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

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March 30, 2007

William A. Bonnet
Vice President
Government & Community Affairs

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PUBLIC UTILITIES COMMISSION

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

Dear Commissioners:

Subject: In the Matter of the Investigation of Hawaiian Electric Company, Inc., Hawaii Electric Light Company, Inc., and Maui Electric Company, Limited, Related to the Major Power Outages of October 15-16, 2006
Docket No. 2006-0431

Pursuant to Order Nos. 23155 and 22986 in Docket No. 2006-0431, Hawaiian Electric Company, Inc., Hawaii Electric Light Company, Inc. ("HELCO") and Maui Electric Company, Limited. ("MECO") respectfully submit the following reports on the investigations of the island-wide power outages on the islands of Oahu and Maui, and the power outage on the island of Hawaii resulting from the October 15, 2006 earthquake:

1. POWER Engineers, Inc. report entitled "Investigation of 2006 Hawaii Island Power Outage",
2. POWER Engineers, Inc. report entitled "Investigation of 2006 Maui Island-Wide Power Outage",
3. POWER Engineers, Inc. report entitled "HECO, HELCO, and MECO Outage and Restoration Comparison",
4. Hawaiian Electric report entitled "Investigation of the 2006 Hawaii Island Earthquake and Widespread Outage -- Review of External Communications", and
5. Hawaiian Electric report entitled "Investigation of the 2006 Maui Earthquake and Island-Wide Outage -- Review of External Communications".

Please contact me with any questions or comments that you may have. Thank you for your consideration in this matter.

Sincerely,

William A. Bonnet
Vice President
Hawaiian Electric Company, Inc.
Hawaii Electric Light Company, Inc.
Maui Electric Company, Limited

Attachments

cc: Division of Consumer Advocacy (3 copies)

POWER Engineers

HELCO Report

March 28, 2007

HAWAII ELECTRIC LIGHT COMPANY

Investigation of 2006 Hawaii Island Power Outage
PUC Docket Number 2006-0431

PROJECT NUMBER:
111836

PROJECT CONTACT:
Ronald Beazer, P.E.
Stephan David

POWER ENGINEERS

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Executive Summary

The State of Hawaii experienced a 6.7 magnitude earthquake west of the island of Hawaii at about 0707 hours on Sunday, October 15, 2006 (epicenter). This was the strongest earthquake recorded in Hawaii in 23 years. According to the Hawaii Volcano Observatory (HVO), a second earthquake (6.0 magnitude) occurred approximately seven minutes later. Associated power system events led to island-wide blackouts for Hawaiian Electric Company, Inc. (HECO) on Oahu and Maui Electric Company, Ltd. (MECO) on Maui, although there was little apparent seismic damage to the electric systems on either island. Hawaii Electric Light Company, Inc. (HELCO) on the island of Hawaii maintained partial service with an isolated section, or "island" of generation and customer load on the east side of the island of Hawaii.

On the island of Hawaii, all transmission lines and distribution feeders were closed in by 1245 hours (5.6 hour outage), with the exception of those where the circuits or substations required repairs prior to restoring service. HELCO had restored service to the remaining customers by 2300 hours on October 15.

POWER Engineers, Inc. (POWER) was retained to investigate the causes of the outage on the island of Hawaii and provide professional opinions on the reasonableness of the responses of the HELCO staff during the event and during power restoration. POWER's principal investigators, experts in power delivery systems and generation plant design and operation, traveled to Hawaii on January 10-12, 2007 to discuss the events with the HELCO staff, conduct field visits and gather information relevant to the events of the power outage and restoration on Hawaii. Additional information was gathered via telephone discussions, through follow up information requests, analysis of system drawings, review of relevant Company logs and records, statements of personnel, and other applicable system documentation.

In summary, we find:

1. The HELCO and Independent Power Producer (IPP) power plants, Kanoelehua Operations Control Center (KOCC) and transmission system were properly configured, dispatched and staffed for normal operations on the morning of Sunday October 15, 2006 at 0700 hours.

2. In POWER's opinion, the HELCO personnel reacted to the circumstances in a reasonable, responsible and professional manner. They applied training and experience in reacting properly to the changing system conditions based on the system configuration and followed established HELCO operating practices to prevent an island-wide blackout and restore power as quickly as practical to the areas that were out of service.

3. The separation of the transmission system from Kealia in South Kona to Pepeekeo on the Hamakua coast was primarily the result of the earthquake triggering auxiliary relays in the transmission protection systems due to seismic shaking. These lines were quickly closed back in by the System Operator using the Supervisory Control and Data Acquisition (SCADA) system following the stabilization of the remaining energized portion of the power system.

4. The manual trip of Puna Steam Unit by the control operator was reasonable and prudent according to HELCO's established operating practices to prevent damage to the machine and risk potentially extensive down time for repairs. Following the unit trip the boiler steam pressure was preserved to minimize the restart time when the system had stabilized.

5. The automatic generator vibration trips of the two Hamakua Energy Partners (HEP) combustion turbines (CTs) were valid to protect the units as the minimum mechanical clearances were exceeded. When this occurs, the machine is in danger of sustaining damage, even if the source of the problem is external shaking.

6. The trip of the Hill 5 boiler is thought to be related to the earthquake but we have not been able to positively identify a cause for the fuel oil trip. Hill 6 had earthquake caused trips of the boiler feed-water pumps from liquid level switches on the deaerator level alarm, but the operators were aware of this possibility and quickly reset the pumps. The boiler feedwater pump trips did not result in the trip of the Hill 6 turbine.

7. The superheated steam leak on Hill 6 that required the unit to be tripped is believed to have been caused by high pressure steam transients due to the extreme system frequencies following the loss of transmission and load during the earthquake.

8. The under frequency load shed scheme operated as designed and prevented the east Hawaii power system from collapsing when the Puna Steam, Hill 5 and Hill 6 generators dropped off line. The System Operator made it a priority to restore portions of the under frequency load shed scheme which again operated later for under frequency when Hamakua Energy Partners Combustion Turbine 1 (HEP CT-1) and the associated steam unit tripped offline again at 1009 hours.

9. Activation of eight transformer sudden pressure protection schemes which tripped the transformers, and opening of transformer primary fuses at 15 substations that were directly associated with the seismic activity prolonged system restoration due to the need for HELCO personnel to travel to the affected substations and manually reset the equipment prior to re-

energizing. This prevented the System Operator from remotely starting diesel generators and CT-5 at Keahole and restoring load at the other substations until field personnel completed equipment inspections and reset the lockout relays.

10. Communications internal to HELCO and with the Civil Defense agencies through the Emergency Operation Center worked very well. The microwave, VHF and UHF communication system operated properly. The only indication of a failure of the internal communication system was with the paging/text messaging system which is increasing in importance, but on the day of October 15th did not pose a hindrance or delay in HELCO's ability to respond to the partial outage and efforts to restore the system. This paging/text messaging system presently depends on equipment routed over Maui to HECO equipment on Oahu and has potential failure modes unrelated to the status of the system on Hawaii.

Discussion of Findings

The Hawaii Public Utilities Commission issued PUC Order No. 22986, Docket No. 2006-0431 ("PUC Order") requiring an examination of whether HECO, HELCO and MECO acted reasonably and in the public interest prior to and during the power outages. The PUC Order, Section II.C Preliminary Issues, page 8 and page 9, established the scope for this investigation.[1] This report addresses the following issues with respect to HELCO.

1. *Aside from the earthquake, are there any underlying causes that contributed or may have contributed to the power outages?*

[1] We understand that the preliminary issues were adopted as the issues for Docket No. 2006-0431 by Order No. 23155 (filed December 21, 2006).

We conclude that the main underlying cause of the outage on the western side of the island was the earthquake acting on transmission protection scheme auxiliary relays that tripped the transmission lines and separated portions of the system.

The Hill 6 power plants had equipment trips associated with liquid level switches that were activated by the earthquake, but these did not result in a unit trip.

HEP power plant, generating 58 MW at the time, was islanded by the earthquake-caused transmission line trips, but also had both combustion turbines tripped by its vibration protection due to the earthquake action. These were valid trips to protect the generators.

In addition, there were eight substation transformers where the sudden pressure protection scheme activated lockout relays and 15 substations where transformer primary fuses opened due to the earthquake action. These events required HELCO personnel to travel to the substations, inspect the equipment for damage, reset the relays, and reconnect the fuses in order to enable the System Operator to complete the restoration.

2. *Were the activities and performance of the HECO Companies prior to and during the power outages reasonable and in the public interest? Specifically, were the power restoration processes and communication regarding the outages reasonable and timely under the circumstances?*

The actions of the HELCO staff were reasonable and in the best interests of the public, and amounted to a good level of performance under the circumstances. In POWER's opinion, the HELCO personnel reacted to the circumstances in a reasonable, responsible and professional manner. The system operations and power plant staff applied their training and experience in reacting immediately and properly to the changing system conditions to prevent an island-wide blackout, protect generation plant equipment, and restore power as quickly as practical. We have considered SCADA reports for the transmission system, load shedding scheme settings, HELCO's breaker trip analysis, relay event reports and personnel interviews following the earthquake on the morning of October 15. We also reviewed statements of power plant operators and conducted direct interviews of various HELCO personnel. In HELCO's case, we have not identified any instance for which we would offer an alternative action. We are not aware of any case where actions could be described as imprudent, or likely to cause injury or damage. There can be no doubt that the operating staff, especially in the KOCC and power plants, during and immediately after the earthquake at 0708 hours on October 15th, experienced conditions outside their normal operations experience. The situation was complicated and confused by the plethora of alarm indications, the transmission system tripping open, transformer protective devices operating, generation tripping, power stabilization of the remaining energized grid and generation and the subsequent need to quickly restore the system. The HELCO personnel acted professionally throughout the event and restoration applying their training and experience to their assigned tasks during a distinctly extraordinary event. The system restoration plan developed by the operations staff was prioritized, reasonable and well executed. The pace of the restoration was very aggressive and well executed where the system could be remotely closed to restore the transmission to generation plants and load centers. System integrity assessment, identification of damage, and repair were expedited as much as possible, considering the staffing assignments and the initial road closures, to safely restore service to all customers as quickly as possible.

Communications internal to HELCO, with the IPP generation plants, and with the Civil Defense agencies through the Emergency Operation Center (EOC) worked very well.

3. *Could the island-wide power outages on Oahu and Maui have been avoided? What are the necessary steps to minimize and improve the response to such occurrences in the future?*

With respect to Hawaii, an island-wide outage was avoided through the separation of the transmission system, the ability of the system to quickly start and connect generation, the quick actions of the System Operator to maximize the connected generation, and operation of the load shed scheme when Puna Steam, Hill 5 and Hill 6 went off-line. HELCO has several systems in place that allow the System Operator to take very fast action in the event of loss of generation and they have a very extensive under frequency load shed scheme, which provides significant flexibility to survive these types of events.

Recommendations

We offer the following recommendations to prevent miss-operation of equipment and keep the system operation in the control of the System Operator and the designed under frequency protection schemes.

The detailed recommendations from Section 5 are summarized below.

1. Evaluate the transmission relaying equipment, mounting methods, and operational schemes related to the employment of ABB, Style AR auxiliary relays to provide relay protection schemes that are less likely to miss-operate during seismic events.

2. Investigate and evaluate the likely miss-operation of the Qualitrol Fault Pressure sensors with magnetic target relays protective equipment installed on HELCO transformers. Determine appropriate sensor/relay replacements or scheme changes that reduce the likelihood of the tripping of substation and generator step-up transformers due to miss-operation during seismic events.

3. Assess the transformer primary fuse holders to determine whether there is another model or changes to its mounting and configuration to make fuses and their holders less susceptible to shaking open during earthquakes.

4. Assess application of mercury liquid level switches on the deaerator level alarms, used in Hill 6, and determine the appropriate equipment to provide elements that are less susceptible to operation due to external shaking.

5. Assess the internal HELCO communications for paging/text messaging to determine potential failure modes and appropriate solutions.

Introduction

The State of Hawaii experienced a 6.7 magnitude earthquake west of the island of Hawaii at about 0707 hours on Sunday, October 15, 2006 (epicenter). This was the strongest earthquake recorded in Hawaii in 23 years. According to the Hawaii Volcano Observatory, a second earthquake (6.0 magnitude) occurred approximately seven minutes later. Associated power system events led to island-wide blackouts for Hawaiian Electric Company, Inc. (HECO) on Oahu and Maui Electric Company, Ltd. (MECO) on Maui, although there was little apparent seismic damage to the electric systems on either island. Hawaii Electric Light Company, Inc. (HELCO) on the island of Hawaii maintained partial service with an isolated section, or "island" of generation and customer load in the east Hawaii area.

HELCO had restored service to the majority of its customers by 1245 hours with the remaining customers restored by 2300 hours on October 15.

POWER Engineers, Inc. (POWER) was retained to investigate the causes of the partial outage on Hawaii and provide professional opinions on the reasonableness of the responses of the HELCO staff during the event and during power restoration. POWER's principal investigators, experts in power delivery systems and generation plant design and operation, traveled to Hawaii on January 10-12, 2007 to discuss the events with the HELCO staff, conduct field visits and gather information relevant to the events of the power outage and restoration on Hawaii. Additional information was gathered via discussions over the phone, through follow up information requests, analysis of system drawings, review of relevant Company logs and records, statements of personnel, and other applicable system documentation.

The Hawaii Public Utilities Commission issued PUC Order No. 22986, Docket No. 2006-0431 ("PUC Order") requiring an examination of whether Hawaiian Electric Company, Inc. (HECO), Hawaii Electric Light Company, Inc. (HELCO) and Maui Electric Company, Ltd. (MECO) (collectively "the HECO Companies") acted reasonably and in the public interest prior to and during the power outages. The PUC Order, Section II.C Preliminary Issues, pages 8 and 9, established the scope for this investigation.

The PUC Order identified the following investigation subjects: [2]

1. Aside from the earthquake, are there any underlying causes that contributed or may have contributed to the power outages?

2. Were the activities and performance of the HECO Companies prior to and during the power outages reasonable and in the public interest? Specifically, were the power restoration processes and communication regarding the outages reasonable and timely under the circumstances?

3. Could the island-wide power outages on Oahu and Maui have been avoided? What are the necessary steps to minimize and improve the response to such occurrences in the future?

4. What penalties, if any, should be imposed on the HECO companies?[3]

[2] We understand that these four issues were adopted in Order No. 23155 (filed December 21, 2006) in Docket No. 2006-0431.
[3] This report does not address this subject.

In addition, a reference under II.A Discussions, at the bottom of page 7 states: "*... there may be some benefits to being able to compare the different utility systems on each of the three affected islands. These differences can and should be explained in the context of the outages and the varying restoration times.*" The comparison is presented in the HECO, HELCO, MECO Outage and Restoration Comparison report being submitted concurrently to the PUC.

From the PUC Order, HELCO established the main statement of work for POWER Engineers to investigate and provide expert opinions with respect to the partial blackout and restoration on Hawaii. POWER's investigation focused on five primary topic areas for the HELCO transmission system, dispatch center and power plants.

These five primary topic areas are:

- System configuration prior to the event, to include operating procedures and prior training relevant to the event.
- Transmission system, dispatch center and power plant operator actions and automatic protection system action during the interval between the time when the earthquake seismic waves reached Hawaii and the onset of the partial system blackout.
- Restoration of the power grid from the time the Hilo system stabilized until restoration of service to all customers on October 15.
- Comparison of the root causes and restoration times of the HECO, HELCO and MECO outages.
- Assessment of the HELCO internal communications.

2 Sequence of Events

2.1 Background

Transmission and Distribution System

The HELCO transmission and distribution system consists of twenty 69 kV transmission substations and fifty-four distribution substations, twenty-eight 69 kV transmission lines, six 34 kV sub-transmission lines, and 126 distribution feeder circuits. The majority of 69 kV and 34 kV circuits are interconnected with redundant circuits that provide multiple options for supplying power to the distribution substations to increase reliability. One of the 69 kV and one of the 34 kV circuits are in a radial configuration without redundant circuits that provide backup sources of power. These 69 kV and 34 kV circuits can be remotely operated by SCADA control by the dispatch center operator. HELCO has an extensive automatic under frequency load shed (UFLS) scheme with 9 steps that would shed an estimated 90 MW during a morning peak.

Operations

HELCO typically operates with a minimum "regulating reserve" – up and down - of approximately 6-7 MW. This means that they have generators on line and running with a total capacity to produce approximately 6-7 MW more than the load in order to absorb typical load fluctuations. The regulating reserve may differ from the 6-7 MW norm under conditions of high as-available energy production, periods of load ramping up or down, or special dispatch considerations. Generators are brought on line (or taken off line) in preparation for the expected load variations throughout the day and to maintain the regulating reserve. This operating philosophy is perfectly reasonable for a relatively small electrical system like that at HELCO with relatively high energy costs, as this strategy reduces energy costs incurred by running more generation at lower efficiency levels to provide larger reserves. It is noted that the system is therefore not operated with a "spinning reserve" sufficient to cover the loss of the largest single generating unit, which is generally the operating philosophy on larger electrical systems such as the HECO system on Oahu. Instead, HELCO relies on a combination of fast start diesel engines and underfrequency load shedding to stabilize the system following the loss of the largest unit. Approximately 276 MW of firm generating capacity is currently installed on the island of Hawaii, with an additional 29 MW of wind and hydro power providing as-available energy. Of the 276 MW, 186 MW is owned and operated by HELCO and 90 MW by Independent Power Producers (IPPs). The HELCO and IPP plant capacities are summarized in Table 1.

The KOCC contains System Operations and the dispatch center. The dispatch center has a large wall display and computer screens to show the status of circuit breakers, transmission lines and generators and is staffed by the on-duty System Operator (SO). This system also has an alarm screen that scrolls up when alarms are received. The Energy Management System (EMS) has an Automatic Generation Control (AGC) function which continuously controls the dispatch of a subset of the online generators and displays this information on the wall screen and computer monitors. Only units that are on AGC participate in load following or frequency regulation. Generating units are brought on-line and taken off-line daily according to changing load requirements. Generator designations, capacities and loading on October 15, 2006 just prior to the earthquake are provided in Table 1. The dispatch center has emergency manual load shed which appears as a button on the monitors and wall display screen that allows the System Operator to quickly shed additional load with a single action sequence. This load shed was designed specifically to correct undervoltage conditions in the North Kona/South Kohala area. HELCO also has two "All-Start" buttons which fast start all of the dispersed diesel generators. One button is for on-peak and includes all the diesel generators including Keahole; the off-peak button excludes Keahole due to operational constraints that prevent operation of Keahole diesels between 10 pm and 7 am. For the time of the earthquake, the on-peak button was used and

Keahole diesels were included in the start sequence, although they could not start because they were isolated by the transmission and generator step up transformer relay trips. The four dispersed diesel units are capable of starting within 30 seconds and synchronizing to the system. The nine EMD units take approximately 2.5 minutes to start, warm up and synchronize to the system. They load at a nominal ramp rate of 2 MW per minute, and thus they can be at full load in approximately 4 minutes from startup. HELCO has three "baseyards" located at Kanoelehua, Waimea and Kona that act as staging locations for transmission and distribution service crews and materials.

Relevant Training

HELCO trains operators in advance so that they are prepared for at least one promotion, and at times more, as vacancies are created at the top of the Line of Progression. This ensures HELCO has qualified personnel to fill the vacancies. The qualification training includes doubling up with a qualified operator for a period of 4 weeks followed by solo operations under supervision for 1 month to qualify for the position.

There is a training program for the entry-level operator trainees that includes system theory with classroom modules. This operator trainee program is more lengthy than qualification training for other advancements in the line of progression. The trainee classroom modules are followed by practical tests and inquiries by the shift supervisor, with hands-on experience, to ensure that the operator understands the systems. Then, as with subsequent qualification training, there is a period of double-up training, followed by the on-shift period. For a new operator trainee, the time involved is 4 weeks for the operator book training, 4 weeks double-up training, and 4 weeks on-shift under supervision – but can vary with position and the skills and experience of the individual. This period can also be shortened at time if extra supervision is on shift. For qualification training for promotion to subsequent position, the training is 4 weeks double-up, 4 weeks on-shift. The supervisor on each shift is responsible to oversee and follow up with the training. The supervisor is to go over the training checklists with the operator trainee to assure that the trainee understands the equipment, and its operation as it pertains to the operation of the plant and its function. Training is provided with any changes or upgrades to equipment within the power plant. The Hilo operator line of progression defines the promotion of operators as advancing from boiler operator, to combustion turbine operator, to turbine control operator, to system operator. Thus, a System Operator has previously qualified and worked as an operator at the Hilo side power plants. The Keahole power plant is not included in the line of progression.

2.2 System Conditions at 7:07 AM Sunday October 15th

On Sunday October 15, prior to the earthquakes, the 69 kV transmission and 34 kV sub-transmission systems were in their normal configuration with all lines in service. No transmission maintenance outages were scheduled for the day. The generation commitments for a Sunday morning were normal. Typically, the HELCO base load generation is located on the eastern side of the island and as load increases, units are started at Keahole on the west side of the island. The capacity of HELCO plant in operation immediately before the earthquake was approximately 136 MW, and the system load was 126 MW. The power plant unit status from the EMS archive is provided in Table 1.

The dispatch center was properly staffed according to HELCO operating procedures. The energy management system (EMS) archive indicated a regulating reserve of 10.3 MW. The System Operator was conducting routine monitoring of the system conditions and coordinating the startup schedule of generation, with the operator at Shipman 3 preparing to bring the unit on-line as demand for power began to increase.

Power plant staffing was normal for a Sunday. The personnel were conducting their normal routines of monitoring the plant conditions.

Table 1: Generation Status 0700 Hours October 15, 2006

HELCO Plant	Unit	Fuel Type	Type	Operation	Capability (MW)	Service Date	Status	Output (MW)	Reserve (MW)
Shipman	3	No. 6 Fuel Oil	Steam	Cycling	7.5	1955	Starting	0.0	0.0
Shipman	4	No. 6 Fuel Oil	Steam	Cycling	7.5	1958	Out-Maint.	0.0	0.0
Puna		No. 6 Fuel Oil	Steam	Baseload	15.5	1970	On-AGC	9.9	5.6
Puna	CT-3	No. 2 Diesel	CT	Cycling	20.8	1992	Off	0.0	0.0
Hill	5	No. 6 Fuel Oil	Steam	Baseload	14.1	1965	On-AGC	10.5	3.6
Hill	6	No. 6 Fuel Oil	Steam	Baseload	21.4	1974	On-AGC	20.3	1.1
Kanoelehua	11	No. 2 Diesel	ICE	Peaking	2.0	1962	Off	0.0	0.0
Kanoelehua	15	No. 2 Diesel	ICE	Peaking	2.8	1972	Off	0.0	0.0
Kanoelehua	16	No. 2 Diesel	ICE	Peaking	2.8	1972	Off	0.0	0.0
Kanoelehua	17	No. 2 Diesel	ICE	Peaking	2.8	1973	Off	0.0	0.0
Kanoelehua	CT-1	No. 2 Diesel	CT	Peaking	11.5	1962	Off	0.0	0.0
Waimea	12	No. 2 Diesel	ICE	Peaking	2.8	1970	Off	0.0	0.0
Waimea	13	No. 2 Diesel	ICE	Peaking	2.8	1972	Off	0.0	0.0
Waimea	14	No. 2 Diesel	ICE	Peaking	2.8	1972	Off	0.0	0.0
Keahole	21	No. 2 Diesel	ICE	Peaking	2.8	1983	Off	0.0	0.0
Keahole	22	No. 2 Diesel	ICE	Peaking	2.8	1983	Off	0.0	0.0
Keahole	23	No. 2 Diesel	ICE	Peaking	2.8	1987	Off	0.0	0.0
Keahole	CT-2	No. 2 Diesel	CT	Cycling	13.0	1989	Out-Maint.	0.0	0.0
Keahole	CT-4	No. 2 Diesel	CT	Cycling	22.0	2004	Off	0.0	0.0
Keahole	CT-5	No. 2 Diesel	CT	Cycling	22.0	2004	Off	0.0	0.0
Panaewa	24	No. 2 Diesel	ICE	Peaking	1.0	1997	Off	0.0	0.0
Ouli	25	No. 2 Diesel	ICE	Peaking	1.0	1997	Off	0.0	0.0
Kapua	26	No. 2 Diesel	ICE	Peaking	1.0	1997	Off	0.0	0.0
Punaluu	27	No. 2 Diesel	ICE	Peaking	1.0	1997	Off	0.0	0.0
HELCO TOTAL FIRM GENERATION					186.1			40.7	10.3

Table 1: Generation Status 0700 Hours October 15, 2006, Continued

FIRM CONTRACT CAPACITY									
HEP		Naphtha	Dual Train Combined-Cycle	Baseload	60.0	1999	On	58.0	0.0
PGV		Geothermal	Geothermal steam	Baseload	30.0	1986	On	21.4	0.0
TOTAL FIRM CONTRACT CAPACITY					90.0				
TOTAL FIRM GENERATING CAPABILITY					276.1				
AS-AVAILABLE GENERATION									
HRD			Wind Turbine	As-avail	10.6	2006	Off	0.0	0.0
Wailuku River			Run-of-river hydro	As-avail	12.1	1993	On	1.8	0.0
Lalamilo wind			Wind Turbine	As-avail	2.3	1986	Off	0.0	0.0
Puueo Hydro No. 1			Run-of-river hydro	As-avail	2.5	2005	On	2.4	0.0
Puueo Hydro No. 2			Run-of-river hydro	As-avail	0.5	1918	On	0.3	0.0
Waiau Hydro No. 1			Run-of-river hydro	As-avail	0.8	1921	On	0.7	0.0
Waiau Hydro No. 2			Run-of-river hydro	As-avail	0.4	1928	On	0.4	0.0
					29.0				
Total Generation Capacity, Output and Reserve					305			**125.7**	**10.3**

2.3 Sequence of Events

2.3.1 Sequence of Events Review

We have reviewed the sequence of events from just before the earthquake to the outage as developed in the *Hawaii Electric Light Company, Inc. October 15, 2006 Earthquake Incident Report*, March 14, 2007.

This report was reviewed against information from the EMS, supervisory control and data acquisition (SCADA) reports, and relay event reports. This sequence of events coincides with the information displayed in the following figures. Figure 1 shows the system generation and frequency on the HELCO system from the time of the earthquake until 0800 hours when the frequency stabilized. Figures 2 shows the megawatt output of the separate generating units and the system frequency, with the timing of significant events, from 07:07:00 to 07:21:00 to provide an expanded view of the generator operation events.

The EMS, SCADA, and relays are continuously synchronized to the same clock so time stamps correlate between devices. Time stamps for the sequence of events determined below are primarily derived from the EMS and SCADA reports which are recorded in two second intervals. All times used in this report are based on the 2400 hour time clock.

