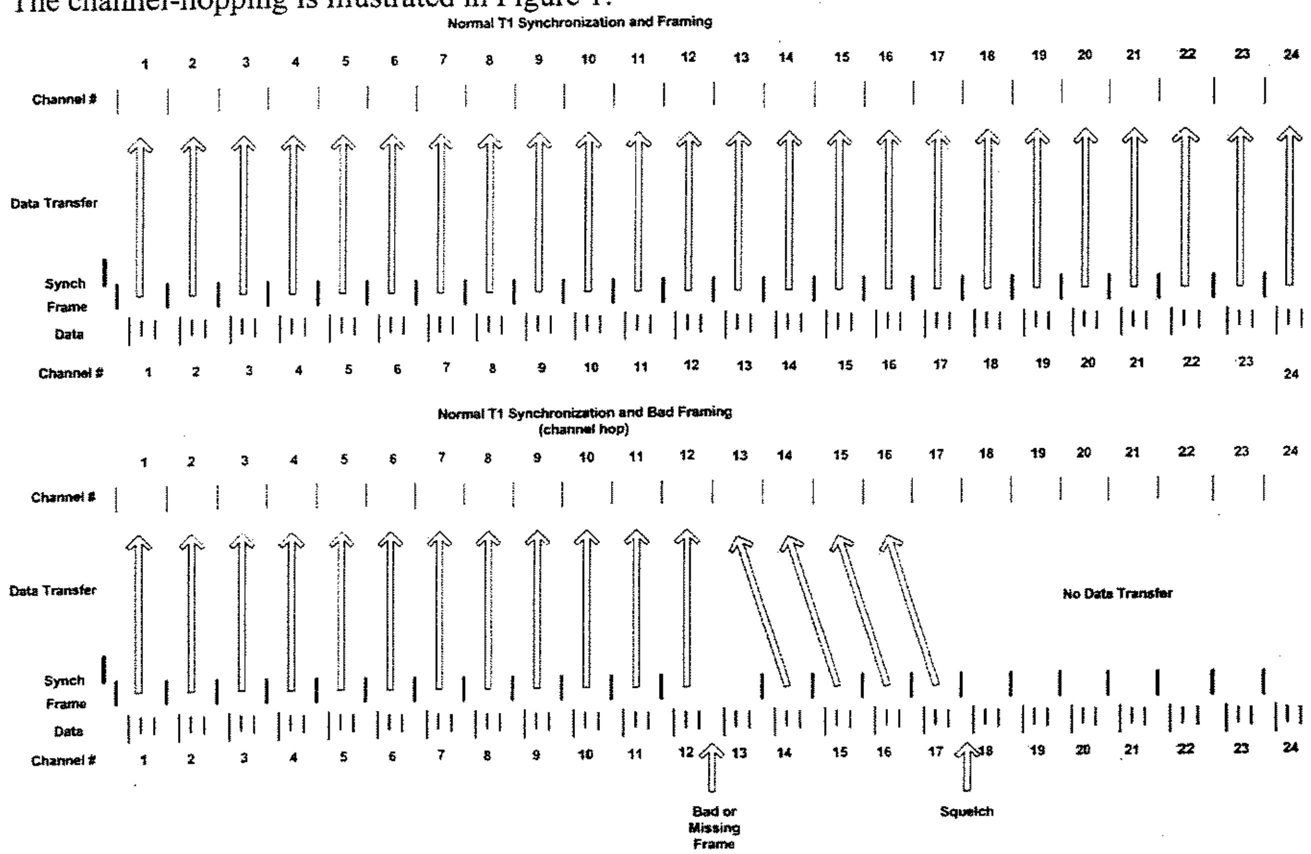

Figure 1 - T1 Framing with channel-hopping illustration.

