# HAWAII DEEP WATER CABLE PROGRAM

## PHASE II-C

## TASK 1

# ENVIRONMENTAL CONSTRAINTS TO USE OF A SEA ELECTRODE IN A SUBMARINE ELECTRICAL TRANSMISSION CABLE SYSTEM IN HAWAII

Prepared by
George Krasnick
Parsons Hawaii

For
Hawaiian Electric Company, Inc.

and the

State of Hawaii

Department of Planning and Economic Development

May 1987

# HAWAII DEEP WATER CABLE PROGRAM

## PHASE II-C

## TASK 1

# ENVIRONMENTAL CONSTRAINTS TO USE OF A SEA ELECTRODE IN A SUBMARINE ELECTRICAL TRANSMISSION CABLE SYSTEM IN HAWAII

Prepared by
George Krasnick
Parsons Hawaii

For
Hawaiian Electric Company, Inc.

And the

State of Hawaii

Department of Planning and Economic Development

May 1987

# INTRODUCTION

The HDWC Program is determining the technical and economic feasibility of electrically interconnecting the islands of Hawaii, Maui, and Oahu with a high voltage direct current submarine cable system. To investigate system feasibility, it has been necessary to "design," at least conceptually, a system capable of meeting all of the technical requirements of a full-scale link while at the same time, attempting to optimize the economics. A major research area has been the system configuration because of the great impact of the hardware on system cost. One element of system configuration is the method of completing the electrical circuit, i.e., the "return" of electrons to the source. The return may be through another cable or through the ground and/or sea. Selection of the method of return is influenced by system polarity which, in turn, determines the return current magnitude; potential environmental impacts associated with the method of return and return current magnitude; impact on system reliability; and, impact on system capital and operating costs. The present report examines the environmental consequences of selection of a "sea return" for the Hawaii interisland electrical cable system. The sections below describe the options for system polarity, the selected design for Hawaii, the characteristics of sea electrodes, their environmental impacts and possible mitigation measures.

## SYSTEM CONFIGURATION OPTIONS

### Categories of HVDC Systems

An HVDC system may be configured as monopolar, bipolar, or homopolar. A monopolar system has but one high-voltage pole, and uses the earth as a return conductor. In this case the ground current is equal to the pole current. A grounded bipolar system consists of two poles with their center point connected to ground. If the current in each pole is equal, the current through the earth is zero. Small unbalances in the pole currents may drive small (1-2%) current flows through the ground. System faults may create conditions where the entire pole current flows through the ground. A homopolar system consists of more than one pole of the same polarity, and the ground current is equal to the sum of the line currents.

### The Preferred Alternative for Hawaii

The baseline commercial cable system described by the HDWC Program utilizes a bipolar configuration of two 300 kV poles with two 125 MW, 12-pulse valve-groups per pole. It has been recommended that the poles be operationally independent such that no common-mode outage could result in loss of the entire bipole.

The poles would have a communication link to facilitate contingency operations. An assumption made at the outset of the HDWC Program was that the commercial cable system would employ a "metallic return." This would comprise a separate submarine cable, possibly of simpler design than that of the pole conductors. The overland portion would be another overhead line and could be carried on the tower used for the pole conductors. The metallic return assumption was made based on the desire to avoid potential environmental impacts associated with use of a sea return. Neither the relative impacts nor the additional costs associated with installation of a metallic return were critically and quantitatively evaluated until PTI's phase II-3 report became available in late 1986 (PTI, 1986). Their analysis concluded that the original assumption was ill-founded because: environmental impacts would be slight and for the most part mitigatable; a metallic return would be expensive to construct; and, with a metallic return in place, system reliability would be decreased.

PTI reasons that the dc currents in the two poles are essentially independent and would normally sum to a value close to zero at the converter ground point common to both poles. "Close to zero" is about 1 or 2% of the pole current. For the commercial cable system each pole would carry half the power (250 MW) at 300 kV so that full pole current would be 833 amperes. The unbalanced current at the ground point would, therefore, be between 8 and 16 amperes at worst. Modern control systems could essentially eliminate that imbalance, if necessary.

Because the pole currents essentially cancel out, with one pole out of service, the remaining pole current would flow in the neutral (ground/sea) path without cancellation. Under this condition up to 833 amperes would be flowing in the ground. If this condition were to occur, the direct current in the ground would seek out the path of least resistance, which could comprise buried/sunken metal structures, and cause accelerated corrosion. This problem is cumulative but could be mitigated by reducing the time for which current flows in the ground path, by judicious selection of the ground/sea electrode locations and by cathodic protection of nearby buried metal structures. Current potentials within a few meters of the electrode may be hazardous to humans and marine fauna.