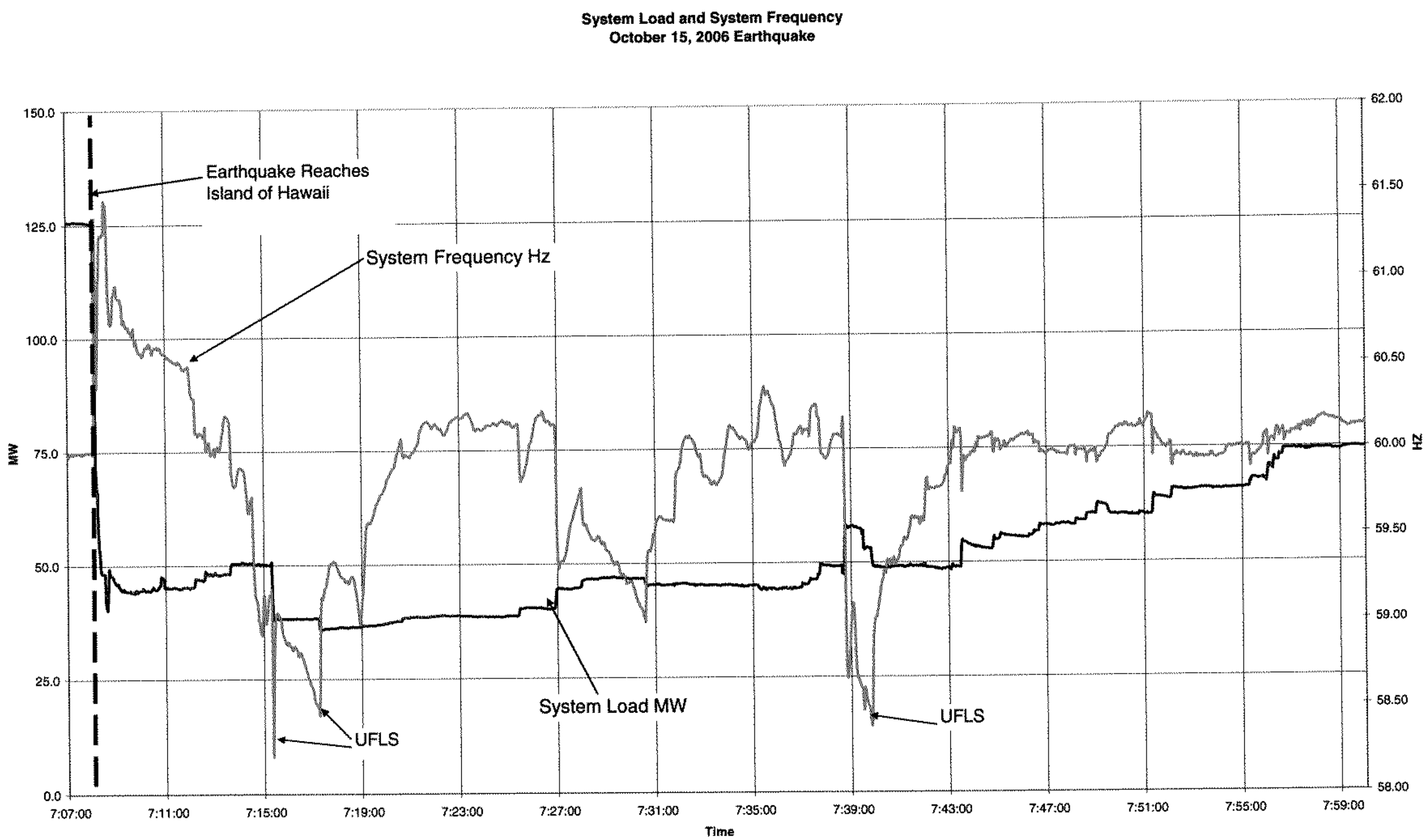

Figure 1: System Load versus Frequency Timeline October 15th, 2006

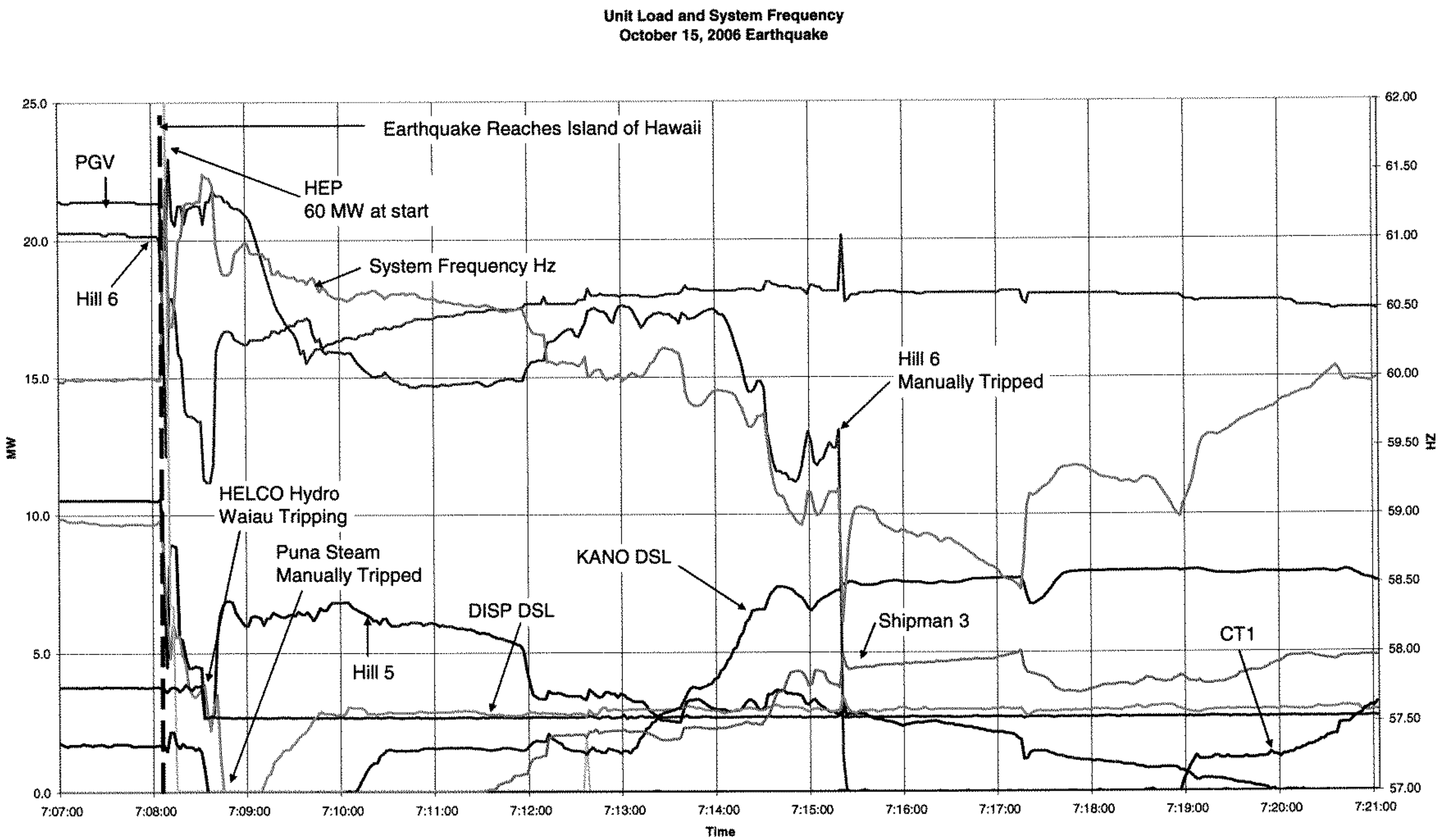

Figure 2: Individual Generator Output Timeline - October 15, 2006, 07:07:00 to 07:21:00

Summary of the System Dynamics

At the onset of the earthquake, the system was operating normally with all transmission lines in service and generation properly dispatched to provide sufficient regulating reserve in accordance with the HELCO operating practices. There were essentially three areas of events from the time the earthquake hit until the generation "island" on the east side of Hawaii stabilized.

PHASE 1 - 07:08:02 to 07:08:32 hours

During the first 30 seconds of the event:

- 19 of 28 transmission circuits tripped open or were de-energized due to faults and relay operations,
- 11 of 20 69 kV switching stations were de-energized,
- 3 of 5 34 kV Sub-transmission lines tripped open,
- 77 of 124 distribution circuits were de-energized,
- Hamakua Energy Partner (HEP) CTs tripped off line due to vibration.

Trips of the transmission circuits blacked out the system from Pepeekeo around the north and down the west side of the island to Kealia. The initial loss of load resulted in over frequency with generation exceeding load on the east side of Hawaii. The Hill 5, Hill 6, PGV and Puna units reduced output to match generation with load as indicated in Figure 2. Waiau and Wailuku hydros tripped off-line.

PHASE 2 - 07:08:32 to 08:00:00 hours

Line 6500 Kaumana to Pohoiki tripped and then automatically reclosed which added to the disturbance on the grid remaining on the east side of the island. As the HELCO steam generation quickly ramped down to match the load lost on the west side of Hawaii when transmission circuits tripped, the Puna steam unit began to motor and was tripped by the operator. The Hill 5 boiler tripped and the generator began to reduce power output as the steam pressure declined. The System Operator noted that the system had separated and that the remaining generation was going through a transient condition trying to maintain generation-load match. At this point the System Operator started the standby diesel generators and Kanoelehua CT1. Shipman 3 was requested to go online. At 07:12:05, the System Operator began to systematically close transmission circuits by SCADA that had tripped to restore the 69 kV grid with the priority to reconnect the power plants. About 0714 hours, Hill 6 was producing about 17 MW when it developed a leak in the turbine steam chest and began to lose power. At this time the frequency began to decay below 60 Hz as the other units began to ramp up to absorb the reduction in power from Hill 6. Hill 6 was tripped by the operator as it was presenting a severe safety risk. Frequency then declined quickly and load shed blocks began to operate between 07:14:49 and 07:18:53 which arrested the frequency decay and increased the frequency to above 59 Hz. At about 0719 hours CT1 was connected to the bus and began to pick up load which quickly restored the frequency to 60 Hz. The 69 kV transmission grid was restored to Keahole at about 0723 hours and CT4 was brought on-line at about 0743 hours. The Puna steam unit was put back on-line at about 0737 hours. Puna CT3 was brought online at about 0748 hours. As Figure 1 shows, the frequency remained low while the System Operator closed in circuits, generation was connected to the grid and load was picked up until about 0745 hours. HEP CT1 was put back online about 0755 hours. The swift actions of the System Operator, as prescribed by the HELCO operating practices, avoided a system-wide outage.

PHASE 3 – 0800 to 2400 hours

In this phase the remaining portions of the system were assessed for damage and restored to service where possible. The System Operator had restored as much of the system as possible by SCADA. At this point the general actions were:

- HELCO Transmission and Distribution (T&D) and Production Supervisors reported to the KOCC
- Field personnel were called out
- HELCO's Civil Defense Liaison reported to the county Emergency Operation Center
- Aerial inspections were coordinated
- Priorities were established for restoration
    - Line 7300 at Ouli Substation
    - Keahole CT-5 generator step-up transformer
    - Honokaa Switching Station (opened due to customer reports of a fire)
    - Reset lockout relays

Dispatch Center

Interviews with the System Operator indicated that when the initial shaking took place, he was immediately aware that it was an earthquake. He reported that SCADA alarms went off continuously and the alarms were too numerous to list. He executed fast start of the standby diesel units and Kanoelehua CT1, and called for Shipman 3 to come on-line. Standard HELCO procedure for a major system upset is to get as much generation ready to come on-line as possible. When Puna Steam, Hill 5 and Hill 6 were taken off-line, automatic load shedding operated and was sufficient to help stabilize the system frequency. The additional generation from the diesel units, Kanoelehua CT1 and Shipman 3 helped to make up for the lost capacity and restored the system frequency to 60 Hz. Manual load shedding was not required.

After the shaking stopped and the system stabilized with a generation island in the east Hawaii area, the System Operator began to close back in transmission lines with SCADA. Additional supervisory and operations staff began to arrive at the KOCC on their own as they recognized that an earthquake had occurred. At that time one System Operator managed the generation while the second used SCADA to open distribution breakers on transmission lines that had tripped open and were de-energized. This allowed test reclosing of transmission lines without addition of load. HELCO's general practice is to test reclose a line that has tripped to determine whether a fault condition remains or if it has cleared. This practice significantly reduces the duration of outages following momentary faults. As generation and load restoration progressed, under frequency load shed circuits were restored as a precaution in case of other low frequency events.

HELCO's internal microwave and land line communications systems for the SCADA and hotline to power facilities and police/fire dispatch remained in service along with base-to-mobile radios and cell phones. The land line telephone system and cell phone system experienced some congestion, but were not significantly hampered. Paging/text messaging via the company email system stopped working shortly after the first message was transmitted and received.

Power Plants

The power plants experienced significant load swings as the transmission system separated the east side generation from load on the west side of the island.

As a result of the over-frequency condition in east Hawaii, resulting from the loss of transmission lines, Puna Steam Plant Unit output ran back down eventually to zero. As the unit began to motor the control operator tripped the unit off-line as they had been previously trained. The unit experienced an event in 2005 where the generator motored for a significant period of time and as a result, operators received subsequent training regarding protective actions under this circumstance. Operators maintained boiler pressure so that they were able to quickly bring the Puna unit back on-line when the system stabilized.

Hill 5 experienced a boiler trip (specific cause is uncertain) and had difficulty purging the boiler for a re-start. The purge problem prevented re-firing the boiler before boiler pressure declined to the point where the unit had to be tripped. After resolving the boiler purge problem, the operators had trouble with a fuel oil trip reset, which when corrected allowed the boiler to be fired and the unit brought on-line at about 0817 hours.

Hill 6 operators noted that this unit is known to have some level indicators on the deaerator that are subject to false trip during physical shaking. During the earthquake these level indicators tripped the boiler feed pumps which did not automatically re-start. The operators were aware that these could falsely operate during an earthquake and quickly restarted the boiler feed pumps manually. As the unit was stabilizing, the turbine chest developed a severe superheated steam leak which caused severe safety concerns due to the high pressure steam flowing into the turbine operation deck. The unit was tripped at this time and was not returned to service until repairs were completed on October 18th.

The Keahole operation room had some cosmetic damage but remained in operational condition. Initially, Keahole was in the black portion of the grid and could not start or connect any units until the 69 kV transmission grid was restored to the station.

<u>IPPs</u>

The HEP Distributed Controls System (DCS) was inundated with alarms and the operators couldn't keep up with them. The quake triggered vibration sensors which tripped the combustion turbine units, which in turn tripped the combined-cycle steam turbine. The personnel reported some minor damage to the control room (books fell off shelves and ceiling tiles fell down). After inspection they found a breeched water line to the de-mineralizer and minor damage to cable trays. When the CTs tripped, the operators started their plant diesel generator and initiated a high speed crank to prevent thermal lock. The transmission system to Haina was restored within five minutes after the earthquake and HEP CT1 was reconnected to the grid at 0755 hours. During the restoration, HEP CT1 tripped due to a cable that had loosened on the aft accelerometer and this trip resulted in underfrequency load shed on the HELCO system at 1009 hours.

Outages of the 7300 and 8800 69 kV transmission lines restricted the output of HEP to about 45 MW to avoid overloading the 7200 69 kV transmission line.

HEP staff indicated that they were able to maintain communication with HELCO and that the coordination was good throughout the event and restoration.

PGV remained online throughout the earthquake and the associated system frequency excursion. Some output was reduced for a period when plant auxiliaries were tripped due to the low frequency. PGV was able to restore generation output to the pre-event level by 0800 hours.

Transmission and Distribution System

The EMS and SCADA indicated automatic Under Frequency Load Shedding (UFLS) scheme activation as designed. The transmission system remained primarily structurally intact. For many of the 69 kV and 34 kV circuits that tripped, the System Operator systematically reclosed circuits through the remote capability of the SCADA immediately after the generation islanded with load on the east side of Hawaii and was stabilized.

2.3.2 System Restoration

The following information is based on interviews with management, the System Operators, and power plant operators, as well as information that were gathered from various sources including the EMS and SCADA.

Key management and supervisory personnel voluntarily responded after the earthquake. Within a few minutes after the earthquake, supervisory staff came into the KOCC to supervise and support the system stabilization. One of the Shift Supervisors was on-site to assist, followed shortly by one of the Assistant Superintendents. They brought in an additional System Operator and supervised the system restoration and set priorities. Within a half an hour, there was a supervisor assisting at Keahole Power Plant, Puna plant, and Hill plant in addition to two supervisors who assisted as necessary at various plants and system operations. The second Assistant Superintendent arrived approximately 40 minutes after the earthquake. As additional supervisory personnel arrived, some remained at System Operations to assist with system recovery and others were sent to the various plants to direct startup (where applicable) and direct assessment surveys. Even though activation of the Incident Management Team was not deemed necessary, several key position activities were performed by the assigned individuals as they arrived and assisted in restoration.

The HELCO senior staff assessed the system and called in trouble inspectors and construction and maintenance (C&M) staff to inspect the system and begin repairs. The staff from the Kona and Waimea baseyards were assigned to assess the condition of local substations and lines and prepare them for re-energization. Additional HELCO staff were mobilized from the eastern side of the island to travel to the west side to assist with reenergizing the substations and transformers. Restoration activities were hampered by road closures as shown in Figure 3.

The primary objectives of the overall restoration were:

1) Stabilize the system by bringing generation and load in balance;
2) Make generation available through restart of the steam plants and by re-establishing the transmission system connections to that portion of the island that was separated. The route taken for transmission restoration was designed to restore generating facilities then add circuits as needed to rebuild the transmission system;
3) Restore underfrequency circuits;
4) Communicate to T&D field personnel regarding lockouts or other problems that required field personnel to resolve; and
5) Complete restoration of customers as generation was made available and as the transmission/distribution system repairs were completed.

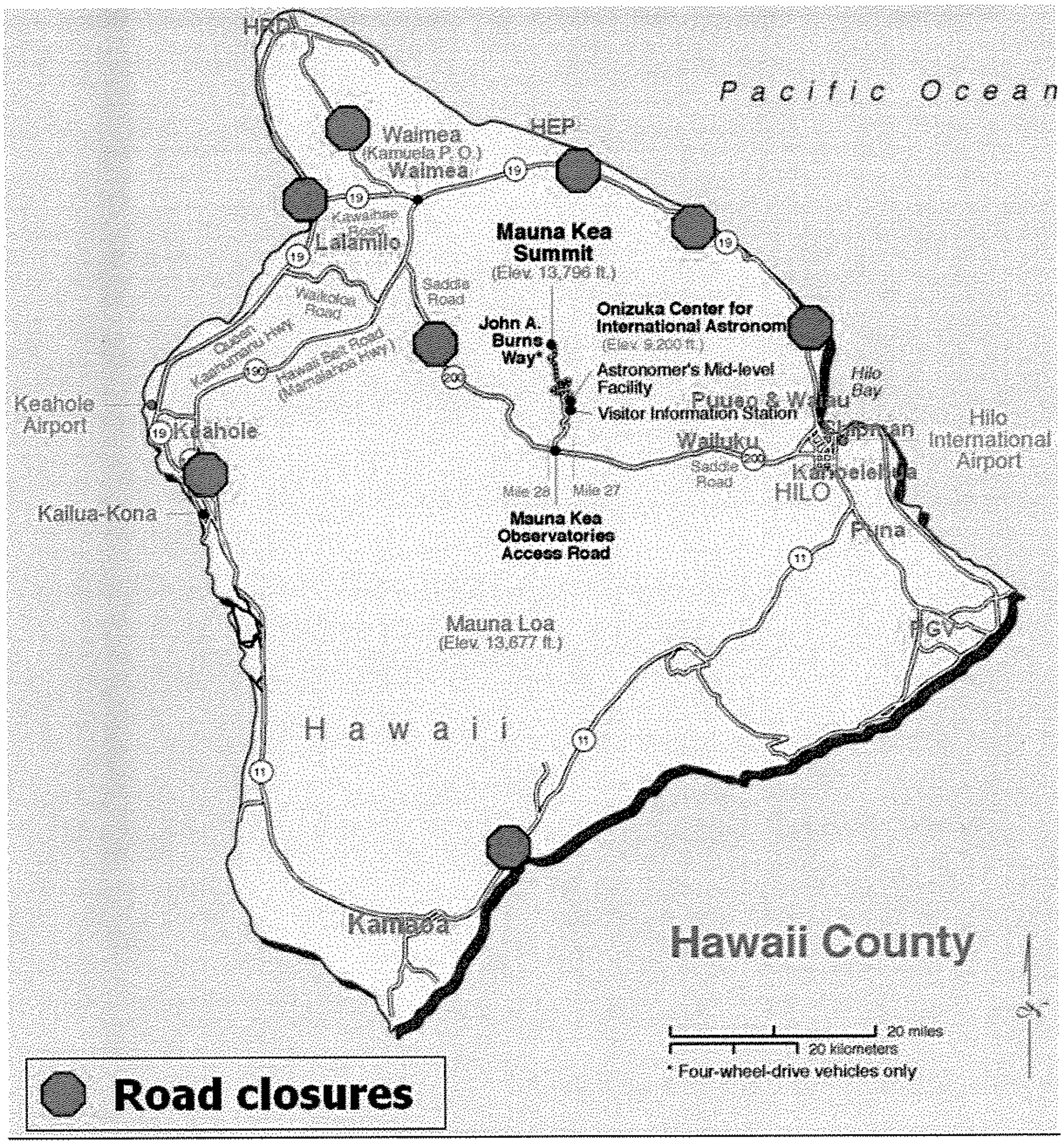

Figure 3: Initial Hawaii Road Closures Due to the Earthquake

System Restoration

The 69 kV grid was restored to Keahole power plant by 0730 hours and CT-4 came on-line about 0742 hours. By 0802 the System Operator had closed in all forty five (45) breakers that could be remotely closed by SCADA control. T&D personnel responded and inspection of the system found the following:

- Ten (10) spans on 3200 line (34 kV transmission line from Honokaa serving Paauilo substation) failed
- Insulator on 3300 line (34 kV transmission line from Waimea serving North Kohala) failed
- Transmission switches at Honokaa Substation out of alignment and arcing
- Four (4) substations had potential transformer secondary disconnect switches damaged
- Fifteen (15) substations had primary transformer fuses shaken off the fuse holders
- Capacitor bank and 69kV bus connectors at Ouli Switching Station damaged, that disabled four 4.8 MVAR shunt capacitor banks
- Eight (8) transformers (substation and generator step-up) had lockout relays (designated 86T) which tripped and locked out by operation of sudden pressure sensors due to the shaking of transformers by the earthquake
- Kahaluu bus differential relay operated.
- Others
    - No power – Honokaa Hospital
    - Structure fire – Puu Nani Drive
    - Power problem – Kona Community Hospital
    - Numerous service line (s/l) problems
    - Honomu Ln – Lightning arrester fell off pole
    - Customer primary service – lines hanging from arresters

The generation available during the initial stage of system stabilization until about 0800 hours was:

- Shipman 3
- Puna Steam
- Kanoelehua Diesel Generators
- CT-1 (Kanoelehua), CT-3 (Puna) and CT-4 (Keahole)

- Puna Geothermal Ventures (PGV)
- Puueo Hydro
- Dispersed Generators at Panaewa, Punaluu and Kapua
- HEP CT-1

Restoration of HEP generation and the Keahole CT-5 were high priorities for the System Operator to avoid a generation shortfall. The transmission grid to HEP was restored by 0713 hours and to Keahole about 0723 hours. Keahole CT-4 came on-line about 0743 hours followed by HEP CT-1 at 0755 hours. The HEP Steam Turbine Generator (STG) was brought online at 0919 hours. The trip of HEP CT-1 generator and STG at 1009 hours caused system under frequency and trip of four UFLS circuits. HEP CT-2 was back online at 1034 hours, followed by the heat recovery steam generator at 1109 hours. Keahole CT-5 came online at 1451 hours after field personnel reset the step up transformer lock-out relays.

Substation and power plant transformers that tripped and locked out (86T) via the transformer sudden pressure protective scheme were visually inspected for physical damage resulting from the earthquake. When no damage was noted the decision was made to reset the sudden pressure lockout relays and perform a test reclose on the breakers that connected the respective transformers while monitoring existing metering and protective relays to check for internal faults. The first transformer energized was the Keahole Diesel Generator transformer at about 0847 hours. When this transformer did not show signs of an internal fault, additional units that had tripped on sudden pressure had their respective 86T lockouts reset and were re-energized.

Lines 7300 and 8300 had tripped open at Ouli Switching Station during the earthquake and failed to close when ordered to close by SCADA. Damaged equipment was subsequently found at Ouli. At 1219 hours, equipment arcing at Honokaa Switching Station led to a forced outage of Line

8800, which routed all HEP power through Line 7200 to the West Hawaii area. The full HEP rated output would exceed the line's emergency rating of 300 amps, and HEP was curtailed to 45 MW to avoid damaging Line 7200.

Transmission lines 7300 and 8300 were restored at 1414 hours after repairs to the air switches were made at Ouli Switching Station. The restoration of the 69 kV transmission system was returned to normal configuration at 1716 hours after transmission line 8800 was restored. Line 3300 (servicing North Kohala) was taken out of service at 1652 hours to repair an insulator that was damaged by the earthquake; it was restored at 1854 hours.

Figure 4 shows the load curve for October 15th in comparison to load on Sunday October 8th. The curve profiles for October 8 and 15 are similar prior to 0707 hrs and after 1800 hrs. Firm capacity and firm capacity with as-available generation are also shown on the graph, to illustrate the reserve margin that is typically available.

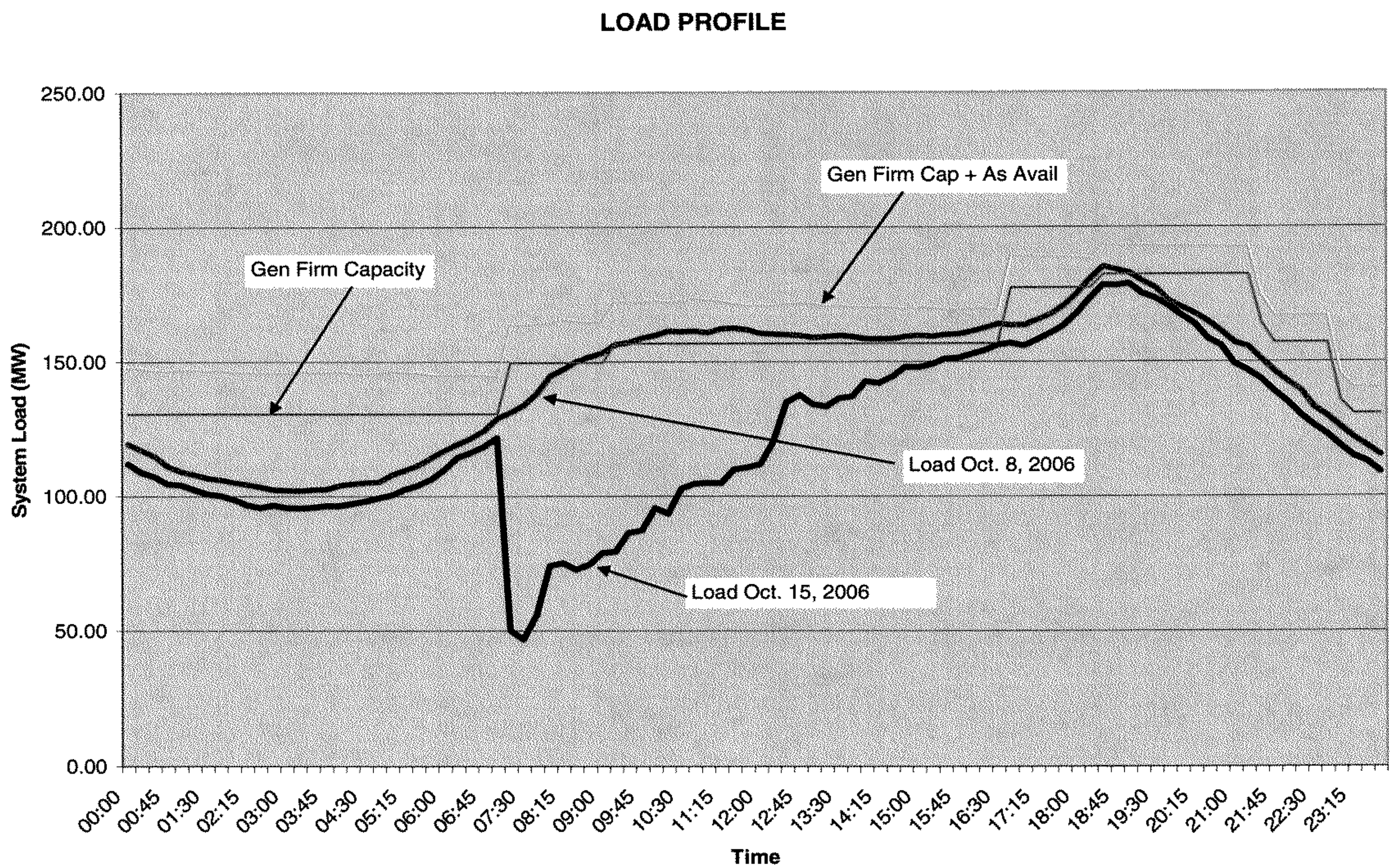

Figure 4: October 15, 2006 Generation Compared to Previous Sunday Load Curve

3 Evaluation

3.1 Generation Capacity

3.1.1 HELCO Generating Fleet

Approximately 276 MW of firm generating capacity is currently installed on the island of Hawaii, with a further 29 MW of wind and hydro power as-available. Of the 276 MW, 186 MW is owned and operated by HELCO and 90 MW by Independent Power Producers (IPPs). The HELCO and IPP plant capacities are summarized in Table 1.

The HELCO generating equipment is notable for:

- 64% of the base load capacity is owned by two IPPs and comprises a combined cycle combustion turbine plant with a heat recovery steam turbine and a geothermal plant. The remainder of the base load capacity comprises steam plant installed between 1965 and 1974.

- The remainder of the load is supplied with combustion turbines in open cycle mode, steam turbines installed in the 1950s, and 15 relatively small reciprocating engines for peaking installed between 1962 and 1998.

Expected Performance of Generating Plant During Major System Disturbances

No reciprocating engine plants were operating at the time of the earthquake because the reciprocating engine plants are used for peaking and emergency, rather than base load.

Steam plants can be very valuable in providing frequency stability. However, older designs at HELCO may have difficulty remaining in service following sudden, large load swings, depending on the boiler ratings. Sudden large load pickup and reduction can take boiler operating parameters, such as drum levels, to the point where control equipment intervenes to protect the plant from damage and automatically trips the unit out of service. Once the boiler trips, getting a purge of the boiler fuel fumes and re-light, while keeping the turbine generating, requires a lot of skill. In HELCO's case, the operators report that they are successful in relighting the fires and keeping the turbine on-line at least 2/3rd of the time, and they continuously work to improve this ability. When a plant is suddenly tripped off-line, there are numerous steps required to secure the plant, assess equipment conditions, and proceed through the startup sequence. To complete these sequences requires between 20 minutes and 4 hours depending on the residual steam pressure/temperature of the boiler.

Combustion turbine plants of the type installed at HELCO and HEP are able to respond well to rapidly changing loads and can be brought on-line relatively quickly. The turbines are manufactured by General Electric, type LM2500. The LM2500 is based on an aero engine that has been modified for use as a land-based generating set. It is typically used, as in this case, in combined cycle mode whereby the heat in the turbine's exhaust gas is used to generate steam for a steam turbine. HEP uses two combustion turbines feeding heat to one steam turbine – again a typical and proven arrangement for a cost effective and efficient installation. The associated HEP steam turbine, which uses steam generated from the exhaust gas heat of the combustion turbines, will take longer to be brought on-line and is less able to accept significant load changes.

However, the combustion turbines can operate in "open-cycle" mode, i.e. without the steam turbines running, to serve load until sufficient exhaust gas heat is available to bring the steam turbines on-line. The HELCO CTs are run in simple cycle mode.

3.1.2 Operational Generating Capacity on October 15

The generating capacity in operation immediately before the earthquake was approximately 136 MW, and the system load was 126 MW. HELCO was running all three of its designated base load steam plants, taking output from HEP and PGV, and a small amount of hydro power. Anticipating morning load increases, Shipman 3 was in the process of steaming up and preparing to go on-line at the time the earthquake struck.

The following generators were in operation at the time of the earthquake:

Hill Generating Station

Hill 5 - Steam turbine, capacity 14.1 MW, load at time of earthquake 10.5 MW

Hill 6 - Steam turbine, capacity 21.4 MW, load at time of earthquake 20.3 MW

Puna Generating Station

Puna Steam turbine, capacity 15.5 MW, load at time of earthquake 9.9 MW

IPPs

HEP - Combustion turbine/steam turbine, capacity 60 MW, load at time of earthquake 58.0 MW

PGV - Geothermal station, capacity 30 MW, load at time of earthquake 21.4 MW

Wailuku River Hydro, capacity 12.1 MW, load at time of earthquake 1.8 MW

Puueo Hydro, capacity 3 MW, load at time of earthquake 2.7 MW

Waiau Hydro, capacity 1.2 MW, load at time of earthquake 1.1 MW.