CONCLUSIONS

Based on information from the RFL presentation, the clear indication of communication system distress and loss of synch, the POTT and DTT schemes all using the same guard and trip frequencies, the Ko'olau-Pukele Line #1 being open for maintenance, and the Line #2 DTT residing on channel 13 with the set POTT tone residing on the adjacent channel 14, we feel channel-hopping is the most probable cause of the Pukele breaker 146 86TT trip.

All other possibilities for the trip have been ruled out. The only device that could trip the Pukele 86TT without a resulting alarm on the EMS is the RFL 6745 tone gear. The RFL tests show that it is possible for digital multiplexer equipment to channel-hop and trip DTT.

If this theory proves to be correct, it requires that a breaker be open, with this type of POTT scheme setting the continuous POTT permissive signal, the POTT and DTT use the same guard/trip frequencies and the communication scheme lose synchronism and allow channel hopping. In essence, four unique items coincided to provide a trip signal to the Pukele breaker 146.

We also note that on the T1-bank 2 there are several POTT and DTT channels. If this communication event is repeated at the time one of these line breakers are open and theses lines use the same type of POTT scheme, it is possible that other 86TT trips could occur. We would like to commend the HECO staff for their professionalism in performing their analysis of this event and assisting POWER in evaluating the event.

Appendix B Glossary of Terms

Analog – Electrical signals analogous to the original sounds. A transmission mode in which data is represented by a continuously varying electrical signal.

Analog Microwave – The transmission of analog information via an electromagnetic carrier signal that oscillates at a high frequency such as 1 Gigahertz or greater.

Breaker Failure Relay – This is a protection scheme, which is intended to operate when the primary protection fails, i.e., the intended breaker fails to operate. Because some time has elapsed to let the primary protection work, the breaker failure scheme is designed to operate with no time delay.

Breaker No. 146 – This is the protective device, which interrupts power flow and separates the Koolau-Pukele No. 2 138 kV transmission line from the Pukele Substation.

Control Wiring – These are the electrical wires connecting various sensing devices such as relays, communication interfaces, etc. to devices that operate electrical equipment.

DC Voltage Relay – This is a device that monitors the trip coil that operates a circuit breaker. It is designed to pass a small amount of current through the circuit to ensure continuity of the circuit. An indicator lamp shows that the circuit is continuous and ready to operate.

Digital – Referring to communications procedures, techniques, and equipment by which information is encoded as either a binary one (1) or zero (0). The representation of information in discrete binary form. Discontinuous in time.

Digital Microwave – The transmission of digital information via an electromagnetic carrier signal that oscillates at a high frequency such as 1 Gigahertz or greater.

Digital Multiplexer – A device that merges several low-speed digital transmissions, often from various sources, into a single high-speed digital transmission, and vice-versa.

Direct Transfer Trip (DTT) – A scheme to transfer a contact closure from the local station to the remote end to disconnect the transmission line for a failed breaker condition at the local station. This is to prevent fault current from coming back through the remote end of the line.

Dispatcher – HECO personnel in the Operations Center responsible for the day-to-day operations of the electric grid.

Distribution Transformer – These are transformers at our distribution substations from which distribution circuits emanate to pick up customer load.

Load Tap Changer (LTC) - An apparatus connected to a transformer that automatically regulates the voltage on the load side of the transformer to desired levels. On the 138/46 kV transmission transformers, an LTC can be remotely controlled by the Dispatcher.

Permissive Overreaching Transfer Trip (POTT) – This relay scheme is the same in concept to the direct transfer trip scheme, except that its operation is supervised by another event (permissive). In other words, another condition must also be present as detected by a protective relay in order for the scheme to operate.

Relay Scheme – Logical strategy to protect equipment under electrical fault conditions.

Remote Terminal Unit (RTU) – These are devices at remote locations, which communicate with the electrical equipment, such as the actual switches, breakers, etc., and collect analog and status data. This information is sent back to and received by the Energy Management System (EMS) over the communications system.

Transfer Trip Tone Signal Interface – A voice-frequency carrier communications system specifically designed for the transmission of protective relaying commands from one point to another.