3.2 Earthquake Events Analysis

3.2.1 System Operations Event Response

After the initial tremor, it was clear to the System Operator that the system had experienced an earthquake. By the time the earthquake (reported to be 15 to 20 seconds by the Hawaii Volcano Observatory), 19 transmission lines, substation transformers and the HEP combustion turbines had been tripped by their protective relays. The west Hawaii HELCO system from Kealia to Pepeekeo was blacked out. The System Operator reported that the SCADA alarms screen was scrolling too fast to comprehend, so he focused on the system wall display to assess the state of the system.

With the separation of the transmission system, the east Hawaii area remained connected to the Puna Steam Plant, Hill 5, Hill 6, PGV and Puueo Hydro. The frequency rose to about 61.5 Hz. As Puna Steam was tripped because it was motoring and Hill 5 reduced power output due to a boiler trip, the System Operator took immediate action, as is standard practice, and fast started the diesel units, and Kanoelehua CT-1 and called for the Shipman 3 unit to be brought on-line.

The HELCO system operators have the ability, in a single operation, to send a start signal to the diesel generators, with the exception of the diesel 11. These fast start units are four dispersed 1MW diesel generator units (one each at Panaewa, Ouli, Kapua and Punaluu), three 2.75MW units at Kanoelehua, and three 2.5 MW units at Waimea and three at Keahole. The generator at

Ouli (on the west side of the island) was, as a result of the loss of transmission lines, unable to be connected, but the other three 1MW units started up and connected to the system to provide 3MW of generation, just after 07:09. These were closely followed by select Kanoelehua units a minute later. The Keahole and Waimea units were also in an area where the transmission system had de-energized, could not connect to a dead bus, and had shut down.

In anticipation of load increasing during the morning, the steam turbine at Shipman 3 had been steamed up and was ready to be brought on-line. It was brought on-line at 7:11:20. This was followed at 7:18:57 by the 11.5MW combustion turbine at Kanoelehua. These units helped to compensate for the loss of the steam turbines at Hill that came off-line at 7:15 and 7:21.

When Hill 6 tripped due to a turbine steam chest leak, the frequency quickly declined below 59 Hz and the automatic load shed scheme activated to arrest the frequency decay and bring the frequency above 59.0 Hz. The frequency again began to decline as Hill 5 power output continued to decrease and it appears additional load was shed returning the frequency to about 59.3 Hz. The frequency then declined again as the Hill 5 output continued to reduce, until CT-1 came on-line and quickly matched load to stabilize the frequency. Once the frequency stabilized, the System Operator immediately began to close back in the 69 kV transmission circuits by SCADA, and bring generation on-line to restore the system load. The transmission path was restored to Haina, Waimea, Keamuku and Keahole by 0725 hours to allow reconnect of the major generation resources. The System Operator had remotely restored the majority of the transmission system to the west side of the island by 0800 hours. Load was added in conjunction with generation as the System Operator and Plant Operators managed generation and load additions. The generation, once connected to the grid, was put on AGC when minimum load for AGC control was reached, to control loading and frequency. As the system restoration continued additional supervisory and system operations personnel reported in and began to assist with the restoration activities.

At about 1009 hours, HEP CT-1 and the steam unit tripped when the cable connection to the aft accelerometer on the CT failed. This dropped 21 MW of generation and the system again went into underfrequency and triggered load shedding. HEP CT-2 was put on-line at 1033 hours followed by the Heat Recovery Steam Generator (HRSG) steam unit at 11:09 hours and HEP CT-1 at 1321 hours.

In cases such as the Keahole diesels and CT-5, the units' associated generator step-up transformers tripped on the activation of a transformer sudden pressure lockout relay which required an inspection of the transformer and manual reset of the lockout relay prior to re-energizing the transformer. There were also a number of cases where substation transformers had fuse elements that were shaken from their fuse holders, requiring maintenance crews to manually close them.

Overall, the separation of the transmission system dropped enough load from the west side of the island so that the east side had a generation surplus with respect to load resulting in over speed/over frequency, which caused the HELCO generators to reduce power output, and consequently the trip of Puna steam on a motoring condition and created boiler upset conditions on Hill 5 and Hill 6. The immediate actions by the System Operator to start the diesels and Kanoelehua CT-1 and to have Shipman 3 put on-line, as per HELCO operating practice, are credited with providing sufficient generation capacity, in combination with the automatic under frequency load shedding to balance generation with load and stabilize the system, preventing an island-wide blackout. The System Operator's actions to immediately begin test closing the 69 kV transmission lines, restoring circuits to HEP and the west side of the island, also per HELCO practice, significantly reduced the outage time for a large portion of HELCO's customers.

3.2.2 Transmission and Load Restoration

HELCO T&D staff were dispatched to inspect the transmission lines and substations and prepare them for restoration where the System Operator indicated that he could not operate the remote controlled devices by SCADA. As the inspection and restoration progressed, the earthquake-caused damages listed in Section 2.3.2 were noted and assessed, and repairs were initiated.

Ouli Switching Station was found to have equipment damage including the following: 8 of 12 capacitor bank VBM style single phase switches were damaged; capacitor bank potential transformer leads had pulled free; the station service transformer had moved and tore loose from its anchors (failed several days later); and a bus PT lead pulled free which would make the line relays non-directional. The transformer sudden pressure relay had operated and locked open the transformer breaker. Isolation and repair of damaged equipment delayed re-energization of transmission lines 7300 and 8300 until about 1414 hours.

Honokaa Substation was reenergized at about 0712 hours. Transmission line 8300 from Honokaa to Haina was tripped open by the System Operator at about 1220 hours when a customer reported a fire in the substation and line crews determined that transmission line 8800 air switch had been knocked out of alignment and was arcing across its contacts.

With transmission lines 7300 and 8800 out of service, HEP was left connected to a radial system transferring its output across Line 7200. Line 7200 is constructed with 2/0 ACSR cable and would overload with the full output from HEP. This concern became a priority for System

Operations and, consequently, HEP output was curtailed to 45 MW until the damage was isolated at Ouli Substation and Lines 7300 and 8800 were restored to service.

Substations that could not be restored by SCADA and required manual assessment for damage were located in the west Hawaii portion of the system and maintenance crews from Hilo were dispatched to assist. These crews were somewhat delayed awaiting road closures to be cleared. The crews assessed equipment condition, reset lockout relays and closed transformer fuses to allow the System Operator to close in load as generation became available. Of the 62,000 customers on the HELCO system effected by the outage, 61,000 had power restored by 1500 hours. The remaining customers had power restored by 2300 hours as distribution line repairs were completed. The following sections evaluate the generator, line and transformer trips.

3.2.3 Generator Trips

Summary of generator trips.

7:08:12 HEP station tripped on high vibration.

7:08:32 Waiau hydro units tripped.

7:09:18 Puna steam turbine was found to be motoring, was tripped offline and kept in readiness to reconnect as soon as possible.

7:15:17 Hill 6 steam turbine showed a deaerator level alarm though this was not a trip condition. But then the turbine developed a steam leak in the turbine chest seal and had to be manually taken off-line.

7:21:19 Hill 5 steam turbine tripped following the trip of the boiler due to a low boiler drum level. The unit had problems with the purge process, lost steam pressure and was tripped.

Puna Power Plant

The generating plant at Puna is part of a decommissioned sugar cane processing plant and was purchased by HELCO when the sugar plant was no longer viable. The boiler was originally sized to feed steam to the turbine and to parts of the sugar refining process, and is approximately twice the size needed to power the steam turbine alone. This means that the boiler can cope very well with sudden load changes.

Tripping of transmission lines to the west side of Hawaii resulted in a surplus of generation on the east side of the island. Consequently, the system frequency increased on the east side and the Puna steam turbine valves closed to try to decrease the speed of the machine. The machine was effectively being motored by the system and the unit is not presently equipped with a reverse power relay to automatically trip for this condition. Motoring a generator can lead to serious problems, and the established operating procedure correctly requires that the unit be tripped under this condition. In 2005, the unit had motored for a prolonged period before being tripped offline. The Puna operators had been provided specific training regarding this possible event and the expected actions to trip the plant and prepare to come back on-line. The Puna operators followed these procedures, tripped the plant, and readied it to come back online when the frequency stabilized.

Hill Power Plant

The steam turbines at Hill, Hill 5 and Hill 6, both came off-line during the disturbance for different reasons.

Hill 6 came off-line first. Initially its boiler indicated a deaerator level alarm, though this is believed not to have been caused by a genuine deaerator level problem but instead by the action of the earthquake's vibrations on the liquid level switch monitoring the level. The shaking of the switch caused the switch to give a false reading. This apparent switching caused the boiler feedwater pump to automatically trip, but it was quickly manually re-set and the feedwater pumps re-started. The boiler feedwater pump trip was not a factor in the trip of the Hill 6 turbine. The boiler and turbine continued to operate. However, the changes in steam pressure created by the rapid and large load reduction in response to the high system frequency, the turbine chest developed a steam leak at the turbine chest gasket. The release of superheated steam is extremely dangerous to personnel (it is very hot, at a high pressure, and invisible until it cools some distance from the leak) and created a serious safety situation that required an immediate shutdown.

It is perhaps significant that the deaerators on the boilers at Hill, in order to absorb water hammer and thermal shocks, are arranged to be able to move slightly. This however can exacerbate the risk that the liquid level switches will move and give false readings – the station operators report that this has happened previously during earthquakes. The switches are:

- LS96 – Hi Level alarm and BTV (3rd extraction) trip 291 SPX
- LS97 – Low Level alarm 291 SPX
- LS490 – Low Level 5A condensate pp trip 291 SPX
- LLS/E – Low Level 5A condensate pp trip 291 SP

Hill 5 suffered a boiler trip due to uncertain causes. The shift supervisor on duty suspected the fuel-oil trip was somehow caused by the earthquake as there were problems resetting this trip, though this cannot be verified by instrumentation or records. Once the boiler had tripped, the operators re-set the drum alarm and attempted to re-start the burners. However, for safety reasons the boilers require a purge cycle to avoid the risk of igniting explosive gasses. During this event, the operators had difficulties in quickly completing the boiler purge and the boiler pressure fell to the point where the turbine had to be tripped to protect it from damage. It was later determined the fuel-oil trip valve was causing the problems and eventually the staff was able to reset the fuel-oil trip, purge and re-fire the boiler.

HEP Power Plant

High vibration caused the two combustion turbines at HEP Generating Station to trip just after 0708 hours. These generator sets are equipped with vibration sensing devices which detect the relative positions of shafts and housings to determine if vibration is occurring which the manufacturer considers could damage the machine. Both the combustion turbine itself and the electrical generator have vibration sensing, and it was the vibration sensing on the generators, (Bentley Nevada 3300) rather than the turbines, that caused the CT's to trip. The HEP CT's both dropped to minimum load as the system frequency increased to above 63 Hz when the transmission system tripped. Then the CTs tripped on vibration about seven seconds after the earthquake began. The steam unit then tripped on logic that shuts it down if no CTs are operating. The operators immediately started the diesel generator and put the turbines on high speed turning gear to prevent thermal lock.

LM2500 Combustion Turbine Monitoring

When used in a power generation application, LM2500 combustion turbine-generator sets, such as the HELCO and HEP sets, are equipped with vibration sensing equipment on both the turbine and generator as follows:

Accelerometers – the combustion turbine is fitted with two accelerometers, one on the gas generator at the air inlet end, the other on the power turbine. These sensors detect vibrations in the combustion turbine casing. The aim is to detect vibrations at normal shaft speeds to provide an alert if a shaft becomes unbalanced. The LM2500 has high background noise (vibration) levels, so a speed signal is taken from each shaft (gas generator shaft and power turbine shaft) in order to filter out vibrations which do not occur at shaft speeds. Alarm and trip levels are set for each accelerometer for vibrations at each shaft speed. Thus, the accelerometers on the combustion turbines are not designed to detect vibrations due to external forces, only vibrations at much higher frequencies due to shaft unbalance problems. In common with most aero-derived combustion turbines it is fitted with rolling element bearings which are resistant to externally applied vibrations.

Proximity probes – the electric generator, which is a separately manufactured component from the LM2500, is fitted with proximity probes which detect the distance between the bearing housings and the shaft. There are four probes, two at each machine bearing (i.e. at each end of the generator). Each pair of probes is arranged at 90°, one in a vertical orientation and one horizontal. The purpose of these probes is to detect relative lateral movement between the generator stationary and rotating parts, which will occur in the event of bearing or lubrication failure, shaft unbalance or other types of internal damage. In fact, these are not truly vibration sensors at all, but are, as the name says, proximity detectors. Proximity detectors are used because the bearings in the generator sets are plain journal bearings which rely on a hydrodynamic film of oil for lubrication, as is the case with generators of this size world-wide. Significant vibration from any source and at any frequency can cause the film of oil to be disrupted which would lead to bearing failure and possible shaft damage. The proximity probes detect changes in shaft/housing clearances which may indicate loss of oil film lubrication. When the earthquake struck, the proximity probes on the bearings of the generators of combustion turbines HEP CT-1 and CT-2 detected movement between the bearing housings and the shafts in excess of the "trip" threshold and caused the machines to shut down.

3.2.4 Transmission Line Trips

Inspection and assessment by the T&D staff during and subsequent to the restoration indicate that relays on 12 of the 69 kV lines that tripped recorded a direct trip (DT), with no other fault sensing relay initiating the trip. After some investigation, it appears that an auxiliary relay contact momentarily closed, attributed to the earthquake shaking, to direct trip the transmission circuits. These relays are an ABB Style AR auxiliary relay. These auxiliary relays are commonly used in the electric utility industry to provide additional contacts from one relay to other protection and control schemes. The HELCO AR relays are typically mounted on the back of the relay panel, as shown in Figure 5, or on swing panels located on the rear of the main relay and control panel.

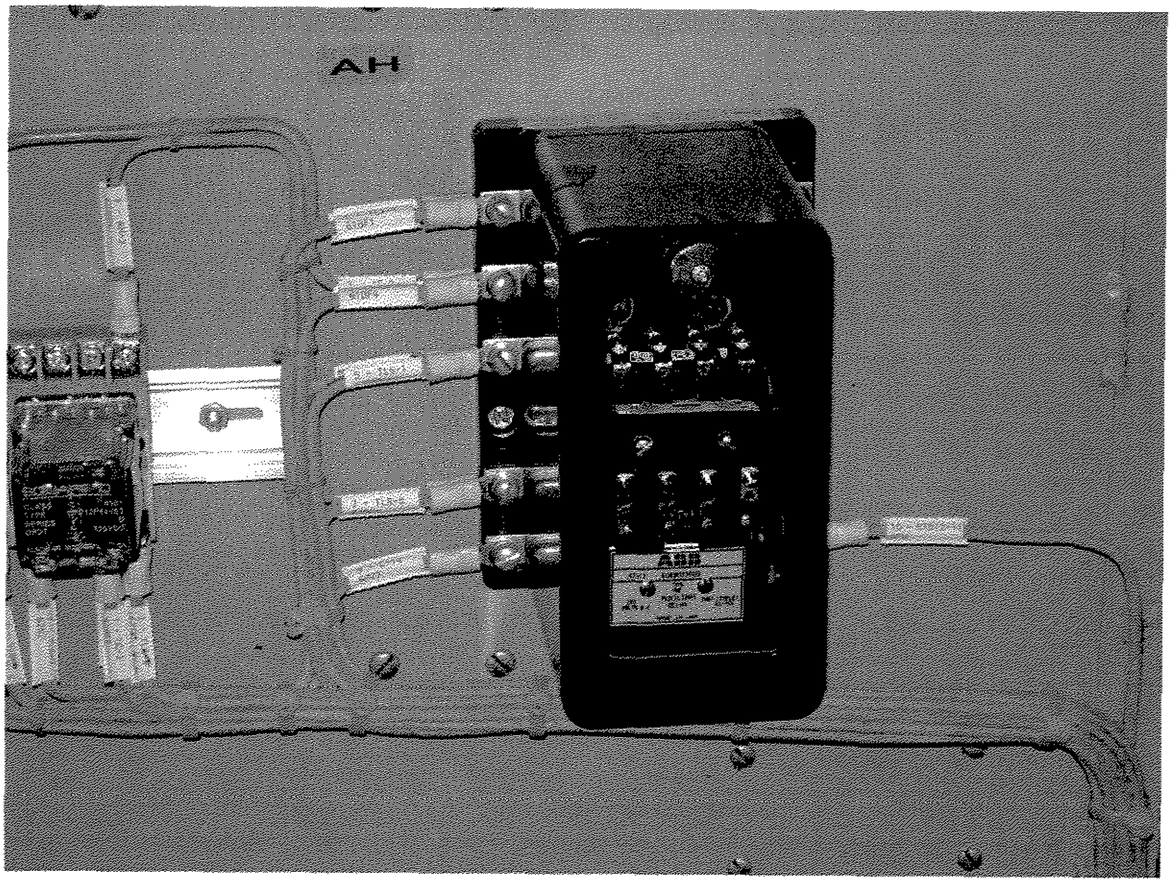

Figure 5: Transmission line AR relay.

These auxiliary relays do not result in a lockout condition so the lines were able to be remotely closed through the SCADA by the System Operator by 0800 hours. While these relays miss-operated, the inadvertent operation resulted in disconnecting load on the west side of Hawaii which helped to offset the loss of the HEP combined cycle units and Hill 6, as indicated in section 3.2.3 above. Relays on transmission lines 7300, 7700, 8600 and 6500 indicated that they had tripped due to phase-to-phase faults, most likely due to phase wire contacts due to the earthquake shaking. These trips are evaluated to be correct operations.

3.2.5 Substation Transformer Lockout 86T Trips and Fuses

Inspection by the T&D staff during and subsequent to the restoration indicates that relays on 8 substation distribution and generator step up transformers tripped on the 86T lockout relay by the Sudden Pressure protection scheme. This relay circuit includes a Sudden Pressure sensor in the transformer that detects a rapid pressure rise inside the transformer and an external target relay to provide an indication that the sudden pressure sensor operated. Rapid pressure rise inside a transformer is typically associated with an internal transformer fault arcing and quickly causing gasses to form, which increases the pressure inside the tank. Severe overpressure can rupture a pressure release mechanism or even the tank. Since this type of fault is always permanent, the sudden pressure relay circuit activates the 86T lockout device, which must be hand reset before the transformer can be re-energized. The typical industry procedure is to perform a visual inspection and disconnect the transformer to perform integrity tests before re-energizing. This process typically would take one to two days per transformer.

HELCO T&D staff noted that 8 transformers had the 86T operate and lock out, had similar sensors and target relays. These sensors are a Qualitrol Fault Pressure sensor as shown in Figure 6 with a magnetic target relay as shown in Figure 7.

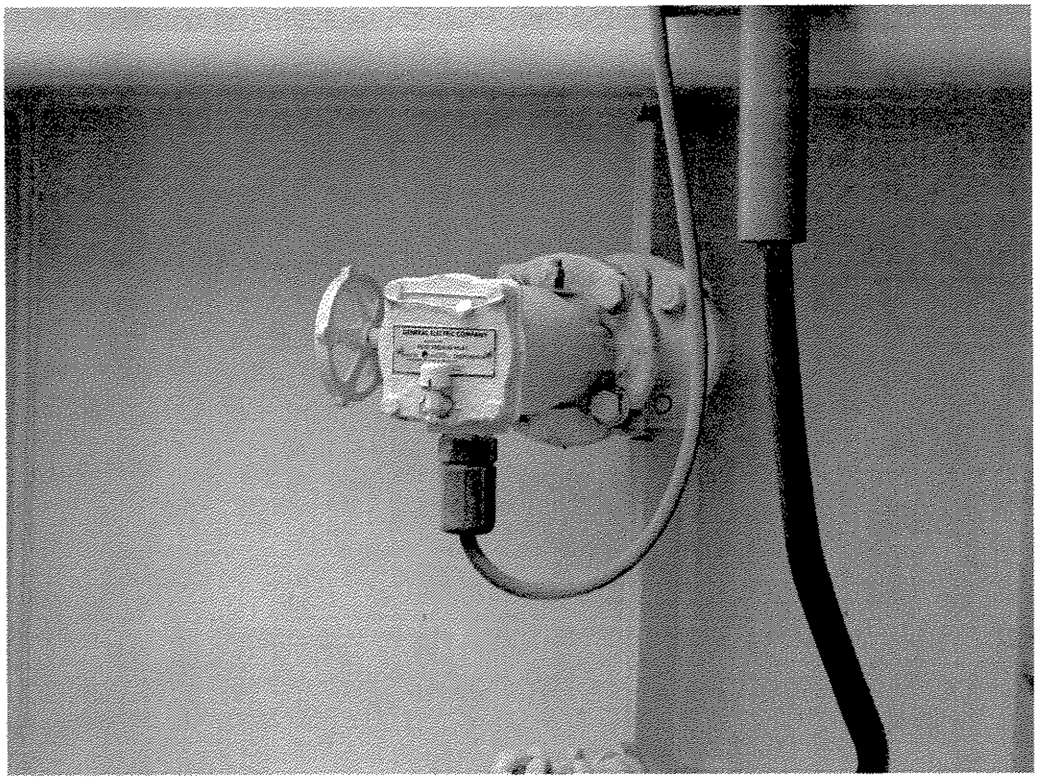

Figure 6: Transformer Fault Pressure Sensor Qualitrol.

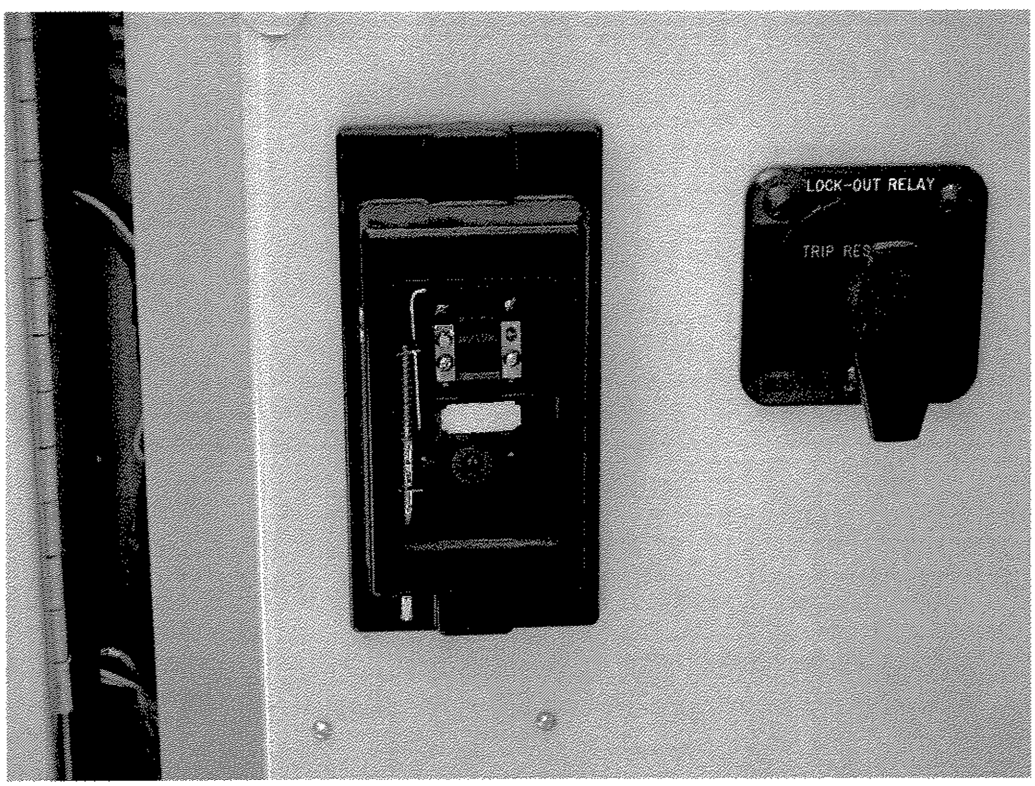

Figure 7: Transformer Fault Pressure Target Relay and 86T Lockout Relay

Other transformers on the system were noted to have a Qualitrol fault pressure sensors and solid state target relays. These units did not trip during the event.

The transformers were visually inspected and no indication of an overpressure condition was noted, such as rupture of a pressure release disk or setting of the pressure release flag. Once the coincidence on equipment was noted, HELCO staff test closed on the Keahole diesel generator transformer while monitoring the existing metering and protective relaying. Since Hawaii is remote from transformer repair facilities, they determined that an internal fault would most likely require replacement of the transformer rather than shipping the unit to a repair facility. Thus, there was little risk that re-energizing a faulted transformer, and increasing internal damage would extend the outage time if a replacement would be required anyway. When this transformer did not show any sign of a fault, they then continued to reset the other substation transformer 86T lockout relays and re-energize the transformer while monitoring the metering and relaying for signs of an internal fault. At this time, it has not been determined whether the miss-operation was due to the sensor or the target relay. It is possible that the sensor construction allowed the seismic acceleration of the oil to trigger the device or that the target relay closed its contact due to seismic shaking.

Fifteen substations had primary fuses shaken open from the fuse holders during the earthquake. These stations required that a maintenance crew member drive to the substation and manually close the fuse.

3.2.6 Communications

HELCO has several internal communication systems with redundant paths. These consist of Digital Microwave and Fiber, UHF/VHF radio, hotline between system operations and the power plants, email and cell phones/pagers for key personnel. All personnel within HELCO and at the HEP power plant indicated that the communications systems worked well throughout the event. The one system that stopped working is the email server that allows text messaging to cell phones and alpha-pagers for key personnel. For this system, the shift clerk dispatcher prepares an email message, keys it in and it is sent to personnel with pagers. Information typically sent includes system status, known problems, and directions for field personnel. In HELCO's case, all email and intranet traffic is routed through HECO. Only HELCO's first text message following the earthquake was routed through properly. When the Maui and Oahu systems lost power, no text messages and alpha-pages could be sent. On October 15th, loss of the paging/text messaging communication system did not hinder or delay HELCO's ability to respond to the partial outage and efforts to restore the system.

4 Conclusions

After evaluating general system information provided by HELCO, the data logs and other automatically generated information and information discussed throughout this report, along with the statements of the operators on duty during the event and restoration, we conclude:

1. The main underlying cause of the partial system outage was the earthquake inducing the operation of relays during the seismic shaking of transmission line ABB Style AR auxiliary relays; and Qualitrol Fault Pressure sensors with electro-magnetic target relays. This led to an outage of the transmission system from north of Kealia in South Kona to Pepeekeo on the Hamakua coast. The earthquake also initiated the trips of HEP on vibration. The loss of load on the east side of the island from the transmission system separation initially resulted in over frequency on the remaining portion of the system, which then went into under frequency and load shed when Puna Steam, Hill 6 and Hill 5 went off-line. Recommendations are presented to assess and remedy these issues.

2. The manual trip of Puna Steam Unit was reasonable and in the public interest. When the system went into over-frequency, Puna Steam's governor droop response characteristic quickly caused the unit to reduce load to the point where the generator began to motor. The operator had specific training to trip the unit in this event to prevent damage that could result in extensive down time for repairs. The boiler steam pressure was preserved so that it was able to be quickly restart when the system had stabilized. No recommendation is made with regard to this operator action.

3. The trip of the Hill 5 boiler is thought to be related to the earthquake but we have not been able to positively identify a cause for the fuel oil trip. Hill 6 had earthquake caused trips of the boiler feed-water pump from liquid level switches on the deaerator level alarms, but the operators were aware of this possibility and quickly reset the pumps. The boiler feedwater trips did not result in the trip of the Hill 6 turbine. The superheated steam leak on Hill 6 is believed to have been triggered by the high pressure steam transients due to the extreme system frequencies following the loss of transmission during the earthquake. A recommendation is forthcoming to assess replacement of the liquid level switches on the deaerator level alarms.

4. The HEP combustion turbine generator vibration trips were valid to protect the units as the minimum mechanical clearances were exceeded. As noted, the unit employs proximity sensors on the generators that detect when the manufacturer's minimum mechanical tolerances are exceeded. When this occurs, the machine is in danger of sustaining damage, even if the source of the problem is external shaking. As this is concluded to be a valid trip to protect the equipment, no recommendations are forthcoming.

5. Communications internal to HELCO and with the Civil Defense agencies through the Emergency Operation Center worked very well. The microwave, VHF and UHF communication system operated properly. The only indication of a failure of the internal communication system was with the paging/text messaging system. This paging/text messaging system presently depends on equipment routed over Maui to HECO equipment on Oahu and has potential failure modes unrelated with the status of the system on the island of Hawaii. On October 15th loss of the paging/text messaging communication system did not hinder or delay HELCO's ability to respond to the partial outage and efforts to restore the system.

6. The power plants, KOCC and transmission system were properly configured, dispatched and staffed for normal operations the morning of Sunday October 15, 2006 at 0700 hours. No recommendations are made with regard to staffing.

7. The actions of the HELCO staff were reasonable and in the best interests of the public. In POWER's opinion, the HELCO personnel reacted to the circumstances in a reasonable, responsible and professional manner. The system operations and power plant staff applied training and experience in reacting immediately and properly to the changing system conditions to prevent an island-wide blackout, protect generation plant equipment, and restore power as quickly as practical. We have considered data logs of the KOCC, power plant units, and transmission system following the earthquake on the morning of October 15. We also reviewed statements of power plant operators and conducted direct interviews of HELCO personnel in various positions. We, we have not identified any instance for which we would offer an alternative action. We are not aware of any case where actions could be described as imprudent, or likely to cause injury or damage. There can be no doubt that the operating staff, especially in the KOCC and power plant, during and immediately after the earthquake at 0708 hours on October 15th, experienced conditions outside their normal operations experience. The situation was complicated and confused by the plethora of alarm indications, the transmission system tripping open, transformers tripping open, generation tripping, power stabilization of the Hilo area grid and the subsequent need to quickly restore the system. The HELCO personnel acted professionally throughout the event and restoration applying their training and experience to their assigned tasks during a distinctly extraordinary event. The system restoration plan developed by the operations staff was prioritized, reasonable and well executed. The pace of the restoration was very aggressive and well executed where the system could be remotely closed to restore the transmission to generation plants and load centers. System integrity assessment, identification of damage and repair was expedited as

much as possible, considering the staffing assignments and the initial road closures, to safely restore service to all customers as quickly as possible.

5 Recommendations

In this section of this report we provide recommendations which, if implemented, could improve the system operation under circumstances similar to those on October 15, 2006, speed up the restoration of electricity to consumers, and reduce the risk of equipment damage in the event of serious system disturbance. We recommend the following:

1. Evaluate the transmission relaying equipment, mounting methods, and operational schemes related to the employment of ABB Style AR auxiliary relays to provide relay protection schemes that are less likely to miss-operate during seismic events.

2. Investigate and evaluate the likely miss-operation of the Qualitrol Fault Pressure sensors with magnetic target relays protective equipment installed on HELCO transformers. Determine appropriate sensor/relay replacements or scheme changes that reduce the likelihood of the tripping of substation and generator step-up transformers due to miss-operation during seismic events.

3. Assess the transformer primary fuse holders to determine whether there is another model or changes to its mounting and configuration to make fuses and their holders less susceptible to shaking open during seismic events.

4. Assess application in the steam power plants of liquid level switches used in Hill 6, and determine the appropriate equipment to provide elements that are less susceptible to operation due to external shaking.

5. Assess the internal HELCO communications for paging/text messaging to determine potential failure modes and appropriate solutions.

POWER Engineers

MECO Report

March 27, 2007

MAUI ELECTRIC COMPANY

Investigation of 2006 Maui Island -Wide Power Outage
PUC Docket Number 2006-0431

PROJECT NUMBER:
111699

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POWER ENGINEERS

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Executive Summary

The State of Hawaii experienced a 6.7 magnitude earthquake west of the island of Hawaii at about 0707 hours on Sunday, October 15, 2006 (epicenter). This was the strongest earthquake recorded in Hawaii in 23 years. According to the Hawaii Volcano Observatory (HVO), a second earthquake (6.0 magnitude) occurred approximately seven minutes later. Associated power system events led to island-wide blackouts for Hawaiian Electric Company, Inc. (HECO) on Oahu and Maui Electric Company, Ltd. (MECO) on Maui, although there was little apparent seismic damage to the electric systems on either island. Hawaii Electric Light Company, Inc. (HELCO) on the island of Hawaii maintained partial service with an isolated section, or "island" of generation and customer load in the Hilo area.

MECO had restored service to the majority of its customers by 1315 hours and the remaining customers by 1432 hours on October 15.

POWER Engineers, Inc. (POWER) was retained to investigate the causes of the outage on Maui and provide professional opinions on the reasonableness of the responses of the MECO staff during the event and during power restoration. POWER's principal investigators, experts in power delivery systems and generation plant design and operation, traveled to Maui on January 8 and 9, 2007 to discuss the events with MECO staff, conduct field visits and gather information relevant to the events of the power outage and restoration on Maui. Additional information was gathered via discussions over phone, through follow up information requests, and analysis of system drawings, relevant Company logs, records, personnel interviews, and other applicable system documentation.

In summary, we find:

- The MECO system was in proper operating condition and appropriately staffed by personnel at the time that the earthquake struck.
- The earthquake causing vibration sensors to trip Maalaea M14 and M16 generators was the direct and proximate cause of the island-wide outage. Loss of these generators set in motion a series of events (through the operation of automatic relays and through operators' actions to protect the equipment) which resulted in sequential loss of generation and eventually led to the system shutdown.
- In POWER's opinion, the MECO personnel reacted to the circumstances in a reasonable, responsible and professional manner. They applied training and experience in reacting properly to the changing system conditions based on the existing system configuration and established MECO operating practices to restore power as quickly as practical.
- Trips of the black start diesel unit at Kahului during the black start process did not impact the system restoration time because the combination and configuration of diesel units at Maalaea Power Plant provided a much faster black start capability.
- Trips of the M5 and M6 diesel units at Maalaea during the initial attempts to re-energize the 69 kV system delayed overall system restoration by approximately 15 minutes. In POWER's opinion, this was a result of attempting to re-energize the system before the transmission and distribution system loads were completely sectionalized.
- In the restoration, MECO operated reasonably and in the public interest by following a systematic, orderly and methodical approach to add priority and customer load to the system as quickly as generators could be started and connected to the bus.
- With the understanding that no system event will ever be identical to the one before it, we do make some specific recommendations which can be found at the end of this Executive Summary and in Section 5 of the report.

Discussion of Findings

The Hawaii Public Utilities Commission issued PUC Order No. 22986, Docket No. 2006-0431 ("PUC Order") requiring an examination of whether HECO, HELCO and MECO acted reasonably and in the public interest prior to and during the power outages. The PUC Order, Section II.C Preliminary Issues, page 8 and page 9, established the scope for this investigation.[1] This report addresses the following issues with respect to MECO.

1. *Aside from the earthquake, are there any underlying causes that contributed or may have contributed to the power outages?*

   We believe that the main underlying cause of the outage was the seismic action of the earthquake triggering vibration alarms and trips on Maalaea unit M14 and M16 generators, due to the shaking of the combustion turbine-generator set. The alarms and trips were valid to protect the equipment, even though the cause was an external event and not equipment damage. In this case, the M14 and M16 generators were tripped simultaneously and the corresponding heat recovery steam generator, M15, also lost its heat source and would soon lose output power. Other generating units were consequently tripped by their protection systems as the loss of M14 and M16 stressed the system.

2. *Were the activities and performance of the HECO Companies prior to and during the power outages reasonable and in the public interest? Specifically, were the power restoration processes and communication regarding the outages reasonable and timely under the circumstances?*

[1] We understand that the preliminary issues were adopted as the issues for Docket No. 2006-0431 by Order No. 23155 (filed December 21, 2006).

MECO's performance prior to and during the outage demonstrated reasonable actions in the public interest. The investigation found that prior to the outage, the system had all transmission lines in service and the appropriate generation available to supply load and reserves according to the MECO operating practices. MECO had a load shed scheme in operation. They have performed regular training; such as emergency response Incident Command exercises and black start training at the power plants.

The operator trip of Kahului unit 4 was reasonable and in the public interest considering the observations and previous experience of the operator. Power plant alarm logs indicate that the unit alarmed on high vibration two seconds after the operator trip, so K4 would have been tripped by the operator in any case based on the alarm.

The actions of the MECO staff were certainly reasonable and timely and in the best interests of the public. Two cases where responses could have been improved are tripping of the Kahului black start generator by overload from too many auxiliaries left on the bus and trip of the Maalaea diesel units M5 and M6 on overload when attempting to pick up too large of load increments. In POWER's opinion, the trip of the Kahului black start did not affect the duration of the outage because the Maalaea Power Plant is configured to allow fast start from the diesel generators without having to reconfigure auxiliary buses. In other words, the island restoration would not have taken any less time if the Kahului black start process did not encounter the overload trip. We are not aware of any case where actions could be described as imprudent or likely to cause injury, or damage. In our opinion, actions by MECO personnel were reasonable, responsible and conducted in a professional manner.

The system restoration plan developed after the outage by the operations staff was reasonable based on the MECO generation available to restart the system and MECO management's historical knowledge of critical restoration issues. The plan appears to have been well executed by the management, dispatchers, power plant operators and field crews after the system was sufficiently sectionalized to allow Maalaea Power Plant to re-energize the system. Initial attempts to energize the 69 kV system with too large an increment of load connected resulted in two trips of the diesel generators. During the restart time, additional loads were disconnected to dial in an increment that could be picked up while energizing the 69 kV and 23 kV systems. This process took about 15 minutes, successfully restoring power at 0902 hours. The aggressive pace of the restoration was balanced against the risk of tripping the generators restored to service, which would have required the system to be re-sectionalized and then re-started. Coordination between load dispatch and the power plants was set up with a *central point of contact* at Kahului power plant to relay messages to Maalaea. The generation/load mix was monitored and controlled by the dispatcher and Kahului station supervisor. The plant operator would tell dispatch how much load they could take as generation was brought on line and dispatch would select a feeder which would fit within the load range, based on experience and load readings prior to the outage, and close the breaker. A significant portion of the MECO system can be closed in by SCADA, which allowed the dispatch staff to select and close priority feeders as generation became available that matched the estimated load of the feeder.

Most of the MECO primary internal communication systems initially failed to operate due to a loss of power, but did not contribute to the outage or significantly hamper restoration as communication between the dispatch center, power plants and field crews was established using the MECO short wave radio system and external land-line and cellular telephones. Once auxiliary and utility power was restored, the MECO internal communications system returned to normal operation. Loss of the communication systems was a result of failure of the backup emergency power sources.

3. *Could the island-wide power outages on Oahu and Maui have been avoided? What are the necessary steps to minimize and improve the response to such occurrences in the future?*

In POWER's opinion, the outage on Maui was unavoidable given the circumstances. The vibration trips of the Maalaea combustion turbine M14 and M16 generators were valid to protect the equipment even though they were initiated by external shaking. At the time of the earthquake the MECO system was carrying a reserve capacity of 36 MW and loss of M14 and M16 dropped 40 MW of generator capacity and also stopped providing heat to the combined cycle boiler for M15, which would soon lose power output and 18 MW of generator capacity. The first load shed block operated as designed when the frequency dropped. With the block 1 load shed and pickup response of the remaining generators, frequency was recovering. Then, M19 automatically tripped on an over-temperature protective trip, and Kaheawa Wind Power (KWP) automatically tripped on an underfrequency protective trip, and K4 was manually tripped, collectively dropping 51.8 MW of capacity. At this point, all remaining load shed blocks operated and there remained a severe load-generation imbalance. The frequency decayed below the EMS measurement threshold of 59 Hz, but protective relay event reports recorded frequencies down to 40 Hz. As the majority of the transmission system remained physically intact, load was disconnected by operation of the automatic load shed scheme. An out of step condition occurred at Puunene and the 69 kV breakers tripped, separating a section of the 69 kV system from Puunene to Kula substations. Operators at Maalaea power plant reported that their remaining generators on line were operating at about 200 rpm when they are designed to run at 450 rpm, indicating a severe overloading and under frequency operation. The M10 and M11 unit auxiliaries had shut down and the operator had to trip them to prevent damaging the machine, resulting in the island-wide outage. POWER could not determine any different actions that could have been taken by the MECO staff that would have clearly prevented a blackout.

With respect to improving responses to future events, POWER offers recommendations 1 and 3 below to improve the MECO communication reliability and reduce the time required to prepare the transmission and distribution system for re-energization.

Recommendations

The detailed recommendations from Section 5 are summarized below.

1. Evaluate the various internal MECO communication systems and associated emergency and uninterruptible power supplies. Institute recommendations from the evaluation to provide robust and dependable internal communication emergency power supply systems. MECO began this assessment soon after the outage has been implementing the recommendations.

2. Assess the communication protocol between dispatch and power plant operators to determine if they can or should be streamlined to allow closer coordination between dispatch and the individual plants during system restoration.

3. As the MECO system has a significant "fast start" capability, assess the possibility of programming a single button "black system" feature in the SCADA system to automatically open SCADA controlled breakers so that this activity does not become the critical path for system re-energization.

4. Evaluate upgrade of the system frequency and voltage recording equipment to install devices with faster scan rates and wider upper/lower limits to provide better data resolution for evaluating future events.

1 Introduction

The State of Hawaii experienced a 6.7 magnitude earthquake west of the island of Hawaii at about 0707 hours on Sunday, October 15, 2006 (epicenter). This was the strongest earthquake recorded in Hawaii in 23 years. According to the Hawaii Volcano Observatory, a second earthquake (6.0 magnitude) occurred approximately seven minutes later. Associated power system events led to island-wide blackouts for Hawaiian Electric Company, Inc. (HECO) on Oahu and Maui Electric Company, Ltd. (MECO) on Maui, although there was little apparent seismic damage to the electric systems on either island. Hawaii Electric Light Company, Inc. (HELCO) on the island of Hawaii maintained partial service with an isolated section, or "island" of generation and customer load on the east side of Hawaii.

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The Hawaii Public Utilities Commission issued PUC Order No. 22986, Docket No. 2006-0431 ("PUC Order") requiring an examination of whether Hawaiian Electric Company, Inc. (HECO), Hawaii Electric Light Company, Inc. (HELCO) and Maui Electric Company, Ltd. (MECO) (collectively "the HECO Companies") acted reasonably and in the public interest prior to and during the power outages. The PUC Order, Section II.C Preliminary Issues, page 8 and page 9, established the scope for this investigation.

The PUC Order identified the following investigation subjects:[2]

1. Aside from the earthquake, are there any underlying causes that contributed or may have contributed to the power outages?

2. Were the activities and performance of the HECO Companies prior to and during the power outages reasonable and in the public interest? Specifically, were the power restoration processes and communication regarding the outages reasonable and timely under the circumstances?

3. Could the island-wide power outages on Oahu and Maui have been avoided? What are the necessary steps to minimize and improve the response to such occurrences in the future?

4. What penalties, if any, should be imposed on the HECO companies?[3]

[2] We understand that these four issues were adopted in Order No. 23155 (filed December 21, 2006) in Docket No. 2006-0431.
[3] This report does not address this subject.

In addition, a reference under II.A Discussions, at the bottom of page 7 states: "... there may be some benefits to being able to compare the different utility systems on each of the three affected islands. These differences can and should be explained in the context of the outages and the varying restoration times." The comparison is presented in the HECO, HELCO, MECO Outage and Restoration Comparison report submitted to the PUC.

From the PUC Order, MECO established the main statement of work for POWER Engineers to investigate and provide expert opinions with respect to the island-wide blackout and restoration on Maui. POWER's investigation focused on four primary topic areas for the MECO transmission system, dispatch center and power plants.

These topic areas are:

- Configuration prior to the event, to include operating procedures and prior training relevant to the event.
- Transmission system, dispatch center and power plant operator actions and automatic protection system action during the interval between the time when the earthquake seismic waves reached Maui and the onset of the island-wide blackout.
- Personnel actions and equipment operations during the interval between the blackout and the return of the first generating units back on the grid.
- Restoration of the power grid from the time the first unit came on line until restoration of service to all customers on October 15.

2 Sequence of Events

2.1 Background

Transmission and Distribution System

The MECO transmission and distribution system consists of fifteen 69 kV transmission substations, seven 23 kV substations, thirty-three distribution substations, seventeen 69 kV transmission lines, fifteen 23 kV sub-transmission lines, and ninety-two distribution feeder circuits. The 69 kV and 23 kV circuits are interconnected with redundant circuits that provide multiple options for supplying power to the distribution substations to increase reliability.

MECO has three blocks of automatic load shedding with set-points of 58.7Hz (5-cycle delay), 58.5Hz (no delay), and 58.0Hz (no delay). The set-points are rotated among the three blocks to avoid disrupting the same customers over and over.

- Block 1, approximately 15.4 MW
- Block 2, approximately 10.5 MW
- Block 3, approximately 12 MW

Operations

MECO typically operates with a "regulating reserve". This means that they have generators on line and running with a total capacity to produce approximately 7 to 10 MW more than the load in order to absorb typical load fluctuations. Generators are brought on line (or taken off line) to anticipate the expected load variations throughout the day and maintain the regulating reserve. The Kahului and Maalaea power plants utilize published unit start up and shut down guidelines for the units but do not have an overall plant or system operating manual. Additional operating guidelines are incorporated in conditional source permit (CSP) documents. This operating philosophy is perfectly reasonable for a relatively small electrical system like that on Maui. It is noted that the system is therefore not operated with a "spinning reserve" sufficient to cover the loss of the largest single generating unit, which is generally the operating philosophy on larger networks. Instead, MECO relies on a combination of fast start diesel engines and underfrequency load shedding to stabilize the system following the loss of the largest unit.

The Dispatch Center has a large wall display to show the status of transmission system, substation circuit breakers and generators and is staffed by the on duty Dispatch Supervisor (DS). This system has an Automatic Generation Control (AGC) function which continuously controls the dispatch of generators that are placed on ACG and displays this information on the wall screen and computer monitors. Units not on AGC control do not participate in load following. One function of the energy management system (EMS) is to record and archive system information such as generator output and frequency. Generating units are brought on line and taken off line daily according to changing load requirements. As load demand increases, the dispatcher coordinates with the Kahului Power Plant operator to dispatch the generation resources. Generator designations, capacities and loading on October 15, 2006 just prior to the earthquake are provided in Table 1.

The Kahului power plant consists of four boiler/steam turbine/generator sets. All four units are operated from one control room that monitors and operates the units. The steam turbine-generator sets are all located on the same floor as the control room.

Maalaea power plant has 15 diesel internal combustion engines (ICE) ranging from 2.5 MW to 12.5 MW generating capacity. The five 2.5 MW ICE units are battery start, while the larger units are compressed air start. Maalaea also has two combined cycle plants with each plant having two combustion turbines (CT) and one heat recovery steam generator (HRSG). One of the HRSG units was in the process of commissioning and was not available on October 15. The ICE and combined cycle plants have separate control rooms.

Each power plant is staffed with a Shift Supervisor who is responsible for the day-to-day operations of the power plant. Kahului power plant has three operators that support steam unit activities. Maalaea power plant has five operators that support diesel and combined cycle plant activities.

Base load units are economically dispatched to meet system requirements, including meeting regulating reserve, and may operate from full output to minimum output on a daily basis. The "base load" terminology in this instance indicates that the machine is connected to the bus and producing power 52 weeks per year, 24 hours per day, unless it is out of service for maintenance. Cycling units are brought on line each day as the load increases and taken off line as load decreases. Cycling units are restarted and synchronized to the system according to the commitment schedule. Peaking units are started when required to supply the system peak load.

Black start procedures are identified in Chapter 11 of the MECO Emergency Restoration Plan (ERP) for Kahului (11.8.1) and Maalaea (11.8.4) power plants.

Relevant Training

Training of operators at power plants is done when a vacancy in an operating position occurs. The training will involve doubling up with a qualified operator for a period of 2-3 months with a solo period of 1 month to qualify for the position. The shift supervisors are responsible to oversee and follow up with the training. The supervisors go over the training checklists with the operator trainee to ensure that the trainee understands the equipment, and its operation as it pertains to the operation of the plant and its function. Training is also provided with any changes or upgrades to equipment within the power plant. During black start training, the black start generator is synchronized to the auxiliary load center and ran at full load; no change in auxiliary bus configuration is made to match the generator load capacity.

Kahului Power Plant black start training is provided to all crew members by the Shift Supervisors on a regular basis. Junior Boiler Operators and Operator Helpers are trained on starting, synchronizing, operating and shutdown of the black start unit when it is capability tested. Maalaea Power Plant training for black start operation is performed during the training of the operators at the respective units and the procedures are kept at the units (M1, M2, M3, and M14-M16 Control Room). During the training to qualify the operators, the operators manually start the black start units and synchronize the units to the grid. The black start unit at the combined cycle power plant (M14, M15 and M16) is started by the operators on a weekly basis and synchronized to grid to ensure that the unit is available when needed. Combined cycle plant training includes matching the auxiliary bus configuration to the Electro-Motive Division generator and black start generator capacities. The 2.5 MW diesel units (M1, M2, and M3) are used for peaking and are operated as needed.

2.2 System Conditions at 7:00 AM Sunday October 15th

On Sunday October 15, prior to the earthquakes, the 69 kV transmission and 23 kV sub-transmission systems were in their normal configuration with all lines in service. No transmission maintenance outages were scheduled for the day. The generation commitments for a Sunday morning were normal. The capacity of MECO and IPP plants in operation immediately before the earthquake was approximately 173 MW, and the system load was 137 MW. The on line capacity exceeded the system load plus the normal regulating reserve in anticipation of morning load increases. The power plant unit status from the EMS archive was as follows:

Table 1: Generation Status 0708:30 Hours October 15, 2006

	FUEL TYPE	UNIT TYPE	NTL (GROSS MW)	MODE OF OPERATION	SERVICE DATE	STATUS	OUTPUT (MW)	RESERVE (MW)
MAALAEA GENERATING STATION								
X1	No. 2 Diesel	ICE	2.5	Peaking	1987	OFF	0	0.0
X2	No. 2 Diesel	ICE	2.5	Peaking	1987	OFF	0	0.0
M1	No. 2 Diesel	ICE	2.5	Peaking	1971	OFF	0	0.0
M2	No. 2 Diesel	ICE	2.5	Peaking	1972	OFF	0	0.0
M3	No. 2 Diesel	ICE	2.5	Peaking	1972	OFF	0	0.0
M4	No. 2 Diesel	ICE	5.6	Cycling	1973	OFF	0	0.0
M5	No. 2 Diesel	ICE	5.6	Cycling	1973	OFF	0	0.0
M6	No. 2 Diesel	ICE	5.6	Cycling	1975	OFF	0	0.0
M7	No. 2 Diesel	ICE	5.6	Cycling	1975	OFF	0	0.0
M8	No. 2 Diesel	ICE	5.6	Cycling	1977	OFF	0	0.0
M9	No. 2 Diesel	ICE	5.6	Cycling	1978	OFF	0	0.0
M10	No. 2 Diesel	ICE	12.5	Cycling	1979	ON - on AGC	6.9	5.6
M11	No. 2 Diesel	ICE	12.5	Cycling	1980	ON - on AGC	8.0	4.5
M12	No. 2 Diesel	ICE	12.5	Cycling	1988	ON - on AGC	6.4	6.1
M13	No. 2 Diesel	ICE	12.5	Cycling	1989	OFF	0.0	0.0
M14	No. 2 Diesel	CT	20.0	DTCC-Baseload	1992	ON - on AGC	19.0	1.0
M15	Exhaust Gas	Steam Turbine	18.0	DTCC-Baseload	1993	ON - on AGC	12.8	5.2
M16	No. 2 Diesel	CT	20.0	DTCC-Baseload	1993	ON - on AGC	18.5	1.5
M17	No. 2 Diesel	CT	21.2	STCC-Cycling	1998	OFF	0.0	0.0
M18	Exhaust Gas	Steam Turbine	18.0	STCC-Baseload	2006	OFF	0.0	0.0
M19	No. 2 Diesel	CT	21.2	STCC-Baseload	2000	ON - on AGC	12.0	9.2
	Total Maalaea Generating Station		214.5				83.6	33.1

Table 1 Continued: Generation Status 0708:30 Hours October 15, 2006

	FUEL TYPE	UNIT TYPE	NTL (GROSS MW)	MODE OF OPERATION	SERVICE DATE	STATUS	OUTPUT (MW)	RESERVE (MW)
KAHULUI GENERATING STATION								
K1	No. 6 Fuel Oil	Boiler/Steam Turbine	5.0	Cycling	1948	ON - not on AGC	2.1	2.9
K2	No. 6 Fuel Oil	Boiler/Steam Turbine	5.0	Cycling	1949	Overhaul	0.0	0.0
K3	No. 6 Fuel Oil	Boiler/Steam Turbine	11.5	Baseload	1954	ON - not on AGC	11.5	0.0
K4	No. 6 Fuel Oil	Boiler/Steam Turbine	12.5	Baseload	1966	ON - not on AGC	12.5	0.0
	Total Kahului Generating Station		34.0				26.1	2.9
HANA SUBSTATION								
H1	No. 2 Diesel	ICE	1.0	Emergency	2001	OFF	0.0	0.0
H2	No. 2 Diesel	ICE	1.0	Emergency	2001	OFF	0.0	0.0
		Total Hana Substation	2.0					
IPPs								
HC&S		Biomass	16	Baseload	1989	ON - not on AGC	9.1	0.0
Kaheawa (KWP)		Wind Farm	30.0	As-Available	2006	ON - not on AGC	18.1	0.0
Makila Hydro		Run-of-river Hydro	0.5	As-Available	2006		0.0	0.0
		Total IPP Generation	46.5				27.2	0.0
TOTAL GENERATION AND RESERVE							**136.9**	**36**

The Dispatch Center was properly staffed according to MECO operating procedures. The EMS archive indicated a generation reserve of 36 MW. The dispatcher was conducting routine monitoring of the system conditions and coordinating the startup schedule of generation with the operator at Kahului Power Plant as demand for power began to increase.

Kahului and Maalaea power plant staffing was normal for a Sunday. The personnel were conducting their normal routines of monitoring the plant conditions. The Kahului operator coordinated with the dispatcher to schedule the generation and unit commitment with the operators at Maalaea. Base load units were near capacity and cycling units were increasing their output as the morning load demand increased.

2.3 Earthquake and Island-Wide Outage Sequence of Events

2.3.1 Earthquake to Outage

We have developed the sequence of events from just before the earthquake to the outage using information from the EMS, supervisory control and data acquisition (SCADA) reports, power plant distributed control system (DCS) alarm logs, relay event recordings, and employee interviews. This sequence of events coincides with the information displayed in the following figures. Figure 1 shows the system generation/load and frequency with the timing of load shed events on the MECO system from the time of the earthquake until M10 tripped. Figures 2 shows the megawatt output of the individual generating units and the system frequency from 07:08:20 to 07:09:00. Figure 3 shows the megawatt output of the remaining generating units from 07:09:00 to 07:18:00 when all units were off line. Figure 4 shows the system load and frequency from 07:08:20 to 07:18:00 to illustrate that the frequency remained below the 59 Hz.

The EMS, SCADA, DCS and relays are not continuously synchronized to the same clock, so time stamps do not exactly correlate between devices. Time stamps for the sequence of events determined below are primarily derived from the EMS and SCADA reports which are recorded in two second intervals. Information from the power plant DCS is used to better describe the sequence of power plant component operations, but the DCS time stamps are not used as they are out of sync with the EMS and SCADA information. The following time estimates were developed by comparing a specific event between the EMS, SCADA, and DCS time stamps. The EMS was used as the base time. Time stamps for the operator trip of K4 were compared for the EMS, SCADA and Kahului Power Plant DCS. The EMS and SCADA were determined to be in time sync and the Kahului DCS time stamp was plus 58 seconds from the EMS. The point on the EMS graph in Figure 2 for the M16 turbine trip and the Maalaea Power Plant DCS time stamp were compared and the Maalaea DCS was found to be minus 74 seconds from the EMS. All times used in this report are based on the 2400 hour time clock.

- K4 Trip (SCADA = 07:08:43, EMS = 07:08:43, Kahului PP DCS = 07:09:41)
- M16 Turbine Trip (EMS = 07:08:31, Maalaea PP DCS = 07:07:17)

We must also note that the MECO generator breakers do not have a direct open/closed status indicator to the SCADA system – when the SCADA register that power output has gone above/below 0.001 MW, it derives the generator breaker has closed/opened and indicates the status change.

Power plants can be tripped in two ways. First, a trip to "shutdown" where the power reduces over a short time and the generator circuit breaker to the system remains closed until tripped by the operator (power output reduces over more than the 2 second scan interval). Second, a trip by a protective device that opens the generator circuit breaker to the system immediately, thus shutting off the power output (power output reduces to zero within the 2 second scan interval). Both of these type events can be seen in Figure 2.

We also note that the EMS archive continued to record the gross output from HC&S after it separated so this value was manually changed to zero from 07:08:46 in the following figures to reflect that no power was exported to the MECO grid.

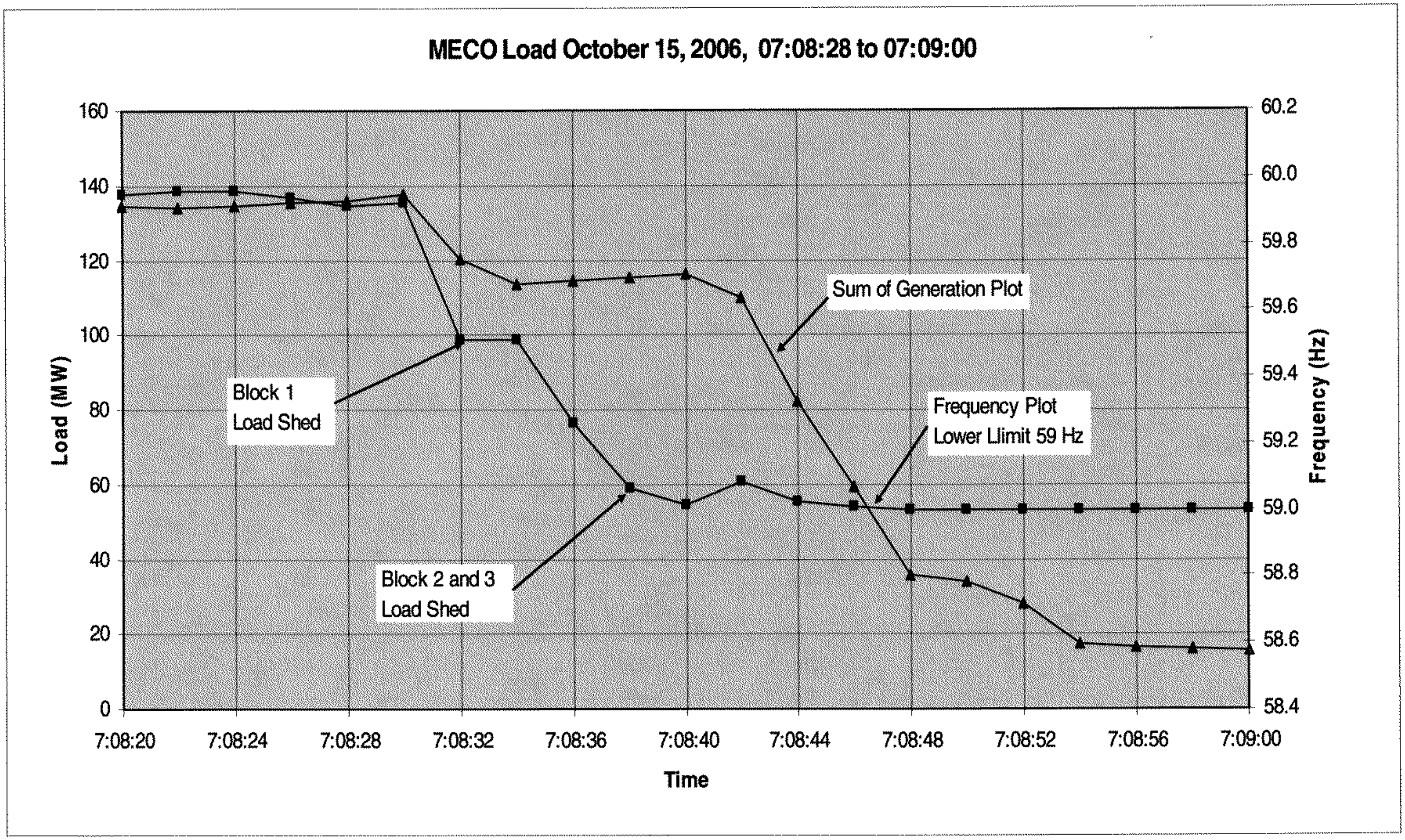

Figure 1: Load versus Frequency Timeline - October 15th, 2006, 07:08:20 to 07:09:00

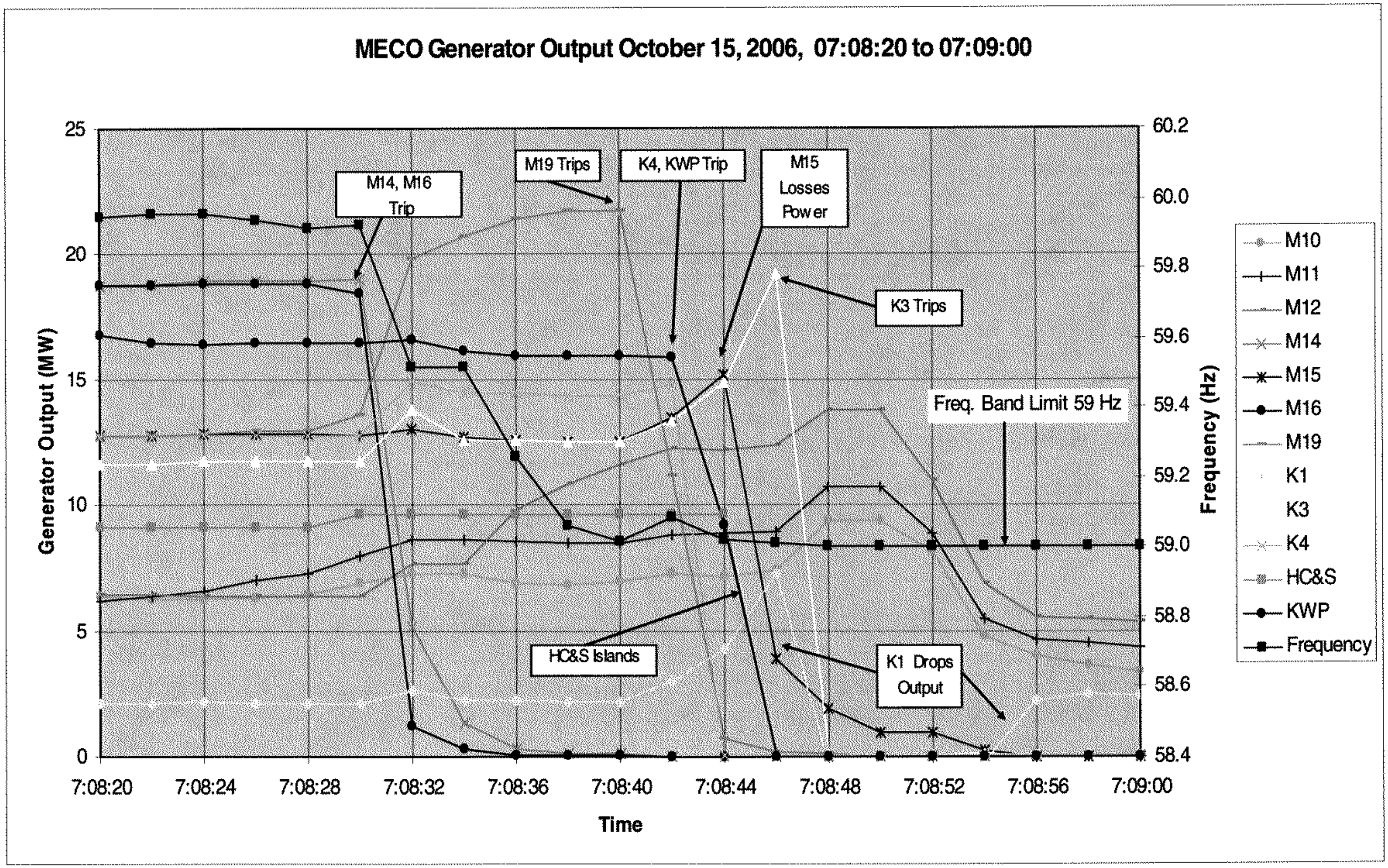

Figure 2: Individual Generator Output Timeline - October 15, 2006, 07:08:20 to 07:09:00

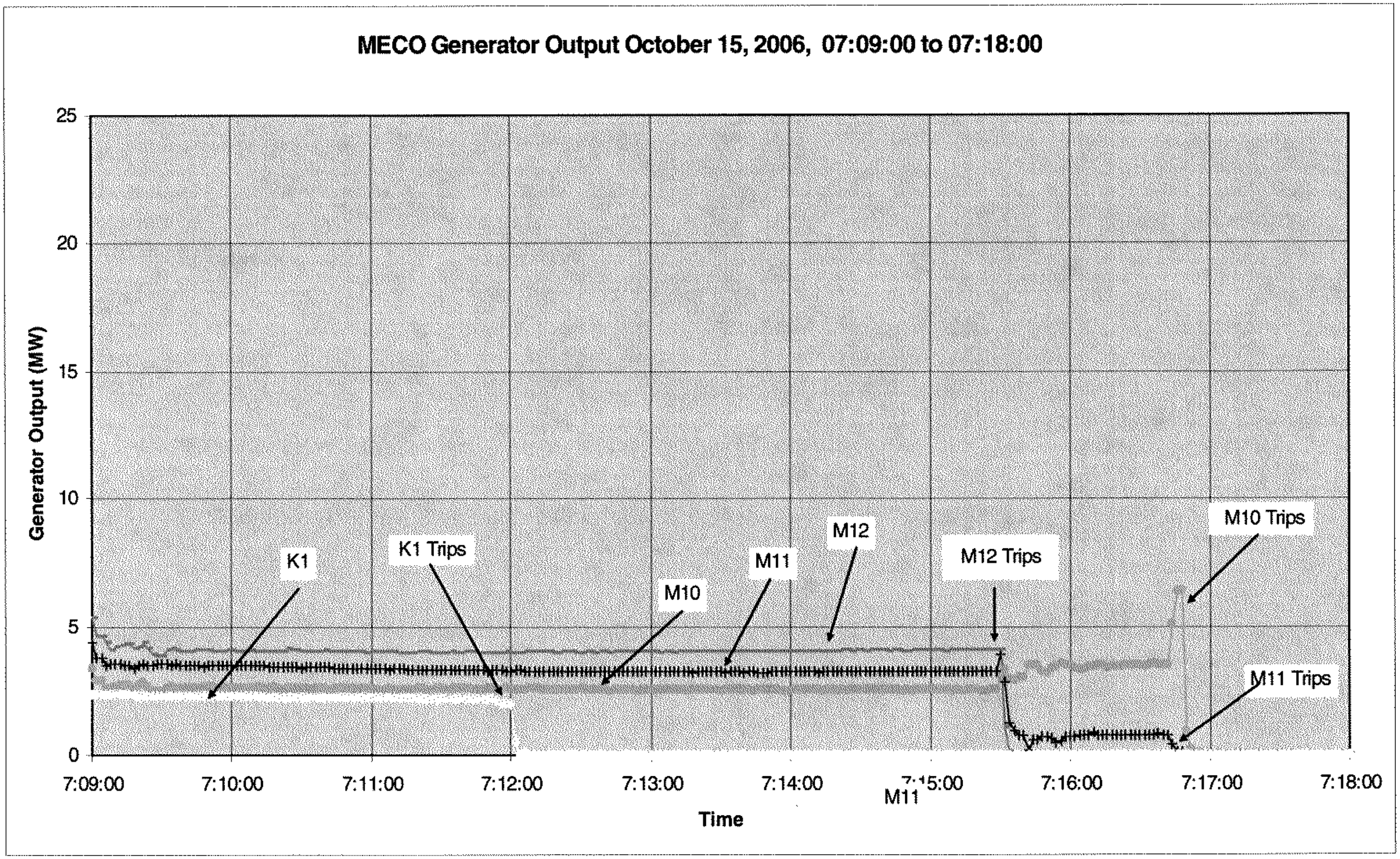

Figure 3: Individual Generator Output Timeline - October 15, 2006, 07:09:00 to 07:18:00

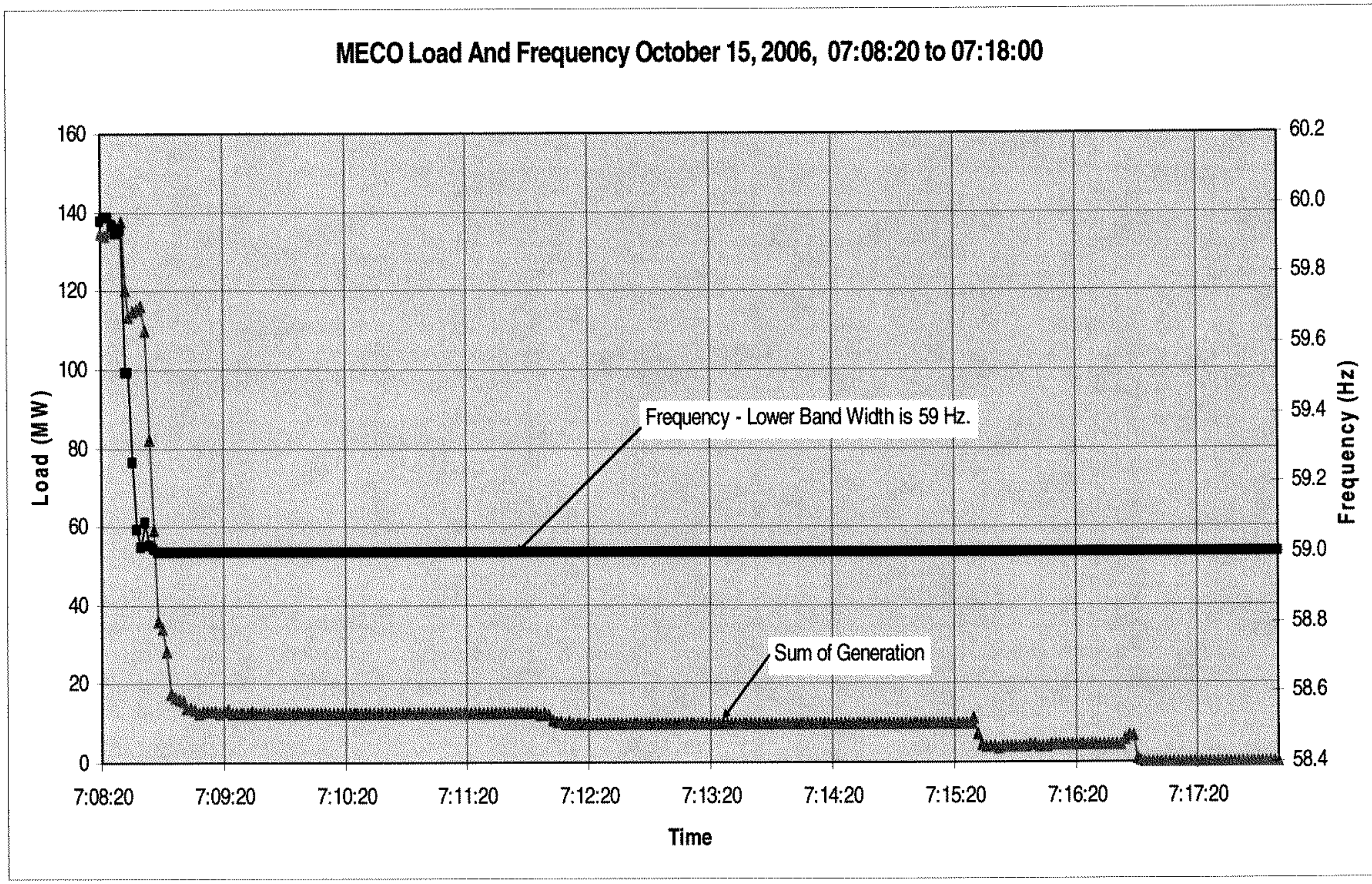

Figure 4: Load versus Frequency Timeline - October 15, 2006, 07:08:20 to 07:18:00

Sequence of Events

7:08:28 – Normal transmission system configuration. EMS indicates 137 MW of generation, 38.9 MW of reserve capacity on line, frequency steady at 60 Hz, and load increasing normally.

7:08:30 – EMS graph shows trip of M14 and M16 (generator vibration).

7:08:31 – SCADA log shows two breakers of load shed block 1 trip.

7:08:33 – SCADA log shows two additional breakers of load shed block 1 trip.

7:08:37 – SCADA log shows M16 breaker open.

7:08:39 – SCADA log shows one breaker of load shed block 2 trips.

7:08:40 – EMS graph shows trip of M19 (turbine over-temp)

7:08:41 – SCADA log shows four breakers of load shed block 2 & 3 trip

7:08:41 – SCADA log shows M14 breaker open.

7:08:42 – EMS graph shows generator trip of K4 (manual – vibration).

7:08:42 – EMS graph shows trip of KWP (07:08:45 SCADA, under frequency trip - 81U).

7:08:43 – SCADA log shows K4 breaker open.

7:08:44 – EMS graph shows reduction of power from M15 (loss of heat from CTs M14 and M16 to the HRSG).

7:08:45 – SCADA log shows eight 69 kV breakers trip (4 tripped by SEL 351A on 81U Sub 97 - KWP).

7:08:45 – SCADA log shows HC&S separated (CB 6848 and 6851 opened at Puunene Out-of-Step)

7:08:46 – EMS graph shows reduction of power from K1. Also shows overload and trip of K3 (86G1 trip of 2252 – static exciter – emergency generator trip).

7:08.48 – EMS graph shows K1 power output near 0 MW.

7:08.50 – EMS graph shows M10, M11 and M12 begin to reduce power output.

7:08:56 – EMS graph shows K1 ramps up to power output to near 2.5 MW.

7:09.30 – EMS graph shows K1, M10, M11 and M12 output stabilizes.

7:12:04 – EMS graph shows trip of K1 (Relay trip – loss of auxiliaries, boiler trip)

7:15:34 – EMS graph shows trip of M12. (Instantaneous overcurrent trip)

7:16:50 – EMS graph shows trip of M11. (Manual trip – loss of auxiliaries)

7:16:52 – EMS graph shows trip of M10. (Manual trip – loss of auxiliaries)

Summary of the System Dynamics

EMS logs, SCADA reports, and power plant DCS logs were analyzed to summarize the activities and system responses to the events. The EMS data provided in 2 second intervals is plotted in figures 1 through 4 to provide a visual interpretation of the data. At the onset of the earthquake, the system was operating normally with all transmission lines in service and generation properly dispatched to provide sufficient reserve in accordance with the MECO operating procedures. M11 was ramping up output as load was increasing. There were essentially two areas of events. In the first 20 seconds after the earthquake, a majority of the generation tripped and load was shed. In the remaining 8 minutes, generation settled out, but the remaining 4 generators eventually tripped.

At the time of the earthquake, numerous alarms began to register at the power plants and Dispatch Center. Power Plant turbine/generator vibration sensors alarmed at the Maalaea Combined-Cycle 1 Control Room and tripped M14 and M16 instantly, dropping 40 MW of capacity carrying 37.5 MW of load. These two units also supply exhaust heat to the M15 HRSG, which then quickly lost power, dropping an additional 18MW of generation. M10, M11, M12, M19 and K3 ramped up to supply the load dropped by M14 and M16. Load shed block 1 tripped four breakers at 07:08:31-33 and arrested the frequency decay for a moment. At 07:08:40, M19 tripped on high exhaust temperature while carrying 21.8 MW of load. The EMS graph shows that at this point frequency began to improve; indicating that load was being shed and other generators were picking up a larger share of the load. This correlates with the SCADA report indicating blocks 2 and 3 shed five breakers. At 07:08:42 when K4 and KWP tripped, the frequency dipped and then straight-lined on the graph (Figure 1 and Figure 2) indicating it had dropped below the lower metering limit of 59 Hz.

The Kahului power plant Shift Supervisor was walking toward the control room when the earthquake hit and observed K4 turbine shaking violently and water leaking from the K4 boiler. He assumed that the turbine was ingesting water and went into the control room and manually tripped the turbine. At the same time the KWP wind farm tripped. An event report for a relay at Substation 97 Kaheawa (KWP) indicated the frequency had dropped to 56.05 Hz at 07:08:41 and the relay tripped KWP on under frequency. K1, K3 and M15 increased output to compensate for the loss of K4 and KWP. M15 then ran out of steam power and electric power output dropped off. K3 overloaded, recorded static exciter alarms, and tripped. At the same time output from K1 dropped off. Breakers opened at Kula, and Puunene substations due to a relay trip on an out-of-step condition. At 07:08:45 HC&S separated from the MECO system and remained in operation with house load. With the above generation loss, M10, M11 and M12 again responded with increased output to meet load and then power output declined between 07:08:50 and 07:09:00, most likely due to reduced output of auxiliary equipment (pumps and motors) due to the extremely low system frequency. At this time, frequency remained below the EMS metering limit of 59 Hz. Relay event reports recorded frequencies as low as 40 Hz in this time frame.

About 3.5 minutes after the earthquake, K1 tripped, followed by M12 3.5 minutes later. The K1 trip was attributed to loss of auxiliary power and M12 to an instantaneous overcurrent relay operation. The Maalaea diesel plant operator indicated that the M10 and M11 were running at about 200 rpm (rated 450 rpm) and lost auxiliaries so the operator manually tripped M11 and then M10 at about 07:16:52 to protect these units from damage.

Load Dispatch Center

At the time of the earthquake, one dispatch supervisor with nine years of dispatch experience at MECO and one dispatcher with less than one year of dispatch experience at MECO were on duty. The dispatchers indicated that when the initial shaking took place, they were immediately aware that it was an earthquake. They reported that the lights, wall display board, computers, phones and radios shut down until the emergency generator came on line. The SCADA alarms were going off continuously and were reported to be too numerous to list. Loss of generation happened too quickly for assessment and intervention by manual load shed.

Power Plants

Interviews with the power plant staff indicated that most of them were not immediately aware that this was an earthquake.

Kahului operators initially thought the shaking was due to turbine vibrations as they visibly noticed turbines shaking and steel floor plates bouncing. The shift supervisor saw the K4 turbine violently shaking and noted water coming down the east side of the boiler. Believing he had a water injection problem he ran into the control room and manually tripped K4. He stated that he did not notice any alarms prior to tripping K4 but began to receive multiple alarms after the K4 trip on all the units. K3 tripped closely thereafter and the DCS indicated that a relay protecting the static exciter initiated the trip. K1 tripped a few minutes later with the DCS indicating loss of auxiliaries and a boiler trip. The operators then began the procedures to secure the boilers, assess equipment status and prepare for black start.

Maalaea operators also were not immediately aware that this had been an earthquake. CTs M14 and M16 generators immediately tripped offline due to vibration alarms and trips. The combined cycle plant operator indicated the alarms on the control panel were too numerous to quickly evaluate what was happening. M19 power output increased sharply and then shortly the unit tripped on high exhaust temperature. M15 HRSG lost power as it no longer had a heat source from M14 and M16. At this point, the operator indicated that he had lost all controls for the plant. The diesel plant operator received multiple alarms on M10, M11 and M12. The operator noted that M12 had tripped on instantaneous over-current, M10 and M11 rpm had dropped from the rated 450 rpm to about 200 rpm, and that the station had lost auxiliaries. The operator tripped M11 and M10 to prevent damage due to loss of auxiliaries. This resulted in the island-wide power outage.

Transmission System

The transmission system remained structurally intact with some leaning poles. The only line that showed a fault trip was the Maalaea-Puunene 69 kV line which tripped at about 0855 hours which was clearly during re-energization. The Kaheawa Sub 97 (KWP) underfrequency relay tripped at 07:08:41, which indicated on SCADA at 07:08:45 (set 56 Hz - 2 cycle delay, 57 Hz - 360 cycles delay). The SCADA log indicates between 07:08:30 and 07:17 that there were numerous records of low voltage, closing and opening of shunt capacitors and opening and closing of transformer motor operated disconnect switches.

Load Shed

All indications from the EMS and SCADA are that the automatic Under Frequency Load Shed (UFLS) scheme operated and shed load as designed. Figure 1 would indicate that the load shed block 1 operated above 59.5 Hz, but it is very likely that the frequency dipped low enough to trip load shed block 1 and then recovered to 59.5Hz within the two second EMS frequency scan interval. Load shed blocks 2 and 3 operated just prior to the point where the Kaheawa Sub 97 (KWP) tripped and the relay recorded the frequency at 56.05 Hz, indicating that they tripped within the appropriate frequency range. This load shed along with a ramp up in output from the remaining generators appeared to arrest the frequency decay due to the loss of M14 and M16. On the loss of M19 the remaining attached load overwhelmed the available generation and the system frequency rapidly declined. Unfortunately, the frequency monitoring equipment in place has a lower limit of 59 Hz so we do not have a clear picture of how the frequency behaved after it reached the lower measurement threshold.

2.3.2 Outage to System Restoration

The following information is based on interviews with management, the dispatchers, power plant operators, as well as information gathered from various MECO sources including the EMS and SCADA.

Key management personnel quickly responded to the engineering offices on their own volition, when they realized that an earthquake had occurred and the power system had blacked out. As they called in, they were redirected in route to the power plants to establish communications and manage the restoration. The key management personnel traveled to the power plants and found that many of the primary communication systems were out of service due to the power outage and the plant personnel were involved in tasks securing the plant, assessing equipment condition and preparing for restart. Communications were established by telephone and radio backup sources.

Numerous activities were taking place in the power plants as power supply personnel prepared to black start generating units at Kahului and Maalaea. Simultaneously, the dispatchers, trouble men and management personnel were preparing the electrical grid for restoration. In addition to preparing the system for restoration, key operations management personnel were developing a sequence for the restoration process. At that point in time, attention was not yet focused on the detailed customer restoration, but rather on a sequence that had to be followed to re-energize the MECO transmission grid.

The primary objectives of the overall restoration plan were:

1) restore power in a safe manner,
2) avoid damage to customer and utility equipment,
3) restore the transmission grid to provide power to the generating plants (from either Kahului or Maalaea depending on what unit was on line first) so that startup power was available to start additional generating units,
4) ensure that there weren't islanded systems if generating units were started at both Kahului and Maalaea,
5) re-energize the 69 kV and 23 kV grid so that loads around the island could be restored, and
6) provide an energized bus to the HC&S so that they could get their generating unit tied back to the MECO system as quickly as possible.

During the time frame from about 0718 hours to 0834 hours when the first unit (M6) was brought on line on the 69 kV bus, different working groups had to coordinate their efforts by communicating what was happening on the system as they prepared the electrical system restoration. A central point of contact was set up at Kahului Power Plant.

Because Maui had just experienced two earthquakes, the dispatch and power plant personnel could not be certain that the equipment was undamaged. As off duty MECO personnel responded to call out, or voluntarily reported to see if they could assist, they visually inspected as much of the transmission and distribution system as possible as they reported to work. The SCADA log indicates that the operators and T&D personnel began to open system breakers to strip load feeders manually and by SCADA at 0740 and were still in the process at 0840 during the first attempt to re-energize the 69 kV system from Maalaea.

With respect to blackouts, because each outage is different and in each case different parts of the system grid/generators may or may not be available, each restoration plan will be unique. Each restoration plan, such as the one developed on October 15, takes into account the available system components, available MECO staff, and experience gained from previous restorations regarding prudent procedures to maintain system stability during the early stages. In the event of a blackout, MECO generally follows guidelines for black starting the system contained in its Emergency Response Plan (ERP). The ERP includes procedures for assembling an incident command team, onsite response teams, communication protocols, and resources to respond.

System Restoration

Transmission and distribution system breakers throughout the system were opened by SCADA or manually. About 65 percent of the MECO distribution breakers are able to be operated by SCADA which reduced the time required to prepare the system. An attempt was considered to energize the system from HC&S, which had continued to operate throughout the disturbance. However, HC&S is a private operation not directly controlled by MECO. In order to protect MECO's staff during maintenance work on the transmission system, the protection and control is designed according to typical utility practice and is arranged such that HC&S cannot connect to a dead MECO bus. After some initial consideration, the attempt to reenergize from HC&S was abandoned as Maalaea was quickly coming back on line. The system was re-energized from Maalaea Power Plant.

Kahului Power Plant

The nature of a steam plant, such as Kahului, is that it takes time and care to "hot" start a boiler and turbine combination. At Kahului a small diesel generator was started up to power auxiliary circuits including the critical turbine turning gear. In addition, steam driven oil pumps were put into operation to use up some of the excess steam in the system and the boilers were stabilized. The auxiliary buses were reconfigured and the turbines put on turning gear. A visual inspection was performed of the fuel system piping and the tank farm. No damage was found. A black start was attempted at Kahului on K1. The initial attempt using the black start generator tripped on overload. Auxiliary air compressors for K3 and K4 were secured from the auxiliary bus and a second attempt was made to start K1. While rolling the K1 turbine the diesel ICE tripped on water jacket over-temperature, due to a problem with the cooling system. At this time, power was restored to the main bus from Maalaea so the auxiliary loads were transferred to the mains, K1 was started and at 1014 hours it was put on line.

Maalaea Power Plant

Diesel internal combustion engines, especially relatively small units, are able to start up and take load within only a few minutes. Maalaea has five diesel ICE units, 2.5 MW each, that are able to start from battery power. The Maalaea 5.6 MW and 12.5 MW units are equipped with an air start system. During and extended outage the air pressure can bleed off. Once station service is restored from the smaller 2.5 MW units, the air system is restored to operating pressure and the larger diesel units perform a blow down and start operation in about 15 minutes.

Combustion turbines can also be started, warmed up, connected to the bus and loaded within 30 minutes, although a key issue for MECO is that the units need to be able to quickly pick up about 8 MW of load to maintain operation within the covered source permit constraints. The LM2500 combustion turbines at Maalaea are equipped with high speed turning gear that must be used to rotate the turbine rotors and circulate air through them after a shutdown to ensure that the rotor cools evenly with the outer case. Without this gear in operation the turbine rotors will distort slightly as they cool or the outer case can cool faster than the rotor causing "thermal lock", and then the unit cannot be re-started until it has cooled down completely. The CT must be on the high speed turning gear within 7 to 10 minutes of shutdown to prevent going into thermal lock. The Maalaea combined cycle plant operator was unable to reconfigure the auxiliary bus, start the emergency generator and put M14, M16 and M19 on the turning gear within this time window. Consequently they went into thermal lock which then required a 3 to 4 hour cool-down period before they could be restarted. The combined cycle plant black start generator was put on line at 0753 hours, and provided power to the combined cycle plants auxiliary circuits.

At Maalaea station, unit M1 was put into operation at 0815 hours, and provided power to the station's auxiliary circuits. At 0834 hours, M6 was connected to the 69 kV bus. Transmission breakers 6777 and 6780 were closed at 0846 to energize the line to Puunene and M6 tripped on overload. Additional transmission and distribution system breakers were opened to reduce connected load. At about 0853 hours M6 and M5 were paralleled to the 69 kV bus and the transmission system breaker closed and both units tripped on overload. Additional distribution system breakers were opened to reduce connected load. M5 and M6 were restarted connected to the bus and began to successfully restore load at 0902 hours.

The system was then re-energized from Maalaea, where nine reciprocating engine sets were started up and brought on line between 0902 hours and 0948 hours comprising five 5.6 MW sets (M4, M5, M6, M7 & M8), two 12.5 MW sets (M10 & M11), and two 2.5 MW sets (X1 & X2). Combustion turbine M17 had been shut down at the time of the earthquake and therefore not restricted from starting. M17 was put on line just before 1000 hours when it was able to take load without violating the covered source permit constraints.

Reciprocating unit M12 at Maalaea was next, at 1041 hours. This set operates under a covered source permit constraint which requires the exhaust gas opacity not to exceed 20% for more than 12 minutes in any hour. Higher levels of opacity are generally experienced on reciprocating engines burning No. 2 diesel during start up and when operating on light loads. Unit M12 is started up on bio-diesel, which has proven cleaner burning characteristics during starting and warm-up, and the fuel is changed over to No. 2 diesel when it has warmed up and loaded. Under a controlled stop, the engine fuel is switched to bio-diesel during shutdown so that it is charged with bio-diesel in readiness for the next start up. However, this unit had tripped during the earthquake event and could not be re-started without risking breaching the covered source permit constraints on exhaust opacity. The fuel system was required to be flushed out and filled with bio-diesel before the engine could be re-started Thus M12's start was delayed by an hour or so compared with the other reciprocating sets.

One of the CT mechanics had responded to the plant shutdown and checked the rotation of CT 14 after about 3 hours of cooling and determined that it was free and a start could be attempted. Combustion turbine M14 was connected to the bus at 1111 hours. The KWP wind farm was reconnected after this, then combustion turbine M16 at 1218 hours and M19 at 1251 hours.

Kahului's unit K3 was brought on line and a very small amount of hydro generation also became available (0.03 MW), bringing the total capacity available by 1432 hours to 217.73 MW.

<u>Load Restoration</u>

Once M6 and M5 were on line, the plant operators would talk to dispatch to communicate how much load they could take. Dispatch would select a feeder which would fit within the load range, based on experience and load readings prior to the outage, and close the breaker. Load was generally added in 2 MW to 5 MW blocks. Criteria for selection of the load to be closed in was the feeder load magnitude prior to the outage and whether it served critical loads.

Understanding and anticipating the system volatility during restoration, MECO operated in an orderly and methodical manner to add load to the system so that there was adequate opportunity to stabilize the operation of the generating units, and stabilize frequency and voltage on the grid. In some cases a feeder or transmission line was taken back out of service when too large a block of load was closed in. As the length of the outage increased "Cold Load Pickup"[4] began to be a factor that the dispatcher and power plant operators had to contend with when energizing circuits.

MECO also encountered a few problems as they energized circuit such as at Sub 40 (Onehee) where two reclosers powered from internal transformers were damaged, Kula circuits that could not be closed by SCADA and a troubleman had to manually close circuits, and circuit 1285 from Maalaea which required sectionalizing into three sections to isolate a fault caused by vegetation contacting the line. All circuits were restored by 1432 hours.

[4] Cold Load Pickup is the term used to refer to the fact that the distribution feeders have lost load diversity (all refrigerators, electric water heaters, and air conditioners come on at once) such that the load, when first energized, is temporarily much higher than normal when the equipment is randomly cycling.

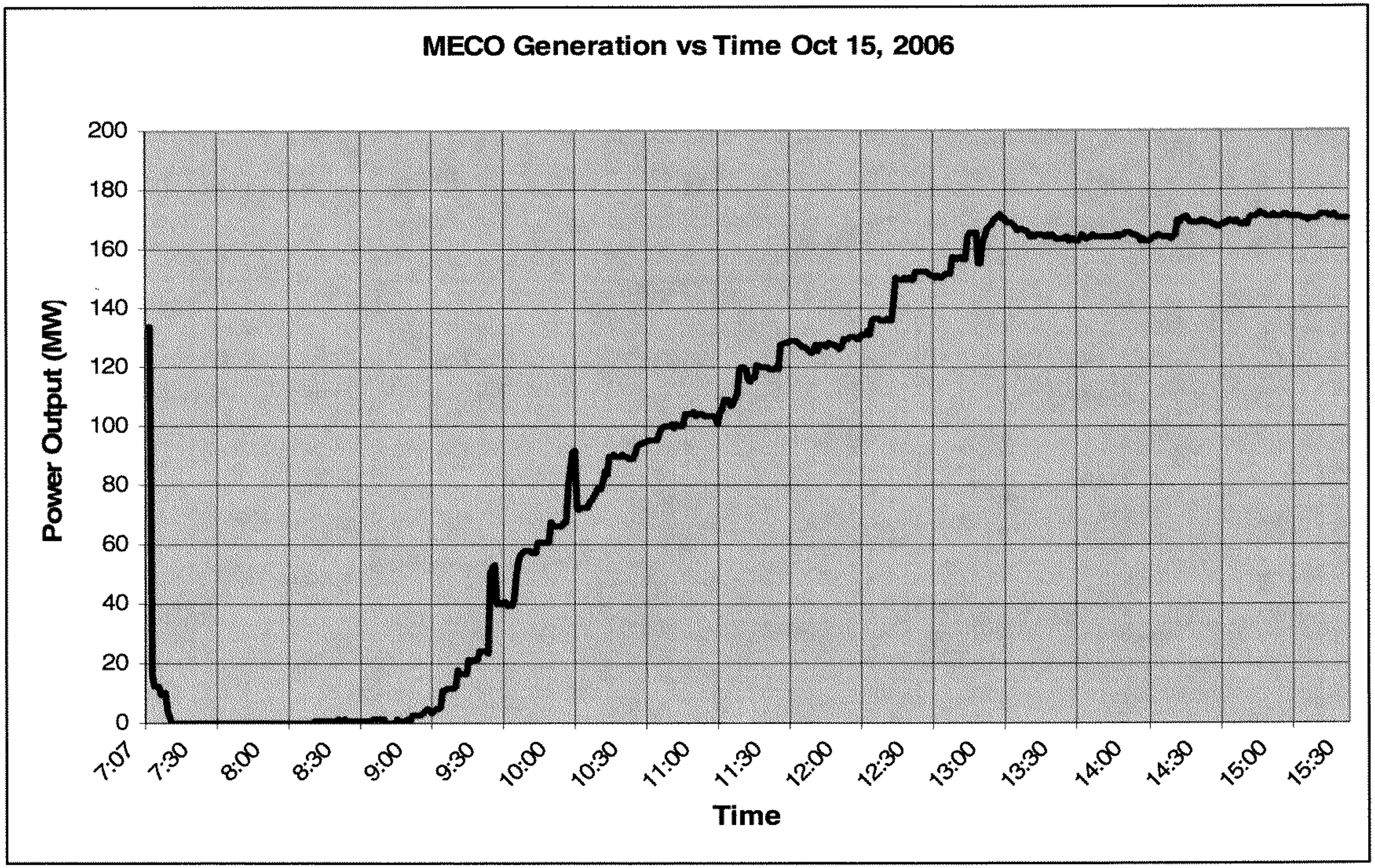

Figure 5: Generation Restoration Megawatts versus Time

3 Evaluation

3.1 Generation Capacity

3.1.1 Maui Generating Fleet

Approximately 293 MW of generating capacity is currently installed on the island of Maui, with 250 MW owned and operated by MECO and 43 MW by Independent Power Producers (IPPs). The MECO and IPP plant capacities are summarized in Table 1. Note that M18, a heat recovery steam generator (HRSG) rated 18 MW, at the Maalaea Generating Station was commissioned in late October 2006 and therefore was not operable around the time of the earthquake. Furthermore, one of the 12.5 MW diesel engines (M13) and one of the 5.6 MW diesel engines (M9) were not available for operation at the time of the earthquake.

The MECO generating equipment is notable for:

- A split between reciprocating engines (approximately 33%), combustion turbines in combined cycle with steam turbines (approximately 40%) and boilers combined with steam turbines (approximately 12%), supplemented by a small amount of renewable generation (approximately 15%).
- The considerable age of the boiler/steam turbine plant. This was installed at Kahului Generating Station between 1948 and 1966.

Expected Performance of Generating Plant During Blackouts

Reciprocating diesel engine generators are generally robust under rapidly changing load events. The newer, 12.5 MW generating sets at Maalaea can be expected to withstand the loss of 100% of their load without tripping, and to be able to start quickly and take on load in steps of several MW at a time. The reciprocating engines themselves would not be expected to have been adversely affected by the ground vibrations during the earthquake. Prior to starting a 2.5 MW unit, the 69 kV bus breakers must be opened in order to isolate the Maalaea power plant buses. The 2.5 MW units have battery start capability and can be quickly started and then provide starting power to the rest of the Maalaea plant. Once one of the 2.5 MW units is started and connected to the bus, it takes about 15 minutes to build up system air pressure, blow down one of the larger ICE units, complete the start/warm-up sequence and connect the unit to the bus to begin restoring power to the 69 kV system.

Steam plants can be very valuable in providing frequency stability. However, older designs of plant such as that at Kahului may have difficulty remaining in service following sudden, large load swings. Sudden large load pickup and reduction can take boiler operating parameters, such as drum levels, to the point where control equipment intervenes to protect the plant from damage and automatically trips the unit, to take it out of service. Once the boiler trips, getting a purge of the boiler fuel fumes and re-light, while keeping the turbine generating, is very difficult and is not often successful. When a plant is suddenly tripped off line, there are numerous steps required to secure the plant, assess equipment conditions, and proceed through the startup sequence. To complete these sequences requires between 2 and 4 hours depending on the residual steam pressure/temperature of the boiler.

Combustion turbine combined cycle plants of the type installed at Maalaea are able to respond well to rapidly changing loads and can be brought on line relatively quickly. The Maalaea combustion turbines are manufactured by General Electric, type LM2500. The LM2500 is based on an aero engine that has been modified for use as a land-based generating set. It is typically used, as in this case, in combined cycle mode whereby the heat in the turbine's exhaust gas is used to generate steam for a steam turbine (HRSG). Maalaea Generating Station uses two combustion turbines feeding heat to one HRSG – again a typical and proven arrangement for a cost effective and efficient installation. As previously described, on shutdown the CTs are required to be put on high speed turning gear within 7 to 10 minutes to properly cool the unit to prevent thermal lock. In normal operation with the auxiliary power available, this is not an issue. When the plant goes black, the auxiliary bus must be properly configured to allow start up of the combined cycle plant 600 kW black start unit to provide auxiliary power. This process takes time, which can lead to the operating CTs going into thermal lock requiring about a 3 to 4 hour cool down time before the unit can be safely restarted. Each CT also requires a minimum load of about 8 MW in order to operate within the covered source permit constraints. The associated HRSG steam turbines take longer to bring on line and are less able to accept significant load changes. However, the combustion turbines can operate in "simple-cycle" mode, i.e. without the HRSG steam turbines running, until sufficient exhaust heat is available to bring the steam turbines on line.

On October 15, the HC&S biomass steam turbine separated from the system and remained in operation. The HC&S plant would have been available to export power to black start the MECO system. However, as is quite normal practice to ensure safety of the MECO system and personnel, the protection and control system is configured to prevent back-energization of a "dead" MECO bus connection by the HC&S unit. The ability of the Maalaea plant to quickly black start using the battery start diesel 2.5 MW ICE units, with no time requirement to reconfigure the auxiliary buses, significantly reduces the value of using HC&S to black start the MECO system.

3.1.3 Operational Generating Capacity on October 15

The system conditions on the morning of October 15 are discussed in sub-Section 2.2 of this report, and the status of the generating units, as of 0708 hours that morning, are shown in Table 1. The capacity of plant operating at that time was 173 MW, 36 MW in excess of total customer demand of 137 MW. The 36 MW of excess operating capacity was substantially greater than the 7 MW to 10 MW regulating reserve normally carried by MECO.

Considering the installed and operationally-available generating capacity and the customer demands on the island of Maui on the morning of October 15, 2006, the black-out of the system was not connected with any shortcomings in the MECO processes for the long-term planning of generating capacity, or the timing of the startup of cycling units, or the selection of generating units to operate that morning.

3.2 Outage

3.2.1 Operator Generator Trips

Units K4, M10 and M11 were tripped manually by their respective operators.

Unit K4 is a steam turbine in Kahului Power Plant. This power station is constructed in the traditional way, with the control room located at the turbine floor level, one floor up from ground level. The main floor comprises steel plates over a framework of structural steel, built around the turbines which are mounted on concrete foundations formed into the ground below. Thus, the turbines and the steel floor are not physically connected at this level. The K4 turbine is located about 10 feet from the control room. When the earthquake struck, the shift supervisor noticed water coming down one side of the boiler of unit K4 and also saw that the turbine was shaking. He did not realize that there was an earthquake in progress, and thought that the boiler had a fault which had caused water to carry over to the turbine, thus causing it to vibrate severely. This would be a potentially very serious problem which could cause major turbine damage, so the shift supervisor went into the control room and hit the emergency stop switch for K4. Another operator on the floor at that time indicated that he observed steel floor inspection plates bouncing up and down around K4 turbine at that time. Two seconds after the manual trip signal was initiated, the DCS recorded vibration alarms on K4, which would have led to a trip of the unit if the shift supervisor had not already done so. We must also note that K2, which was off line for overhaul, registered a vibration alarm two seconds after the K4 vibration alarm.

By 0716 hours, only units M10 and M11 were still generating. The SCADA log indicates between 07:08:45 and 07:16:50 numerous alarms were logged for low voltage, loss of bus potentials and loss of station AC. Under low voltage conditions, motor contactors would open and cause auxiliaries to shut down. The Maalaea diesel plant operator indicated that M10 and M11 were operating at about 200 rpm (rated for 450 rpm) and that the auxiliary systems were off line. The diesel plant operator notified the control operator that the M10 and M11 generator breakers were still closed with the engines running 200 rpm, they were showing about 2 MW output and no auxiliaries were operating. At this point it became evident that it would be impossible to safely maintain operation of these engines, and the control operator manually tripped the generator breakers and shut down the diesel engines to protect the systems from overheating and improper lubrication.

3.2.2 Generator Relay and Control Trips

Units K1, K3, M12, M14, M15, M16, and M19 were tripped by their respective protection and control systems.

Trips Due to High Vibration

High vibration caused units M14 and M16 generators to trip just after 0708 hours. These combustion turbine-generator sets are equipped with vibration sensing devices which detect the relative positions of shafts and housings to determine if vibration is occurring which the manufacturer considers could damage the machine. The DCS indicated that both units received a "Combustion Turb High Vibration" alarm followed by "CT Emergency Stop" and "Combustion Turb Trip By Shutdown" alarm. The turbine and generation vibration alarms and trips are common to the DCS, thus it is difficult to determine which vibration element tripped the units. In MECO's discussion with vendors and other plant personnel, it suspected that the generator proximity probe initiated the trip signal. The proximity probe trip on the generator directly trips the generator breaker and the combustion turbine fuel valve to the unit at approximately the same time. The loss of these two units, which were carrying 37.6 MW or 28.5% of the island's load, precipitated the island wide blackout. Without M14 and M16 exhausting heat into the HRSG to produce steam for steam turbine M15, M15 was unable to continue carrying load and lost power output capability some 14 seconds later.

K2 registered high vibration alarms even through it was off line for maintenance. We expect that the earthquake was shaking the generator sufficiently to trigger the proximity probe monitor. M19 did not alarm for high vibration. In review of the CT operation to try to explain why M19 did not trip on vibration, we noted that M17 and M19 are equipped with different models of generators, different models of vibration monitors, they are physically located in a different section of the yard and they are oriented 90 degrees from the layout of M14 and M16. Any of these factors could reduce the effect of the earthquake shaking on the generator bearing clearances.

The vibration monitoring equipment installed is as follows:

- K1-K4: Bently-Nevada model 3500 System
- M14 and M16: GE LM2500 CT with Brush Electrical Machines, LTD generators and Bently-Nevada 3500 System vibration monitors
- M17 and M19: GE LM2500 CT with Dresser Rand/Electrical Machinery generators and Vibro-Meter ABE 022 MMS System vibration monitors

LM2500 COMBUSTION TURBINE VIBRATION MONITORING

When used in a power generation application, LM2500 combustion turbine-generator sets, such as the four units at Maalaea, are equipped with vibration sensing equipment on both the turbine and generator as follows:

Accelerometers – the combustion turbine is fitted with two accelerometers, one on the gas generator at the air inlet end, the other on the power turbine. These sensors detect vibrations in the combustion turbine casing. The aim is to detect vibrations at normal shaft speeds to provide an alert if a shaft becomes unbalanced. The LM2500 has high background noise (vibration) levels, so a speed signal is taken from each shaft (gas generator shaft and power turbine shaft) in order to filter out vibrations which do not occur at shaft speeds. Alarm and trip levels are set for each accelerometer for vibrations at each shaft speed. Thus, the accelerometers on the combustion turbines are not designed to detect vibrations due to external forces, only vibrations at much higher frequencies due to shaft unbalance problems. In common with most aero-derived combustion turbines it is fitted with rolling element bearings which are resistant to externally applied vibrations.

Proximity probes – the electric generator, which is a separately manufactured component from the LM2500, is fitted with proximity probes which detect the distance between the bearing housings and the shaft. There are four probes, two at each machine bearing (i.e. at each end of the generator). Each pair of probes is arranged at 90°, one in a vertical orientation and one horizontal. The purpose of these probes is to detect relative lateral movement between the generator stationary and rotating parts, which will occur in the event of bearing or lubrication failure, shaft unbalance or other types of internal damage. In fact, these are not truly vibration sensors at all, but are, as the name says, proximity detectors. Proximity detectors are used because the bearings in the generator sets are, in common with generators of this size world-wide, plain journal bearings which rely on a hydrodynamic film of oil for lubrication. Significant vibration from any source and at any frequency can cause the film of oil to be disrupted which would lead to bearing failure and possible shaft damage. The proximity probes detect the relative shaft/housing clearances; changes to which may indicate loss of oil film lubrication.

When the earthquake struck, we believe that the proximity probes on the bearings of the generators of combustion turbines M14 & M16 detected movement between the bearing housings and the shafts in excess of the "trip" threshold and caused the machines to shut down. The threshold levels are: lower level alarm at 3.5 mil peak to peak; trip level at 6.5 mil peak to peak. These levels are consistent with the commonly accepted standard design practice of one thousandth of an inch clearance per inch of shaft diameter. Furthermore, the levels are specified by the generator manufacturer to protect the equipment from damage. Though the generator manufacturer can be approached to ascertain if higher vibration levels can be accepted, we consider it highly unlikely that it will do so.

Trips By Other Plant Relays

Following the loss of M14 and M16, the combustion turbine M19 picked up load. The Maalaea DCS recorded several alarms at 07:07:29 (07:08:43 EMS/SCADA). The senior operations supervisor and combined cycle operator interviews indicated that M19 then tripped on PT (power turbine) Inlet Temp. Dev. (T54DLT) or high exhaust temperature.

After trying to hold onto the system until about 07:15:30 hours, M12 was reported to have tripped on overload by an instantaneous overcurrent relay.

HC&S separated from the MECO system and islanded with their local load. KWP was tripped off line by the Sub 97 – Kaheawa under frequency relay. At this point M12, K3 and K1 attempted to pick up the load. At 07:09:45 DCS, (07:08:45 EMS/SCADA) K3 recorded "Generator Emer. Trip" and "K3 Gen. Backup Protection" alarms. Prior to these events K3 had recorded alarms for auxiliary power loss and static exciter trouble. The Maalaea diesel plant operator recorded a device 50-instantaneous overcurrent relay and primary Volts/Hertz 59p/81/X1 trip switch activated on M12.

Trips Due to Loss of Auxiliaries

After a duration where Kahului steam unit K1 and Maalaea reciprocating engines M10 and M11 attempted to hang onto the remaining load and seemed stabilized, they lost auxiliary power and were shut down. The SCADA log records numerous low voltage alarms but does not indicate any additional breakers opening to separate load. It can be surmised that the system remained with a severe load-generation imbalance between 07:09:00 and 07:17, which would significantly distress the connected generators and their auxiliary systems. DCS logs for K1 indicated at 07:12:56 (07:11:58 SCADA/EMS) that the unit lost auxiliary power and the boiler tripped on "Low Fuel Pressure". Approximately 1 minute later the SCADA system recorded CB 2252 open.

3.2.3 Dispatch Center Event Response

After the initial tremor, it was clear to Dispatch Center personnel that Maui had experienced an earthquake. M14 and M16 had immediately tripped off line and breakers had tripped for load shed block 1. The SCADA began logging multiple alarms. The lights were reported to have flickered and then the display board, computers, phones and radios shut down. By the time the earthquake was over, reported to be 15 to 20 seconds by the Hawaii Volcano Observatory, the majority of the system generation was off line and the K1, M10, M11 and M12 were trying to support the system. System frequency remained below the minimum EMS recording level of 59 Hz. The Kahului Baseyard emergency generator was reported to have been slow to come on-line.

With the temporary loss of primary communications the dispatch personnel were not able to communicate or participate in the events over the next few minutes before total system blackout. However, given the amount of generation that was lost as a result of the earthquake, it appears that the dispatchers did not have sufficient time to assess the unfolding events and take actions that could have maintained some portion of the system energized.

3.2.4 Load Shed

The frequency scan rate of the EMS is two seconds. It is surmised in this evaluation that the frequency decayed below load shed relay set points, triggered the relays and frequency recovered within the 2 second scan window.

From Figures 1 and 2, it appears that the generator trips of M14 and M16 caused the frequency to quickly decay below the 58.7 Hz trigger-point of the UFLS block 1. UFLS block 1 operated along with a ramp-up in power output from the other generators; the frequency recovered to above 59.5 Hz and then began to decay again as the power output from M14 and M16 finally dropped to zero at 07:08:38.

At this point it again appears that during the next 2 second interval that the frequency decayed below 59 Hz and then recovered as the remaining generation ramped up and load shed blocks operated. Block 2 and 3 seem to have operated at about 7:08:41 which corresponds to a dip below 59 Hz and then a slight rebound. However, one relay of block 2 is reported to have a 10 second delay so it did not operate. Breakers on the 69 kV system operated on Out-of-Step and de-energize the 69 kV transmission system from Puunene to Kula. Relays outside the UFLS recorded frequencies about 47 Hz in this time frame, which would have triggered all of the UFLS relays. The UFLS that operated was unable to compensate for the loss of M14, M16 and M19 with an aggregate generation capacity of 61.2 MW.

3.3 Restoration

3.3.1 Black Start

Plant personnel formulated the black start plans and identified the units to be started first. Under the circumstances, extra caution was required to assess equipment possibly damaged by the earthquake that could endanger additional equipment or personnel safety during operation. The process was started in parallel at Kahului and Maalaea power plants.

It was realized that HC&S was still operating and about 30 minutes was spent trying to determine a way to connect them to the dead MECO system to provide starting power. It soon became clear that this could not be accomplished safely before one of the MECO plants came back on line and the effort was abandoned.

At Kahului, the first K1 start attempt tripped the black start generator on overload. The K3 and K4 auxiliary air compressors were then stripped from the auxiliary buses to reduce the load to within the capability of the black start diesel. As they were beginning to roll K1 for the second start attempt, the diesel generator tripped on water jacket temperature, due to a cooling system problem. At this point power was restored from Maalaea, auxiliaries were transferred to the main bus, and K1 was restarted. This delayed restart of Kahului, but did not affect the restart of the system. If Kahului and Maalaea had both restarted and began to pick up islands of load, one plant would have to shut down and have power restored from the other plant.

At Maalaea Power Plant, the first order of business after assessing the plant condition was to open all of the breakers on the 69 kV bus, which is required to start a 2.5 MW diesel unit and connect to a dead bus. At this time the Maalaea plant SCADA was not functioning due to failure of the backup power supply so the breakers had to be opened manually. MECO staff reporting to the station immediately after the outage realized this action was necessary and began the process to manually open the breakers, which minimized the impact to the overall restart time. The SCADA report indicates that it took about 22 minutes before the 69 kV breakers stripping was initiated after the blackout and it took about 10 minutes to complete. Once the 69 kV bus was cleared, diesel unit M1 was started and began to supply station auxiliary power about 58 minutes after the plant went dark. The battery start 2.5 MW diesels are too small to pick up initial customer load so one of the larger 5.6 MW or 12.5 MW diesels needed to be started. These units (M6 to M12) use compressed air for starting, instrumentation and controls. Once the auxiliary power was restored, it took about 15 minutes to build up sufficient air pressure, perform blow down to purge any water from the combustion chambers and start M6.

3.3.2 Transmission and Distribution Load Restoration

The restoration plan developed was based on MECO's past experience with the frequency and voltage stability conditions of the system during restoration. Numerous activities were taking place in the power plants as personnel prepared to black start generating units at Kahului and at Maalaea. Simultaneously, the dispatchers, trouble men and management personnel were preparing the electrical grid for the first unit to come on-line. In addition to preparing the system for restoration, key operations management personnel were developing a sequence for the restoration process. A significant portion of the MECO system can be closed in by SCADA, which allowed the dispatch staff to select and close priority feeders as generation became available that matched the estimated load of the feeder.

MECO personnel have indicated that during the outage and initial stages of restoration, the loss of primary communications between the dispatch center and power plants provided challenges to the operating personnel. Personnel resorted to backup sources (radios, landline, cell phones) to re-establish communications. Once utility and auxiliary power was restored to the plants, the communication system returned to normal operations. Coordination between load dispatch and the power plants was set up with a central point of contact at Kahului power plant to relay messages to Maalaea. The generation/load mix was monitored and controlled by the dispatcher and Kahului station supervisor. The plant operator would tell dispatch how much load they could take as generation was brought on line and dispatch would select a feeder which would fit within the load range, based on experience and load readings prior to the outage, and close the breaker.

Once M6 was on the bus, the first circuit closed was the 69 kV line to Puunene. The system had not been sufficiently sectionalized at Puunene and M6 tripped on overload. M6 was restarted and additional feeders were opened at Maalaea and Puunene. M6 paralleled to the bus and began picking up load. M5 started, paralleled with the bus and began picking up load. M5 and M6 tripped on overload and the process was restarted. At 0902 hours, the re-energization sequence was again initiated with M6 and progressed successfully to energize the 69 kV system, parallel with HC&S, start Kahului Power Plant and pick up priority and customer load. The majority of the load was restored by about 1315 hours with the last feeder breaker closing at 1432 hours.

MECO staff indicated that they took a fairly aggressive approach to restoring load and in some cases overloaded the generator(s) or had to reopen lines when load sections were larger than expected. The early trips of M6 and M5 in the loading sequence added about 15 minutes to the overall restoration time. Based on the timing of the startup and loading of the Maalaea CTs, it appears that the thermal lock of the units had released prior to them being required for the next increment of load and did not delay restoration.

3.3.3 Communications

MECO utilizes SCADA, an Avaya phone system, Maalaea Power Plant Gai-tronics phone system, interdepartmental Gai-tronics phone system, intra-company shortwave radio, Maalaea short wave radio, inter-company email, and external land lines and cell phones. Reports from personnel interviews indicate that primary internal communication systems failed on loss of utility or auxiliary power. SCADA, phone and radio communications were restored at the Kahului Baseyard Dispatch Center when the emergency generator came on line. Soon after the loss of primary communications, communications were re-established between the dispatch center and the power plants using backup communications sources including use of shortwave radios, external land line and cell phone service. Once auxiliary power was restored to the power plants, internal MECO communication mediums returned to normal.

4 Conclusions

After evaluating information provided by MECO, the data logs and other automatically generated information and information discussed throughout this report, along with the interviews of the operators on duty during the event and restoration, we conclude:

1. The main underlying cause of the island-wide outage was that the earthquake induced the operation of vibration sensors when generator minimum mechanical clearance tolerances were exceeded during the seismic shaking on M14 and M16. These were in fact valid alarms caused by exterior forces, rather than from actual equipment faults, which could still result in machine damage. The loss of these two units which were carrying 37.6 MW or 28.5% of the island's load, precipitated the island-wide blackout. Loss of M14 and M16 led to a cascade of operation of protective equipment on the remaining generators, such as high exhaust temperature on M19, under frequency on KWP, and static exciter trouble and low fuel pressure on K3. Loss of M19 appears to have been the event that overwhelmed the system's ability to recover frequency by shedding load and ramping up remaining generation. Without M14 and M16 exhausting heat into the boiler producing steam for the HRSG steam turbine M15, M15 was unable to continue carrying load and lost power output capability some 14 seconds later. The loss of the above generators resulted in very low frequency on the remaining generators (K1, M10, M11, and M12), that eventually led to their trip and system wide blackout. The equipment operated as designed to protect the generators and POWER has no recommendation for further evaluation.

2. The manual trip of K4 was reasonable and prudent. Considering the shift supervisor's observations and experience, it was reasonable for him to conclude that the K4 turbine was the source of the vibrations and act expeditiously to minimize damage. In fact, the vibration alarm received immediately after the manual trip would have prompted the operator to trip the turbine in any case. In the time line, K4 was tripped slightly after M19 tripped and the system was already in severe distress. When the earthquake struck, the Kahului shift supervisor noticed water coming down one side of the boiler of unit K4 and also saw that the turbine was shaking. He had not realized that there was an earthquake in progress, and thought that the boiler had a fault which had caused the turbine to ingest water causing it to vibrate severely. This would be a potentially very serious problem which could cause major turbine damage, so the shift supervisor hit the emergency stop switch for K4. Two seconds after the manual trip signal was initiated, the DCS recorded vibration alarms on K4, which would have led to a trip of the unit if the shift supervisor had not already done so. POWER concludes that the operator's actions were reasonable under the circumstances and that protective equipment would have operated in the next couple of seconds to protect the generators. POWER has no recommendation for further evaluation.

3. The sequence of load shed operation indicates that the UFLS operated as designed. The scheme was not designed for contingencies and multiple events which result in the percentage of generation lost due to the October 15th earthquake (45% of the system load at the time of the earthquake). From the EMS and SCADA data it appears that on the generator trips of M14 and M16, the frequency quickly decayed to below the 58.7 Hz trigger-point of the UFLS Block 1, and the load shed block operated. Then frequency recovered to above 59.5 Hz, but began to decay again as the power output from M14 and M16 reduced to zero. When this occurred, the frequency decayed below 59 Hz and then recovered as the remaining generation ramped up and load shed blocks 2 and 3 operated. One breaker of block 2 did not operate

because other breakers on the 69 kV system operated before the 10 second delay had elapsed to de-energize the 69 kV transmission system that fed this circuit. We do note that the frequency data provided from the EMS has limited value in assessing the system response to an underfrequency event as the frequency monitoring equipment has a lower limit is 59 Hz which is above the settings for the UFLS relays. Concluding that the UFLS operated as designed, no recommendations are forthcoming for evaluation of the UFLS, but we do recommend examining the EMS frequency recording capability.

4. HC&S separated from MECO but remained on line, supplying local load for some time. The interconnect scheme is set according to common utility practice and does not allow HC&S to close on a dead MECO bus. In the case where this unit continues to operate following a system disturbance and "island" to local load, it might be used to restart the grid, if the substation equipment is reconfigured to allow HC&S to close on the "dead" MECO bus. The ability to make these changes, however, will be impacted by other factors such as safety considerations, permitting limitations, control and other technical limitations of the equipment, and contractual agreements between MECO and HC&S that define requirements and obligations of both parties in such a restart situation. As MECO has a very quick black start capability with the Maalaea diesel units and CTs, an option to use HC&S to black start the system has a much reduced value. Thus, POWER is not proposing any recommendation with respect to use of HC&S for black start of the MECO system.

5. Loss of several of the internal MECO communication systems and SCADA between the dispatch center and plants impeded coordination during the outage, but did not contribute to the outage and does not appear to have delayed the restoration. MECO has SCADA, an Avaya phone system, a Gai-tronics phone systems and shortwave radios along with external land line and cell phone communications. MECO personnel have indicated that the many of the internal communication systems initially failed on loss of utility or auxiliary power and external systems were congested. Communications were established between the dispatch center and the power plants using the radios, external land line and cell phone service. Once auxiliary power was restored to the power plants, internal MECO communication mediums returned to normal. MECO's present communication protocol is for the dispatcher to coordinate with the plant operator at Kahului, who then dispatches the generation from Kahului or Maalaea. This adds an additional leg to traverse and could be problematic when communication systems are stressed. In this event, however, communications were restored quickly enough to not hamper the coordination between the dispatch center and the power plants.

6. The power plants, Dispatch Center and transmission system were properly configured, dispatched and staffed for normal operations the morning of Sunday October 15, 2006 at 0700 hours. The Dispatch Center was properly staffed according to MECO operating procedures. The dispatcher was conducting routine monitoring of the system conditions and coordinating the startup schedule of generation with the operator at Kahului power plant as demand for power began to increase. Kahului and Maalaea power plant staffing was normal for a Sunday. The personnel were conducting their normal routines of monitoring the plant conditions. The Kahului operator coordinated with the dispatcher to schedule the generation and coordinated unit commitment with the operators at Maalaea. POWER is not proposing any recommendation with respect to MECO dispatch or staffing.

7. The actions of the MECO staff were reasonable and in the best interests of the public. In POWER's opinion, the MECO personnel reacted to the circumstances in a reasonable, responsible and professional manner. The dispatch and power plant staff did not have time to respond to the major loss of generation over a 20 second period. After the major loss of generation, the data indicates that the system was experiencing severe low frequency which eventually resulted in the trip of the four remaining generators by protective relay action or operator intervention. They applied training and experience in reacting properly to the changing system conditions based on the system condition and established MECO operating practices to restore power as quickly as practical. We have considered data logs of the dispatch center, power plant units, and transmission system following the earthquake on the morning of October 15. We also reviewed statements of power plant operators and conducted direct interviews of dispatchers, power plant operators, engineers and management staff. Our assessment has found only two issues that could perhaps have been handled differently, and neither significantly extended the outage. First, additional stripping of the K3 and K4 auxiliaries would have avoided the trip of the Kahului black start unit on overload. Second, trips of the Maalaea M6 and M5 units occurred on overload as the plant attempted to pick up load increments that were too large in the early stages, due to the fact that stripping the load from the transmission and distribution system had not been completed by the time the plant was in the position to re-energize the 69 kV system. As Maalaea power plant can fast start with ICE and CT generation that is better adapted to reenergizing the system, we conclude that the black start trip of K1 essentially did not have any effect on the duration of the outage. We are not aware of any case where actions could be described as imprudent or likely to cause injury, or damage or have materially improved restoration time. The senior staff that reported in after the earthquake were directed to respond to the power plants to assist in establishing communications and managing the system restoration. The MECO personnel

acted professionally throughout the outage and restoration applying their training and experience to their assigned tasks during a distinctly extraordinary event. The system restoration plan developed by the operations staff was prioritized, reasonable and well executed; and generally followed the procedures outlined in the Emergency Response Manual. As noted above, the pace of the restoration was initially aggressive which resulted in tripping the generators while additional sectionalizing was in progress and then re-start of the unit. In the MECO case, with the magnitude of diesel generation available, this is not as large a risk in the early stages as restart can be performed in five to ten minutes as additional load is stripped until the remaining system load matches the generation on line.

8. The power plant staff exercised reasonable judgment in the planning and execution of the black start procedures. The black start process was slowed at Kahului due to overload trip when K3 and K4 auxiliary air compressors remained connected and overheating of the black start generator due to a cooling system fault. However, these events did not impact the start outage duration as this was occurring in parallel with other activities. It appears that the black start of Maalaea Power Plant was only impacted by the time required to strip loads on the transmission and distribution system to match the generation brought on line. Both of the initial trips of the Maalaea occurred because the connected system load remained above the generator capability. As the Maalaea diesel plant can theoretically be restarted in 30 to 60 minutes, sectionalizing the transmission and distribution system to disconnect load could become the critical path for the system restoration.

5 Recommendations

In this section of this report we provide recommendations, which, if implemented, are not likely to reduce the likelihood of a repeat of the system blackout of October 15, 2006 due to similar circumstances, but they could speed up the restoration of electricity to consumers in the event of a system blackout. We recommend the following:

1. Evaluate the various internal MECO communication systems and associated emergency and uninterruptible power supplies. Institute recommendations from the evaluation to provide robust and dependable internal communication emergency power supply systems. MECO began this assessment soon after the outage has been implementing the recommendations.

2. Assess the communication protocol between dispatch and power plant operators to determine if they can or should be streamlined to allow closer coordination between dispatch and the individual plants during system restoration.

3. As the MECO system has a significant "fast start" capability, assess the possibility of programming a single button "black system" feature in the SCADA system to automatically open SCADA controlled breakers so that this activity does not become the critical path for system re-energization.

4. Evaluate upgrade of the system frequency and voltage recording equipment to install devices with faster scan rates and wider upper/lower limits to provide better data resolution for evaluating future events.

POWER Engineers

Comparison Report

March 28, 2007

HAWAIIAN ELECTRIC COMPANY

HECO, HELCO, and MECO Outage and Restoration Comparison
PUC Docket Number 2006-0431

PROJECT NUMBER:
111409

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1 System Comparison Summary

In PUC Order No. 22986, Docket No. 2006-0431 ("PUC Order"), a reference under II.A Discussions, at the bottom of page 7 states: "... there may be some benefits to being able to compare the different utility systems on each of the three affected islands. These differences can and should be explained in the context of the outages and the varying restoration times." This report specifically addresses the comparison of the Hawaiian Electric Company (HECO), Hawaii Electric Light Company (HELCO) and Maui Electric Company (MECO) systems with respect to the power outages and restorations associated with the earthquake on October 15, 2006.

POWER Engineers, Inc. (POWER) was retained to investigate the cause of the outages on the islands of Oahu, Hawaii and Maui and provide professional opinions on the reasonableness of the responses of the HECO, HELCO, and MECO staff during the event and during power restoration. At this time, investigations of the outages and restorations on the HECO, HELCO, and MECO systems have been completed and separate reports have been submitted pertaining to each respective company. Based on data regarding the outages and historical information provided by the utilities, and analysis performed for each of the three reports, POWER has formed opinions regarding the comparison of the outage and restoration of the three power systems.

1.1 Findings

A. On Oahu, Maui and the island of Hawaii major portions of their generation fleet tripped due to effects of the earthquake or the actions of operators in response to the earthquake. The Oahu and Maui transmission and distribution systems remained intact, which kept all system load connected as multiple generators tripped and consequently upset the generation-load balance. The load shed schemes operated but the generation to load imbalance on Oahu and Maui was too great, resulting in automatic trips of generators, extended low frequency operation and operator trips of the remaining generators to protect the units. Island-wide blackouts ensued.

B. The initial events on the HELCO system differed from HECO and MECO. On the Island of Hawaii where the seismic activity was the strongest, transmission and distribution circuits opened and the Hamakua Energy Partners power plant tripped as a result of the earthquake shaking equipment and protective devices. The earthquake-induced separation of the HELCO transmission system resulted in significant load reduction and unlike on Oahu and Maui, initially caused an over-frequency condition. The over-frequency condition led other generators to trip which then led to an underfrequency condition. The ability of the system operator to quickly bring additional generators on line, and the operation of the load shed scheme allowed the HELCO system to stabilize a portion of the system and prevent total blackout.

C. The HECO and HELCO systems had protective devices that operated due to the earthquake shaking these devices and not by actual conditions for which the protective devices were meant to operate. The devices involved were the HECO Kahe 5-6 plant Electro-Hydraulic governor system "Low-Low Fluid Level" level switches and the HELCO transmission line auxiliary relays, transformer sudden pressure relays and transformer fuses.

D. On the island of Hawaii and Maui, vibration protection equipment tripped combustion turbine generators, which comprise a significant portion of both systems' base load generation. These were deemed to be valid trips to protect the machines, even though they were caused by forces exterior to the turbine/generator units.

E. HECO dispatchers took appropriate actions to start additional generation and manually shed load to try to maintain operation of their system. The HELCO system operator took appropriate actions to start additional generation to maintain operation of their system. The MECO dispatchers were unable to assist the system with load shedding due to the faster loss of generation.

F. After starting generation that was immediately available, the HELCO system operator followed established procedures and began to close transmission lines that had tripped, start generation when the grid was restored to the plants, and restore load as additional generation became available. These actions minimized the length of the outage to HELCO customers in areas where the system could be restored by remote control.

G. The HECO system is comprised primarily of steam generation. In contrast, as is appropriate given the much smaller size of their islands' loads, the HELCO and MECO system generation resources are primarily diesel internal combustion engines and combustion turbines. The HELCO and MECO diesel plants provide a faster black start for each system than for the black start of steam plants on the HECO system. The main advantage for HELCO and MECO is the reduction of time to get diesel and combustion turbine generation on line after a blackout to start the other plants. However, due to the generally smaller unit ratings MECO must add generators and match expected feeder load pickup (in 2.5 MW to 5 MW increments) with the available online generator capacity.

H. Although overall restoration time was not significantly delayed, black start of steam units on Oahu and Maui was initially delayed by malfunctions on equipment in the steam plants being started and problems in reconfiguring auxiliaries. These equipment malfunctions were attributed to the earthquake or subsequent shock of the emergency shutdown of the boiler/turbine/generator sets that complicated the restart and contributed to errors in reconfiguring auxiliaries. The steam plant black start generators for Oahu and Maui are sized such that they require the steam plant personnel to configure the black start auxiliary load so that it is within the rating of the black start unit. Additional reconfiguration of these auxiliaries, as a result of equipment malfunctions, added complication to the black start process. As this island-wide black start procedure is seldom put into actual use, and those rare occurrences usually follow an emergency shutdown which stresses the equipment, it is understandable that problems and malfunctions could arise and delay the restart.

I. Overall, internal utility communication systems worked well on Oahu and Hawaii, but primary communications were temporarily lost on Maui due to loss of station service power at the power plants. The initial communication setbacks on Maui did not appear to have delayed the restoration or contribute to the outage.

J. HECO's distribution system is much larger than the HELCO and MECO distribution systems. HECO, HELCO and MECO must first sectionalize their transmission system and disconnect distribution feeders before black starting generating units. The transmission grid must be systematically re-energized and distribution circuits carefully restored to avoid overloading generators as they return online. HECO has SCADA control over the 138 kV and 46 kV breakers and some of the 12.47 kV distribution breakers. A large portion of HECO's distribution level breakers require a trouble-man or maintenance crews to travel to the station to open the breakers, and then again be present to close the breakers. Due to the large geographic size of its transmission and distribution system and a greater reliance than HECO on load shed to deal with generation trips, HELCO has all of its transmission system and 60% of its distribution system available to SCADA control. Because of a similar reliance on load shed to deal with generator trips, MECO can control about 65% of its distribution breakers by

SCADA. HECO, HELCO, and MECO system operators can utilize SCADA remote control to sectionalize the transmission system and close sections of the transmission system to provide starting power to the other power plants, so this attribute is common to all three systems. The smaller number of distribution circuits and greater portion of the remote SCADA control on the HELCO and MECO distribution system breakers provides an advantage for their dispatchers to select loads to restore across the system, without a need to have personnel at the substations.

With its distribution system feeder breakers mostly manually operated, HECO needs to direct personnel outward from its power plants and baseyards in an organized manner. All feeders are restored at a particular substation, before moving methodically to the next substation to minimize travel time and thus restoration time. On October 15, 2006 availability of crews to perform manual operations was not a major limiting factor on Oahu, as HECO had sufficient crews to close in feeders at several substations simultaneously. For most of the day and evening, the HECO maintenance crews were in place and awaiting generation to stabilize so they could restore the next feeder under direction from the dispatcher.

K. Making a meaningful comparison between restoration times between the island systems is difficult, as the size and makeup of each system is different and the events that transpired on each island were different. Unlike HECO and MECO, HELCO did not have an island-wide blackout and therefore, did not have to undergo black start procedures. When looking at the initial time required to restart the systems, the predominance of diesel internal combustion engines (ICE) and combustion turbine (CT) generation on Maui provides a much quicker black start and restoration capability. However, when looking at the overall rate in which generation capacity was added and load restored over the length of the outage, HECO added load more than twice as fast as HELCO or MECO. This is consistent with the larger generator ratings and number of personnel available to restore the HECO system.

1.2 Conclusions

A. The earthquake on October 15, 2006 was of large enough magnitude and energy to cause damage or operational failure on equipment in all three systems. This led to the island-wide outages on Oahu and Maui and a partial system outage on the island of Hawaii.

B. On all three systems the seismic activity triggered multiple automatic and manual generator trips which severely stressed the systems and caused generation to load imbalances. During the course of the events, operations personnel on all three systems responded in an appropriate and professional manner to protect equipment and prevent system wide collapse where possible. Dispatchers on Oahu followed their established system operating procedures, starting remote generation and shedding load, in response to the system upset and resulting frequency decline. The HELCO system operator took appropriate actions to start additional generation to maintain operation of their system.

C. The generation mix on Oahu is primarily comprised of steam units which take longer to start up. In contrast, the generation mix on Maui and Hawaii are primarily comprised of diesel internal combustion engines and combustion turbines of smaller capacities which by their inherent nature can be black started more quickly.

D. Total restoration times for the HECO, HELCO and MECO systems varied due to differences in system size and generation mix for each island, the fact that HELCO did not experience an island-wide outage, and the fact that the earthquake caused damage and trips on the HELCO transmission system. Considering these factors, we conclude that no there were no discernable delays in restoring the HECO system compared with the HELCO and MECO systems, with the exception of the time to get the first unit black started on the grid, and even in this case, the delay did not significantly impact the total restoration time.

2 System Comparison

2.1 System Background

Approximate system loads on October 15th, 2006, just prior to the earthquake were HECO at 837 MW, HELCO at 126 MW, and MECO at 137 MW. Energy demand was increasing on all three systems. Table 1 below shows a comparison of the number of transmission and distribution system components between the three systems. Please refer to Section 3 of the HECO, HELCO and MECO individual reports for specific details regarding the outage and restoration analysis of the separate systems.

Table 1: HECO, HELCO and MECO T&D System Summary

T&D System Summary HECO, HELCO and MECO *Approximate values only	HECO	HELCO	MECO (Maui)
Transmission Substations			
138kV	17		
69kV		20*	15
23kV			7
13.8kV		1	
Distribution Substations	134	50	33
Total subs	**151**	**71**	**55**
*(11 of HELCO 69kv transmission stations also serve distribution load)			
Transmission Circuits			
138kV	32		
69kV		28	17
46kV	5		
13.8kv		3	
Sub-transmission Circuits			
46kV	62		
34kV		6	
23kV			15
Distribution Circuits	455	126	92
Total circuits	**554**	**163**	**124**

When comparing the three systems, the approximate customer count (# of meters) for the three systems are: HECO: 292,779; HELCO: 76,144 (only 62,000 affected by the outage); and MECO: 59,998. This indicates that the HECO system has about 3.8 times the number of customers as HELCO and 4.9 times the number of customers as MECO. Of particular note in Table 1 is that the HECO system on Oahu has significantly more distribution substations and feeders to restore than the systems on Hawaii and Maui.

HECO's system on Oahu can be remotely controlled by the dispatcher for all of the 138 kV and 46 kV transmission system breakers and about 10% of the 12.47 kV distribution system circuit breakers. The majority of the distribution breakers must be opened/closed locally by a trouble-man or maintenance crew during system restoration. HECO has an automatic load shed scheme which initially trips 12.47 kV distribution breakers to drop small blocks of load. Then, if frequency continues to decay, it trips 46 kV breakers and drops substations with larger load blocks. On October 15th, 2006, approximately 1,737 MW of generating capacity was currently installed on the island of Oahu, with 1,278 MW owned and operated by HECO, and 459 MW by Independent Power Producers (IPPs). The HECO-owned 1,278 MW plant capacity consists of 1,162 MW steam boiler/turbine plant equipment, 103 MW of combustion turbine and 15 MW of distributed diesel generation. HECO's system is of sufficient size that it operates with a spinning reserve capacity to absorb the loss of the single largest plant in operation at the time (up to 180 MW for Oahu).

HELCO's system has a significant amount of SCADA controlled distribution breakers in place due to the large geographic area of the HELCO grid and the greater reliance on load shedding in lieu of spinning reserve. This normally allows the majority of distribution circuits (75 of 126) to be closed in remotely from the dispatch center rather than having crews drive to the substations and manually open/close breakers during restoration. This provides added flexibility in the load restoration sequence. HELCO employs an underfrequency load shed program with nine steps that would shed approximately 81 MW of load on a day peak (March 1, 2007 data). On October 15, 2006, approximately 276 MW of firm generating capacity was installed on the island of Hawaii; with a further 29 MW of wind and hydro power as-available. Of the 276 MW, 186 MW is owned and operated by HELCO and 90 MW by IPPs. Sixty four percent of the base load capacity (90 MW) is owned by two IPPs (HEP at 60 MW and PGV at 30 MW). Puna Geothermal Ventures (PGV) comprises a geothermal plant and HEP is a combined cycle plant with two combustion turbines and a heat recovery steam turbine. The remainder of the base load capacity is comprised of HELCO steam plants Hill 5, Hill 6 and Puna.

The MECO system operates in a similar manner to the HELCO system with a load regulating reserve rather than a spinning reserve and depends on an underfrequency load shed scheme to maintain generation-load stability on loss of a generation unit. MECO's system operator can remotely control the 69 kV and 23 kV system breakers and about 65% of the 12.47 kV distribution breakers, which allows significant flexibility in the system restoration sequence. MECO has a 3 step load shed program. On October 15th, 2006, approximately 293 MW of generating capacity was installed on the island of Maui, with 250 MW owned and operated by MECO and 43 MW by IPPs. The MECO generating equipment is split between reciprocating engines (approximately 33%), CT in combined cycle with steam turbines (approximately 40%) and boiler/turbine steam plants (approximately 12%), supplemented by a small amount of renewable generation (approximately 15%).

On Maui and Hawaii, the generating fleets are comprised mainly of diesel engines and combustion turbines. Steam plant capacity makes up only around 24% of HELCO's generating capacity, and 12% of MECO's. HECO (including both utility and IPP) has 91% of its generating capacity in its steam plant fleet. HECO's distributed diesel units are generally used only for peaking service as they are the least economical units to operate. HECO, HELCO and MECO all have combustion turbines (self-owned or IPP) which comprise a portion of their fleet. HECO's next planned generation is a 110 MW combustion turbine to be installed at Campbell Industrial Park in 2009, which will have black start capability. The types of capacity of installed generation on each of the islands appear to be reasonably selected to economically serve their respective loads.

The generation technologies and the smaller generating units on Maui and the island of Hawaii are quite different to start and operate compared to those employed by HECO. HECO's steam boiler/turbine units are inherently slower to start and bring on line and can be somewhat temperamental to start and re-load after a system upset. In the early stages of restoration on the HECO system, great care must be taken to stabilize the system, properly increase boiler pressure as load is added, and operate within the covered source permit constraints. The smaller individual unit ratings of the HELCO and MECO units provide a faster start for each unit, but this also limits the amount of load that an individual unit can pick up. Thus, HELCO and MECO also must carefully match expected feeder load pickup with the available on line generator capacity. We must also note that operation within the covered source permits also causes some constraints on starting sequence and loading of generators on all three systems.

2.2 Comparison

The separate outage investigation reports for the HECO, HELCO and MECO systems were reviewed and compared with respect to the events of the outages and varying times of system restorations.

A number of outages on the U.S. mainland were assessed to see if they had any comparable relevance. In all cases examined, the generation mix, cause of the outages, interconnections between utilities, and (in most cases) extensive transmission system damage from storms, were so dissimilar that they do not provide a reasonable basis for comparison to the HECO, HELCO or MECO system outages or restorations on October 15, 2006.

Significant comparison items between HECO, HELCO and MECO:

- All three systems had a major portion of their generation capacity initially tripped as a consequence of the earthquake.
  - HECO had trips of the "Low-Low Fluid Level" on the Electro-Hydraulic (E.H.) governor system that regulates steam flow to the turbines. These switches on Kahe 5 and Kahe 6 operated the "Low Fluid Level Lockout" relays that prevent the E.H. system pumps from restarting to maintain the required operating hydraulic pressure, thereby leading to the loss of power from Kahe 5 and Kahe 6. These were evaluated to be caused by operation of the switches by the earthquake shaking the contacts into closed position rather than actual low liquid levels. These two trips resulted in loss of 280 MW of generation capacity.
  - HEP's two combustion turbine generators on the island of Hawaii were tripped by their vibration protection when the minimum mechanical clearances were exceeded due to the earthquake shaking. When mechanical clearances are exceeded, the machine is in danger of sustaining damage even if the source of the problem is external shaking. The Hill 5 unit's boiler tripped and difficulties resetting the fuel oil valve resulted in a manual trip of the turbine as steam pressure fell. (74 MW)

- ➢ MECO's Maalaea M14 and M16 combustion turbine generators were tripped by their vibration protection due to the external shaking. Kahului Unit 4 was tripped by the supervisor noting visible shaking, but immediately thereafter recorded a vibration alarm which would have led to a trip of the unit. (40 MW without K4)

- o All three systems had some generation capacity tripped by the operators.
  - ➢ In response to the shaking and alarms, HECO operators tripped Kahe Unit 3 and Honolulu Unit 8, suspecting that they had turbine vibration problems. In each case, the unit tripped was the only unit operating in the pair of units normally operated by the control room (108 MW). And as stated in the HECO report, we found these operator trips to be reasonable and in the public interest considering the alarms, observations, and previous experience.
  - ➢ HELCO operators tripped the Puna Steam turbine off-line when the unit went into a reverse power mode. This action was warranted and operators are provided specific training in this regard to protect the machine. (15.5 MW)
  - ➢ The MECO Kahului Power Plant Shift Supervisor was walking toward the control room when the earthquake occurred. He observed Kahului unit 4 turbine shaking violently and water leaking from the Kahului unit 4 boiler. He assumed that the turbine was ingesting water, went into the control room, and manually tripped the turbine. Immediately after the manual trip, the distributed control system (DCS) recorded a turbine vibration alarm which would have otherwise caused the unit to automatically trip. (12.5 MW)

- o The HECO and MECO transmission systems remained primarily intact, keeping all system load connected as multiple generators tripped from earthquake or operator action and load shed operated. The initial loss of multiple generators resulted in an unrecoverable generation-load imbalance on both systems, causing additional generator trips and severe low frequency operation which the load shed was unable to correct. Both systems were subjected to extended low frequency operation while the remaining generation tried to support too great a load. Given the speed in which events occurred and the level of generation to load imbalance, the HECO system dispatchers were unable to manually shed enough load to correct the imbalance. The MECO system dispatchers also were unable to manually shed load to help correct the imbalance before the system collapsed.

- The earthquake caused transmission line auxiliary and transformer sudden pressure relays to operate from the shaking on the HELCO system, primarily on the west side of Hawaii in closer proximity to the earthquake epicenter. HELCO's system also had substation transformer primary fuses shaken from the fuse holders. These earthquake induced relay operations resulted in separation of the HELCO transmission system on the west side of the island. The resulting significant load reduction created an extreme over-frequency condition on the remaining portion of the grid. The combination of the events, the ability of the system operator to quickly bring additional generators on line, and the operation of the underfrequency load shed scheme resulted in a significantly different system stability response for Hawaii than for Oahu and Maui.
- Immediate Operator Response:
  - HECO's dispatcher initiated remote start of the dispersed diesels and called Waiau power plant to start the Waiau combustion turbine generators when he noted that the plant operators had tripped Kahe 3 and Honolulu 8, and that Kahe 5 lost power output as the E.H turbine governor shut off steam to the turbines. By the time the diesel and CTs could get through their start and warm-up sequence, Kahe 6 lost power as its E.H system shut off the steam to the turbines. System frequency continued to drop, which resulted in tripping of additional generation plants and prevented the distributed generators and CTs from synchronizing and connecting to the system. Automatic load shed operated and the dispatcher manually shed load but was unable to restore generation-load balance.

- MECO operators experienced initial communication outages with the power plants. As the power output dropped off from the loss of units M14, M16 and Kahului 4, the remaining units began to pick up load. Some of these remaining units tripped due to over-temperature, under frequency or over load. The Maui automatic load shed scheme operated as designed but was insufficient to balance the load with the remaining generation due to the magnitude of generation-load imbalance. The system then went into extended low frequency operation and the operators tripped the remaining units to prevent low frequency damage.
- The HELCO system initially went into over-frequency when the transmission system separated. The system operator was able to start additional diesel, steam and combustion turbine resources and get them on-line, consistent with established HELCO procedure during a system upset. These units were able to connect to the grid to balance generation lost from the steam units. With the manual trip of the Hill 6 steam unit, an underfrequency load shedding event occurred with the frequency recovering to 59.05 Hz. With the decline of the Hill 5's output, the frequency continued to decay and triggered a second underfrequency event, with recovery to 59.15 Hz. In parallel with these events the system operator began remotely reclosing transmission lines and starting additional power plants as they were reconnected to the grid.
- Both HECO Waiau CTs were not scheduled to run and were off line at the time of the event in accordance with economical unit commitment practices. The Kalaeloa Power Partners CT that separated from the HECO system during the event was put on turning gear but it still incurred shaft warp, which required additional time to correct the problem before returning the unit to service. MECO had three combustion turbines operating -- M14, M16 and M19 -- that went into thermal lock when they could not be put on turning gear within 7 to 10 minutes of the shutdown. HELCO's CTs were all off-line when the event occurred. The two HEP CTs on the island of Hawaii tripped on vibration and were

put on turning gear, powered by their plant diesel generator, and were ready to be restarted when the grid was restored to the plant.

- System Restart: The HECO restart took 4 hours and 27 minutes. The Maui system restart took 1 hour and 17 minutes. HELCO maintained power to a portion of its system on the east side of the island, so a black start and complete system restoration was not required. After experiencing the earthquakes, each utility required extra care to assess whether there was equipment damage in the plants and on the transmission/distribution systems. In all cases, some equipment was damaged or had problems due to the earthquakes or the emergency shutdown. HECO and MECO steam units had black start delays due to trips of the black start generators for various reasons. The primary reasons were related to malfunctions on equipment in the steam plants being black started and properly configuring the auxiliary loads and connections.
  - Power plant personnel at the Kahe power plant on Oahu and at the Kahului power plant on Maui encountered trips from too much auxiliary load for the black start generator capability. As the black start progressed at Kahe, equipment failures encountered on Kahe 1 and Kahe 3 led to switching the startup priority from one unit to another, which eventually resulted in a trip of the black start diesels because the progress of each unit was not fully communicated, resulting in overload of the units from too many auxiliary loads. The HECO Waiau 6 unit also had a trip when the DCS tripped while troubleshooting a problem with the DCS on the sister unit, Waiau 5. This is indicative of the fact that steam plants are, in general, more difficult to black start. In the case of HECO, the decision to parallel black start efforts at both Kahe and Waiau soon after the onset of the island-wide blackout reduced the impact of black start delays encountered at Kahe from affecting the overall island restoration effort. Similarly, on Maui the trip of the Kahului black start unit did not delay system restoration as the decision was made to

parallel black start efforts at both Kahului and Maalaea and that Maalaea diesel units were restarted in much less time.

- On Oahu, black start capability is presently provided at Kahe and Waiau. This capability is installed in a similar manner at the Kahului power plant on Maui, though much larger in size. The black start generators are sized such that they require the steam plant auxiliary load to be matched to the generator capabilities to prevent trip on overload. There are step by step procedures for the proper sequence for turning on auxiliary systems. In a typical blackout situation such as one caused by a system separation event, an outage would leave a number of steam units with their boilers pressured up, in which case they could come back on line in approximately two to three hours. On Oahu, it takes two to three hours to open feeder breakers to prepare the system to begin load restoration.
- The Maui Maalaea Power Plant has diesel internal combustion engine units which are battery-started, and with a capacity of 2.5 MW, those units are sufficient to start and connect to the dead 69 kV bus without any modification of the auxiliary load connections. The auxiliary load required to start one of the larger diesels units or one of the combustion turbines at Maalaea is well below this rating. One of the peaking generators can be started in minutes, but time is still required to open all of the 69 kV breakers at Maalaea and open the system distribution feeder breakers to isolate loads. It then takes about 15 minutes after power is restored to the other generators to recharge their system air pressure and start one of the larger diesels that can better handle load pickup. This provides MECO, with a restart capability of one to two hours to begin restoring load, depending primarily on the time required to sectionalize the transmission and distribution system. On October 15th, MECO had the M6 unit started and ready to take load before the grid was completely sectionalized so the unit twice tripped on overload attempting to reenergize the system. This is not deemed to have significantly

impacted the restart time as the diesel units were able to restart in minutes while additional sectionalizing was performed.

- Combustion turbines can be started, warmed up, connected to the bus and loaded within 30 minutes and some even as fast as 5 minutes on the HELCO system, although a key issue is that the CTs need to be able to quickly pick up to their respective minimum loads (5-8 MW) of load to maintain operation in compliance with covered source permit requirements. The CTs are equipped with turning gear that must be used to rotate the turbine rotors and circulate air through them after a shutdown to ensure that the rotor cools evenly with the outer case. Without this gear in operation, the turbine rotors can distort slightly as they cool or the outer case can cool faster than the rotor causing "thermal lock", and then the unit cannot be restarted until it has cooled down completely. The LM 2500 CTs on Maui and the island of Hawaii must be on the high speed turning gear within 7 to 10 minutes of shutdown to prevent going into thermal lock. The Maalaea combined cycle plant operator was unable to reconfigure the auxiliary bus, start the emergency generator, and put M14, M16 and M19 on the turning gear within this time window. Consequently the units went into thermal lock and required about 3 hours to cool down before they could be restarted.

- Communications: Internal utility communications worked well on Oahu and Hawaii. MECO experienced initial communication problems, but these were resolved once station power was restored to the power plants and did not delay restoration or contribute to the island-wide outage.
- System Sectionalization: The HECO crews needed to travel to, make condition assessments of and energize 3-1/3 times as many substations as the HELCO system and 4-1/2 times as many as the MECO system. The HECO system requires about 3 hours to configure the distribution substations and MECO requires about 1.5 hours. Because of the larger geographic area of the transmission and distribution system and the greater reliance of load

shedding instead of spinning reserve, the HELCO T&D system is almost fully automated and the distribution loads can be quickly stripped by SCADA.

- System Restoration: It is difficult to find a meaningful method of comparing the pace of restoration, as the makeup of each of the systems is unique to their island, generation mix, and load. However, we can offer the following observations.
  - Each utility has a priority to restore the transmission system to the power plants to allow them to start additional generation units.
  - Each utility has a practice to close in on loads sized from 2.5 MW to 6 MW to maintain system generator stability as load is added (during later stages of the HECO restoration, load was restored in larger blocks, up to 10 MW in size once more units were in operation).
  - HELCO and MECO have much more distribution automation than HECO which allows them more geographic flexibility to match available generation capacity with anticipated feeder loads at different substation locations. HECO's practice is to close in all feeders in a substation, fanning out from the power plants, and then have the crews move to the next substation to avoid backtracking between substations.
  - Restoration of the majority of the customer load took 15.5 hours on Oahu and 6 hours on Maui. On the island of Hawaii, all feeders were closed in by 1245 hours (5.6 hour outage), with the exception of those where the circuits or substations required repairs in order to be restored to service.
  - Despite greater SCADA control of distribution breakers and faster black starting of their first units on Maui and start of generation the island of Hawaii (black start was not required on Hawaii), in the timeframe beginning with the start of the outage to point when restoration of power was provided to the majority of their customers, HECO restored load at an average of 54 MW/hour compared with MECO's average rate of 23 MW/hour and HELCO's average rate of 27 MW/hour.

- Each utility experienced events which slowed system restorations. For HECO the events that slowed restoration were trips during the black start process and resetting of load shed relays which added a total of approximately 1.5 hours to the restoration time. MECO was slightly slowed as the generation was started and twice tripped on overload as they tried to reenergize the system while continuing to sectionalize the system load. HELCO's restoration was slowed due to the operation of transformer sudden pressure lockout relays and transformer fuses due to the shaking caused by the earthquake. Personnel were required to visit stations and correct the problems before affected transmission breakers and distribution feeders could be energized or generators started. HELCO's system also experienced earthquake damage at two switching stations and 34 kV transmission lines which required repair before the complete transmission system could be restored to western Hawaii. In the process of getting personnel to the stations to reset relays, replace fuses and make repairs, HELCO also had to contend with delays from road closures.

HELCO's External
Communications Report

Investigation of the 2006 Hawaii Island Earthquake and Widespread Outage

Review of External Communications
PUC Docket 2006-0431

Prepared by Hawaiian Electric Company, Inc.
March 2007

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HAWAII ELECTRIC LIGHT COMPANY
OCTOBER 15, 2006 EARTHQUAKE OUTAGE
EXTERNAL COMMUNICATIONS REPORT

I. EXECUTIVE SUMMARY

On October 15, 2006 at 7:07 a.m., a 6.7-magnitude earthquake struck just off the west coast of the Big Island near Puako, followed only minutes later by a second earthquake. The two earthquakes precipitated widespread outages on the Big Island and hampered cell phone and land line reception. Hawaii Electric Light Company (HELCO) personnel responded according to the Company's emergency response plan:

- A HELCO representative immediately reported to the Hawaii County Emergency Operations Center (EOC) to serve as the utility's civil defense/emergency services liaison.

- Additional dispatchers reported in to HELCO's Dispatch Center to respond to customer calls and concerns. Recorded messages also provided updates throughout the day and evening hours.

- As is the standard Hawaii County Civil Defense practice for major emergencies, all media communications were disseminated through the EOC, passing on information provided by the HELCO liaison as needed. Information on restoration status provided by the HELCO liaison was posted on a wallboard and used by the civil defense operators in responding to calls by the general public made directly to them. Several media located on site at the EOC also obtained system status information directly. The HELCO liaison and the HELCO President also responded directly to several media calls.

- Communications to key commercial customers were initiated to assess which facilities were out of power and determine priorities for restoration.

- The Company's accessibility, ongoing communication efforts and cooperation with Civil Defense and emergency services personnel have been acknowledged as excellent by the Hawaii County Mayor.

II. OVERVIEW INFORMATION

This review of external communications during the October 15 earthquake covers (1) communications with the public via the media and (2) through the Company's customer service communication channels (in this situation, the company's Trouble Desk), (3) communications with specific commercial customers and (4) communications with key emergency responders and other government contacts.

Staffing

Formal external communications with these audiences during the October 15 earthquake were performed by HELCO's Administration, Energy Services and Distribution personnel. Supervisors were alerted to the outages by a dispatcher who sent out an alpha-page. Key managers, supervisors and staff members reported to work at HELCO's main office or the Hilo Baseyard. In addition, the Administration manager reported to the Hawaii County Emergency Operations Center located at the Hawaii County Civil Defense offices by 8:00 a.m. Most personnel were on site at their respective positions between 7:40 and 9 a.m., and stayed until power was restored to customers (the island of Hawaii did not experience an island-wide outage and the majority of customers were restored by 12:45 p.m.). Dispatch personnel remained until 2:45 a.m. on the following morning to respond to customer calls.

III. COMMUNICATIONS WITH MEDIA

During a major public emergency in Hawaii County, the Hawaii County Civil Defense (CD) takes the lead in sending out any public announcements/press releases covering all matters including electricity. The role of HELCO is to serve as a liaison between the utility and the Hawaii County Emergency Operations Center (EOC), providing information to Civil Defense which in turn disseminates the information to the public via their emergency broadcast system and via press releases.

On October 15, 2006, the HELCO liaison reported to the EOC by 8 a.m. to coordinate activities with the state, county and municipal agencies. In doing so, the EOC was able to provide to HELCO the initial road closures status and EOC Civil Defense (CD) priorities through the liaison. The HELCO liaison, in turn was able to communicate the power system restoration status to the EOC CD, other emergency response agencies as well as media in attendance at the EOC. In addition, the CD operators used the HELCO information as needed in responding to calls by the general public made directly to their office.

The HELCO civil defense/emergency services representative was able to communicate using her personal cellular phone which allowed her to relay messages between the EOC and HELCO, as well as to answer direct media calls regarding HELCO specifically.

On October 15, 2006, these calls included a live phone interview with MSNBC and a phone interview with the Honolulu NBC affiliate, KHNL. By the time of the 2:32 p.m. afternoon interview with KHNL, the HELCO liaison was able to report that about 1200 customers remained without power in pockets across the Big Island, and HELCO crews were in the process of restoring those customers based on accessibility to the locations. (In some instances, landslides and other road closures limited access to the customers). See Appendix A for a media chronology.

HELCO President Warren Lee also responded to media inquiries made by local daily papers, the Hawaii Tribune Herald and West Hawaii Today which contacted him directly during the restoration progress.

Though the power outages that resulted from the earthquake were restored on the same day, at the Mayor's request, HELCO's civil defense liaison remained at the EOC during daylight hours over the next several days[1]. On October 16, HELCO distributed its own press release regarding the events of the previous day. See Appendix B.

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[1] On the afternoon of October 16, 2006, a lightning storm on the Big Island caused widespread power outages unrelated to the earthquake. The EOC remained in operation through October 19, 2006 to respond to both the storm effects and the earthquake after-effects. Non-County agencies and companies were released from the EOC after the last briefing on October 19, 2006, though the EOC continued to operate and respond to earthquake-related matters affecting the island of Hawaii.

IV. COMMUNICATIONS WITH CUSTOMERS VIA THE TROUBLE DESK

HELCO's Dispatch trouble line serves as the primary communication contact point for customers to call for information during system emergencies. On the morning of October 15, 2006, the trouble line was manned by a single dispatch operator whose shift had started at 7:00 a.m. After the earthquake hit and power outages occurred, the operator sent an alpha-page via email to all supervisors informing them of the power interruptions. Many supervisors arrived by 7:40 a.m.

Customers who called the trouble line from 7:51 a.m. would have heard the following customized recorded greeting:

> "Aloha, you have reached the Hawaii Electric Light Company's Trouble Desk. All calls are recorded so that we may better serve you. Today is Sunday, October 15, 2006 at approximately 7:51 a.m. Due to the earthquake this morning, there are numerous power interruptions in various locations on the Big Island. We have dispatched personnel to investigate and will work to restore power to the affected customers; however we do not have an estimated time of power restoration. If you still need to speak to a HELCO representative, stay on the line and the next available agent will assist you. Mahalo."

It should be noted that due to the specific system conditions on the island of Hawaii, power outages were not island-wide. While initial call volumes were higher than usual, it appears most customers heard the recorded message, and hung up which helped to free up the phone lines for additional callers to get through.

Additional dispatchers arrived at 8:30 a.m. and 9:00 a.m. to provide assistance, followed by another dispatcher at 10:15 a.m.

Customized recordings were made at the following times with these appended updates to the original message for customers calling into the trouble line. These recorded messages provided basic system status, and once heard, most customers hung up which allowed other callers to dial in.

> 8:46 a.m. – "Due to the earthquake this morning, there are power interruptions throughout West Hawaii and the Puna areas."
>
> 10:07 a.m. – "Due to the earthquake this morning, there are power interruptions in the South Kohala resort areas and Honokaa areas."
>
> 4:52 p.m. – "Due to the earthquake this morning, there are power interruptions in the Honokaa area. Also a problem related to the earthquake was found in the North Kohala area that requires an interruption of customers in the area. Power restoration for the North Kohala area is expected to be completed within 2 to 3 hours."

Anecdotal comments from the Assistant Technical Superintendent – Operations indicated that customers who spoke to the dispatchers were very understanding of the situation and once they knew that HELCO was working on the restoration effort, they quickly got off the phone to free up the phone lines.

All dispatchers stayed through 9:30 p.m. when one staff was released. A second staff left at 10:10 p.m., and the remaining dispatchers stayed until 2:45 a.m. on October 16, 2006.

V. COMMUNICATIONS WITH SPECIFIC COMMERCIAL CUSTOMERS

Following the earthquake and outage, HELCO's Energy Services group reported to the utility's main office in Hilo, while one staff worked out of her home. From approximately 9 a.m. until 6 p.m., Energy Services staff initiated calls to key commercial customers including critical facilities such as the airport and hospitals, and the hotels.

Initial calls were to assess which customers had power and which did not. The Energy Services Manager stayed in close contact with the Transmission & Distribution Manager and Dispatch to assess the situation and assess why specific commercial customers were out of service. In some instances, there were problems on the customer side in restoring power.

The Energy Services representatives worked with the T&D Manager to prioritize customer needs while still ensuring the system could be restored in a safe and reliable manner.

VI. COMMUNICATIONS WITH GOVERNMENT OFFICIALS

Local civil defense and emergency services

Immediately following the earthquake and outages across the Big Island, HELCO sent a representative to the Hawaii County Emergency Operations Center (EOC) to serve as HELCO's liaison with the Hawaii County Civil Defense (CD) and other emergency services. The HELCO staff person arrived at approximately 8 a.m. and stayed throughout the day until the early evening, about 6:30 p.m. A substitute from the Energy Services Department replaced her until he was released that evening at about 9:00 p.m. At the Mayor's request, HELCO's representative continued to report during the daylight and early evening hours to the EOC through Thursday, October 19, 2006.

As noted earlier in this report, during a major event in Hawaii County, the Hawaii County CD takes the lead in sending out public announcements covering all matters including electricity. HELCO's CD liaison provides information to the EOC to coordinate activities with the state, county and municipal agencies. This provided the initial road closure status and the EOC Civil Defense priorities to HELCO, such as hospital power supply problems, and provided the status of the power system restoration to the other emergency response agencies. In an interview with the consultants, Power Engineers, the Hawaii County Mayor praised the communications between HELCO and the EOC, and the cooperation of HELCO throughout the restoration to accommodate the needs of the other agencies.

VII. CONCLUSIONS AND RECOMMENDATIONS

In following its emergency response plan, Hawaii Electric Light Company acted in a responsible manner to communicate the effects of the earthquake and resulting outage to its customers, key government contacts and emergency responders. As restoration progress continued throughout October 15, 2006, HELCO personnel provided updates to the public and media via the Hawaii County Emergency Operations Center. The Dispatch staff also provided updated recordings on the company Trouble Line and answered calls until the early morning of October 16, 2006. The Company's accessibility, ongoing communications efforts and cooperation with Civil Defense and emergency services personnel have been acknowledged as excellent by the Hawaii County Mayor.

APPENDIX A

MEDIA COMMUNICATIONS CHRONOLOGY

Date	Time	Activity
15-Oct-06	8:00 a.m.	HELCO Manager of Administration arrives at the Hawaii County EOC - Civil Defense
	8:00 a.m. - 6:30 p.m.	Government agencies and companies report status of situation and operations at EOC. Media is present. Hawaii County Civil Defense broadcasts informational updates.
	a.m. - time unknown	HELCO Manager of Administration returns call to MSNBC News and is interviewed live concerning status of power outages on the island of Hawaii.
	1:10 p.m.	HELCO Manager of Administration returns call to KHNL and provides information on status of power outages on the island of Hawaii.
	2:32 p.m.	HELCO Manager of Administration calls KHNL to provide updated information at station's request.
	7:00 a.m. - 6:00 p.m.	Government agencies and companies report status of situation and operations at EOC. Media is present. Hawaii County Civil Defense broadcasts informational updates
16-Oct-06	7:30 a.m.	HELCO Manager of Administration speaks with Japan Broadcasting concerning status of power outages on the island of Hawaii.
	9:15 a.m.	HELCO Manager of Administration speaks with KHBC concerning status of power outages on the island of Hawaii.
	10:25 a.m.	HELCO Manager of Distribution speaks with KHBC concerning technical information related to HELCO's T&D system.
	2:40 p.m.	HELCO Manager of Administration speaks with KHON News concerning status of power outages on the island of Hawaii.
	time unknown	HELCO President speaks with KITV
	time unknown	HELCO President speaks with Honolulu Advertiser numerous times concerning damage to HELCO facilities and estimated cost of damage.

HELCO NEWS RELEASE

CONTACT: *JAY IGNACIO*
PHONE: 969-0224

Monday, October 16, 2006
3:00 p.m.

FOR IMMEDIATE RELEASE

Hawaii Electric Light Company (HELCO) has announced that on Sunday, October 15, 2006 at 7:08 a.m., approximately 40,000 customers islandwide experienced a power interruption as a result of the 6.7 magnitude earthquake that occurred that morning. The earthquake caused many transmission and distribution breakers to trip open as well as the following HELCO and Independent Power Producers (IPP) generation units:

- Hill 5 Steam Unit
- Hill 6 Steam Unit
- Waiau Hydro-generation
- Hamakua Energy Partners (IPP)
- Wailuku Hydro-generation plant (IPP)
- Hawi Renewable Development Windfarm (IPP)

HELCO System Operators started additional generation units and remotely close breakers, restoring power to approximately affected 30,000 customers by 8:00 a.m. HELCO personnel were dispatched to manually close circuits that could not be remotely closed and repair equipment impacted by the earthquake.

At 10:09 a.m., approximately 1,800 customers that had power restored earlier had power interrupted again when Hamakua Energy Partner's CT-1 tripped off-line again. Additional generation units were started and those 1,800 customers had power restored.

The earthquake damaged numerous pole top insulators, and various substation equipment. One of the severely impacted areas was along

Highway 19 by Honokaa where six (6) spans of transmission lines fell when pole top insulators broke. Crews worked through the night and had power restored to most customers, including those in other areas, shortly after midnight.

HELCO's Trouble Desk has been receiving calls throughout the day from customer's reporting continued power problems and low electrical wires, and has been dispatching personnel to work to make necessary repairs. HELCO requests that all customers that are still experiencing power problems or see low electrical lines to contact HELCO's Trouble Desk at 969-6666. HELCO also reminds the public to stay clear of downed or low wires.

HELCO has been working closely with the Hawaii County Civil Defense and other County and State Agencies to coordinate and prioritize restoration work. HELCO would like to thank them for their hard work, as well as customers for their cooperation and understanding. Mahalo.

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Investigation of the 2006 Maui Earthquake and Island-wide Outage

Review of External Communications
PUC Docket 2006-0431

Prepared by Hawaiian Electric Company, Inc.
March 2007

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Maui Electric Company
October 15, 2006 Earthquake Outage
External Communications Report

I. EXECUTIVE SUMMARY

As a result of a powerful 6.7-magnitude earthquake that occurred west of the Big Island at 7:07 a.m. on Sunday, October 15, 2006, an island-wide blackout occurred on Maui at approximately 7:08 a.m. This was the strongest earthquake felt throughout the islands in the past 23 years, and has been recorded as the largest seismic event to occur in the U.S. in 2006 according to U.S. Geological Survey data.

Maui Electric Company (MECO) personnel responded in a timely, appropriate manner by activating the company emergency phone tree to reach key department personnel and later major commercial customers. Efforts were hampered by such challenges as sporadic reception and service from cell phone and land line providers; however, key MECO personnel were able to reach each other within 12-15 minutes following the blackout.

In addition, without prompting, personnel located across the island also reported to the Kahului Base Yard within approximately one hour following the outage, while a civil defense/emergency services liaison for the company reported directly to the Maui County Emergency Operations Center (EOC) within approximately 40 *minutes following the outage.*

Despite setbacks due to congested phone networks and poor cell phone reception, MECO initiated calls to and responded to calls from state and federal emergency responders, essential service providers, large commercial customers, media and the general public to advise them of the restoration efforts.

Anecdotal comments from Customer Service representatives indicate that most customers were highly appreciative of the Company's frequent communications and the accuracy of information provided throughout the restoration process.

II. OVERVIEW INFORMATION

This review of MECO's external communications during the October 15 earthquake outage focuses primarily on (1) communications with the public via the media and through the Company's customer service communication channels, (2) communications with specific commercial customers and (3) communications with key emergency responders and other government contacts.

Staffing

Formal external communications with customers, media and government officials during the October 15 earthquake outage were primarily managed and executed by MECO's Administration, Customer Service and Energy Services personnel. Key managers, supervisors and staff members arrived at the Dispatch office located at the Kahului Base Yard between 8:15 – 9:30 a.m. and stayed throughout the duration of the outage. Additional call center representatives also reported in to assist with incoming calls from the general public.

In addition, MECO's civil defense/emergency services liaison reported directly to the Maui County Emergency Operations Center (located in the basement of the Maui County office building) where he remained throughout the day.

MECO also has a designated government relations liaison who called and left messages along with his cell number for the Maui Public Utilities Commission representative and the HECO Regulatory Affairs contact.

Telecommunications Challenges

As will be noted within this report, MECO personnel responding to the island-wide outage were initially hampered in their communication efforts by intermittent service and poor reception from telecommunications equipment and networks.

- Following the earthquake and outage, various department personnel initially tried to reach MECO's Dispatch office but were unable to get through. Calls to the company "Hot Phone," a cellular phone that Customer Service uses after hours and on the weekends to connect with Dispatch, also did not go through. The Field Services Supervisor who had been assigned the Hot Phone for that weekend sent a text message to the Dispatch office at approximately 7:30 a.m. requesting a call to her land line. She was quickly contacted on her land line phone between 7:30 and 7:45 a.m. by the Customer Service Manager who advised her of the island-wide blackout and confirmed that other staff were reporting to work, as she had been preparing to do.

- Attempts by other Customer Service and Energy Services personnel to reach the Hot Phone were hampered by sporadic cell phone and land line service, however, personnel on their own accord arrived at the Kahului Base Yard to assist in contacting major customers. Personnel began arriving between 8:15 and 9:30 a.m. and were briefed on the situation and restoration plans.

- Energy Services personnel who did have cell phone service made attempts to reach essential customers, making contact by about 8:30 a.m. to Maui Memorial Hospital and Kihei Wastewater plant to verify that they were operating on emergency back up generators. Contact also was made to Kahului Airport with an update on the plans to restore the airport circuit.

- The civil defense/emergency services liaison reported to the Maui County Emergency Operations Center by 7:45 a.m. and had access to a regular phone line which had intermittent service. Cell phone reception was poor within the building's basement, but the staff person also had a portable radio which allowed him to communicate with the MECO Dispatch Supervisor, Trouble Supervisor and company President who were at the Kahului Base Yard.

- Incoming calls from the general public to MECO's trouble line (Dispatch) *began almost immediately following the earthquake but most were unable* to get through due to the flood of calls that clogged phone lines. Callers who were able to get through would have heard a generic message, although many calls were likely abandoned by customers choosing not to stay on hold. A generic outage message recording was activated early in the outage and, in order to respond to the volume of calls, additional Customer Service representatives were called in to assist in answering the phones.

III. COMMUNICATIONS WITH MEDIA

Concerted attempts were made to keep the media and public informed of the island-wide outage and restoration efforts. MECO's Communication Specialist distributed two press releases to on-island print and broadcast media as well as to *The Honolulu Advertiser, Honolulu Star-Bulletin* and four TV stations on Oahu; and conducted phone interviews and e-mail communications with Maui's emergency broadcast station, Pacific Radio Group, with progress updates throughout the restoration.

- MECO's Communication Specialist was called at approximately 8:00 a.m. by the Administration Manager who advised her of the island-wide outage. She reported from her home in Kula to the Dispatch Center at Kahului Base Yard.

- Since MECO's civil defense/emergency services liaison was at the Maui County Emergency Operations Center from 7:45 a.m., restoration progress information was being disseminated by Civil Defense from early on to the emergency broadcast station – Pacific Radio Group – which was operating after the earthquake and which reaches the largest percentage of the island.

- After electricity was restored to the Kahului Base Yard slightly before 9:30 a.m., the MECO Communications Specialist was able to access her office and computer to begin drafting the first press release. At approximately 10:15 a.m. MECO initiated media contact with the news director at Pacific Radio Group, via her personal cell phone. The Communications Specialist reported what essential services and parts of the island had been restored to power. The phone interview was conducted off-line and the information relayed on the air within 5 minutes after the interview.

- A second off-line phone interview with Pacific Radio Group occurred at 11:10 a.m. advising that about 60% of the island had been restored. This was followed by MECO's first press release distribution at 11:20 a.m. via e-mail to Pacific Radio Group and *The Maui News*. See Appendix "A."

- By 1:15 p.m., most of the island had power except for a few isolated pockets. A second press release confirming this information was distributed at 1:30 p.m. via e-mail and fax to Pacific Radio Group, *The Maui News*, radio stations KAOI and KONI (fax) and the Oahu media (fax). Due to busy phone lines, actual transmittal of the release took place between 1:30 and 3 p.m. See Appendix "B."

- See Appendix "C" for a media communications chronology.

IV. COMMUNICATIONS WITH CUSTOMERS THROUGH THE TROUBLE LINE

MECO's trouble line is manned by the Dispatch office which responds to customer calls related to outages. On October 15, 2006, immediately following the earthquake and island-wide outage on Maui, the calls to the trouble line exceeded the capacity of the Dispatch office and many customers heard only a busy signal when they dialed in.

By 7:30 a.m., the Customer Service Manager and other Customer Service personnel had attempted calls to the Dispatch office numbers only to hear a busy signal. Despite the inability to communicate with Dispatch, the key Customer Service staff were able to reach each other through working land lines and cellular phones, and most arrived at the Dispatch office between 8:15 and 9:30 a.m.

Initially, the volume of calls clogging the phone circuits delayed the ability of MECO to communicate with the general public through its trouble line. Callers who were able to get through the phone lines heard a standard recorded greeting:

> "You have reached the Maui Electric Company's Trouble Dispatch Department. Please hold and your call will be answered in the order it was received. Mahalo."

The call was either held in queue or dropped by the customer if they did not want to wait on hold.

Around 8:22 a.m., a generic outage message was activated by MECO personnel:

> "You have reached Maui Electric Company's trouble dispatch department. We are experiencing system outages at this time and are investigating the cause. We apologize for the inconvenience. Mahalo."

By 10:30 a.m., additional Customer Service representatives had arrived to assist in answering phone calls. The majority of customers were restored by 1:15 p.m.

Later in the afternoon after power was restored to most of the island, an updated customized announcement was recorded for the trouble line:

> "You have the reached the Maui Electric Company's Trouble Dispatch Department. Today is Sunday, October 15, 2006, and it is approximately 2 p.m. We are currently experiencing outages in the Keonekai – Maui Coast area and in Kahului, by the Onehee substation. If you are calling to report an outage outside of the affected area, please remain on the line for the next available agent. Mahalo."

The remaining customers were restored by 2:32 p.m. Phone representatives remained on duty to answer calls until about 3:30 p.m.

V. COMMUNICATIONS WITH SPECIFIC COMMERCIAL CUSTOMERS

MECO account managers assigned to key commercial customers – including critical facilities and essential services – began calling their respective contacts from approximately 8:30 a.m. on the morning of October 15, 2006.

From 8:30 a.m. to 12:30 p.m., the communications with these commercial customers informed them a) what happened, b) the gradual process and projected restoration of most customers by noon and c) later confirming when restoration had taken place.

By 12:30 p.m., nearly all major customers had been restored.

VI. COMMUNICATIONS WITH GOVERNMENT OFFICIALS

Local and State Civil Defense, Emergency Responders and other Government Agencies

Following the earthquake and island wide outage, MECO's civil defense/ emergency services liaison reported to the Maui County Emergency Operations Center by approximately 7:45 a.m. where he remained throughout the day to provide restoration updates directly to the local and state civil defense and emergency responders. These also included the Mayor, County Managing Director, Deputy Director of the County Department of Public Works and Environmental Management, Maui police and fire chiefs, among others.

The liaison also attended all briefings and reported back to MECO using a land line, cell phone and portable radio. The latter provided two-way communications to MECO's Dispatch Supervisor, Trouble Supervisor and company President when poor cellular reception within the building hampered his efforts to communicate clearly.

Having a MECO representative at the EOC proved invaluable, as MECO was able to communicate to the group quickly and with the most updated information available.

At 8:26 a.m. on the morning of the earthquake, MECO's government relations liaison left a message regarding the outage and his cell number for the Maui Public Utilities Commission (PUC) representative (on his cell phone) and by 8:30 a.m., a similar message was left for HECO's Regulatory Affairs director. As the Mayor also was at the EOC, a contact had already been established though MECO's civil defense/emergency services liaison.

After restoration had been completed, the final press release time-stamped at 1:30 p.m. was distributed to Maui and Oahu media as well as the Maui PUC and HECO PUC contact.

VII. CONCLUSIONS AND RECOMMENDATION

The external communications efforts of the MECO emergency personnel responding to the island-wide outage on Sunday, October 15, 2006 were diligent and responsible and appear to have been very effective in keeping customers and key government contacts, including emergency response partners, informed.

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<u>Telecommunications</u>

Sharing information with the public was not without its challenges. As the report indicates, communication efforts were hampered by sporadic reception and service from cell phone and land line providers. Initially, getting information from MECO's Dispatch office proved difficult as the high volume of calls clogged the circuits. These are shared lines for both incoming and outgoing calls.

An automated recorded message was activated with a generic outage message, which may have helped alleviate some of the caller traffic into the phone center as customers were informed that MECO was aware of and responding to the outage.

Recommendation: Staff should continue to activate the generic outage message as soon as possible. It is recommended that more frequent updated customized recordings be made on the Trouble Line throughout the duration of the outage to provide more current information for callers who are waiting on hold.

MAUI ELECTRIC NEWS RELEASE

POST OFFICE BOX 398 • 210 KAMEHAMEHA AVENUE • KAHULUI, MAUI, HAWAII 96732 • (808) 871-8461

CONTACT: Kau`i Awai-Dickson
Maui Electric Company
Communications Specialist
(808) 872-3263

FOR IMMEDIATE RELEASE
October 15, 2006
11:20 AM

As a result of the earthquake this morning, Maui Electric Company (MECO) experienced an island-wide blackout at approximately 7:08 AM.

Essential services including Maui Memorial Medical Center, Kula Hospital, County of Maui, Maui Police Department and Kahului Airport were restored at approximately 9:30 AM.

As of this time, MECO has regained 60% of its generating capacity. Power has been restored to Hana and parts of central Maui, Kula, Wailea and Ka'anapali. Power on the islands of Lana'i and Moloka'i was not affected.

The initial fault occurred when the earthquake tripped the vibration sensor on several of MECO's Kahului and Maalaea Generating Station units causing them to automatically shut down.

As power resumes, MECO requests the public's help in turning on home appliances one at a time and not all at once.

Maui Electric apologizes for any inconveniences this may cause and we thank the public for their patience and understanding. Further updates will be provided as they become available.

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MAUI ELECTRIC NEWS RELEASE

POST OFFICE BOX 398 • 210 KAMEHAMEHA AVENUE • KAHULUI, MAUI, HAWAII 96732 • (808) 871-8461

CONTACT: *Kau`i Awai-Dickson*
Maui Electric Company
(808) 872-3263

FOR IMMEDIATE RELEASE
October 15, 2006
1:30 PM

As a result of the earthquake this morning, Maui Electric Company (MECO) experienced an island-wide blackout at approximately 7:08 AM.

Essential services including Maui Memorial Medical Center, County of Maui, Maui Police Department and Kahului Airport were restored within two and a half hours of the outage.

At approximately 10:00 AM, additional restoration began in parts of central Maui, Kula and Hana. *As of this time, power has been restored to all Maui customers* with the exception of isolated pockets in Kahului near Onehee Street and Kamaole in Kihei.

Power was not affected on the islands of Moloka'i and Lana'i except for Manele Bay.

The initial fault occurred when the earthquake tripped the vibration sensor on several of MECO's Kahului and Maalaea Generating Station units causing an automatic shut down. This shut down resulted in a "thermal lockout" or generators in an overheat condition, which required MECO to cool the units before bringing them back online.

We request the public's assistance in notifying MECO at 871-7777 of any outages that may occur following this notice.

Maui Electric would like to thank the public for their patience and cooperation during this emergency situation.

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APPENDIX "C"

MEDIA RECAP
Earthquake Power Outage
October 15, 2006

October 15, 2006

Interviews:

10:15 AM: PACIFIC RADIO GROUP – via phone
RE: Essential services including Kahului Airport, Maui Memorial Medical Center, County of Maui, Maui Police Department restored. Parts of Central Maui also restored.

11:10 AM: PACIFIC RADIO GROUP – via phone
RE: 60 % restoration complete

11:20 AM: PACIFIC RADIO GROUP – via e-mail
MAUI NEWS – Ed Tanji via e-mail
RE: PR1 (See Media Exhibit "A")

*1:30 PM: PACIFIC RADIO GROUP – via e-mail
MAUI NEWS – via e-mail & fax
KAOI, KONI via fax
HONOLULU ADVERTISER, HONOLULU STAR BULLETIN via fax
KHNL, KITV, KHON, KGMB via fax
RE: PR2 (See Media Exhibit "B")

*Note that distribution began at 1:30, however, due to busy phone lines, actual transmission took place between 1:30 and 3:00 pm.