## SEA ELECTRODES

### Design Considerations

Sea electrode design must take into consideration the thermodynamics and geophysics of the site, as well as aspects of the dc system configuration and operation (IEC, 1981). Design criteria include:

- Current - The electrode must be capable of handling the maximum overload current.
- Operating Time - A balanced bipolar system is usually rated for the length of time the electrode can operate at its full current rating without overheating.
- Lifetime - Electrolytic action, thermal cycling and the natural wastage of electrode materials act to reduce electrode life.
- Reliability - Electrodes are naturally very reliable but sectionalizing to allow partial operation during maintenance, repair or replacement, and redundant cable feeds and switches are advisable.

- Polarity - A ground electrode may be operated as a cathode, to which current flows from the earth, or as an anode, from which current flows into the earth. In a balanced bipolar system, however, the polarity of the electrodes will automatically change with operating conditions.

- Vicinity Potentials - Potentials between two points near the electrode can be appreciable. For sea electrodes the potential difference is measured between two points in the volume of water. A ground electrode submerged in water creates voltage gradients in the surrounding water, which may present safety or environmental problems. It has been found that head-to-tail voltages in the order of 1 to 5 volts make a fish unconscious and that fish are attracted to the anode but not to the cathode. Voltage gradients up to 1.25 volts per meter can be tolerated by humans and large fish, so that adequate protection can be obtained by installing nets or screens in the water or fences around the immediate area of the submerged ground electrode out to the point where gradients at maximum current are below the acceptable level. Measurements at the Sardinian sea electrode indicate that the distance from the electrode needs only to be a few meters to reach this condition.

- Temperature - The final design temperature must consider the maximum ambient temperature of the earth or water around the electrode to insure that the boiling point is not reached.

## Typical Locations

A sea electrode may be built on the shore near the ocean or actually in the ocean. Either is vastly superior to a land electrode because of the very low resistivity of seawater (about 0.2 ohm-meters) compared with typical land resistivities (10 to 1000 or more ohm-meters.) Where a dc return current flow is between two points on opposite shores, the ocean floor may be considered an insulator and it may be assumed that all current flows in the water.

Design of a typical shore electrode element is shown in Figure 1. In this example, the perforated pipe has an outer diameter of ten inches. Generally, an electrode will consist of an array of individual elements each connected to the converter station through a disconnecting switch to facilitate maintenance and repair. Because a shore or sea electrode is so much more efficient than a comparable ground electrode fewer elements of

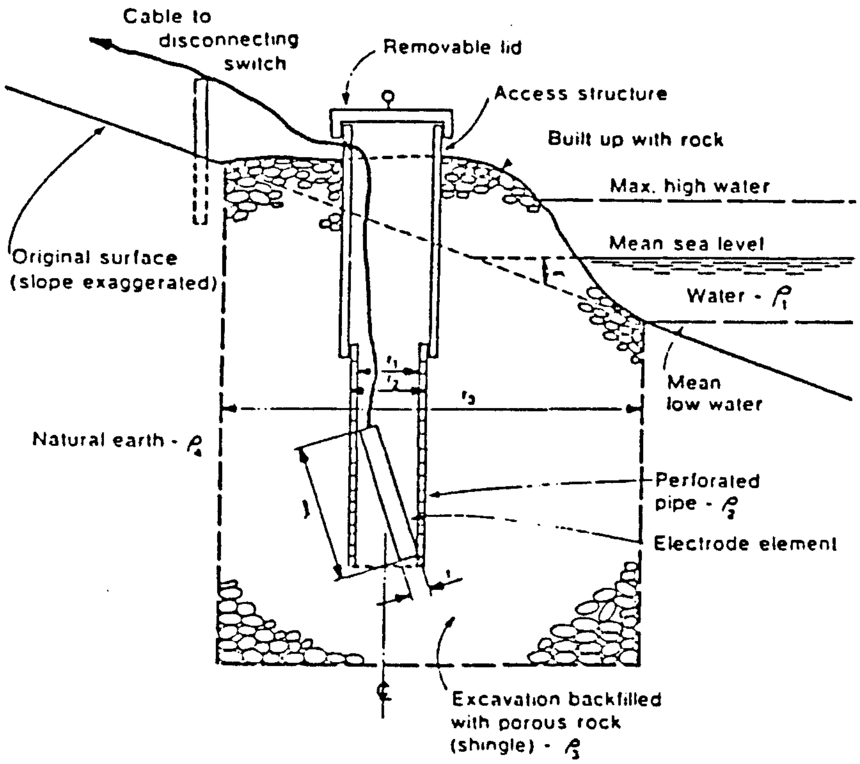

FIGURE 1. Diagrammatic section through hypothetical shore electrode.

smaller size are required. Where a ground electrode may require tens of acres and extend linearly hundreds of meters, a linear shore electrode may spread over 100 meters or less. A primary design criterion is that the electrode elements always be in contact with water. Where there is the possibility of the electrode drying out, for example from excessive heating, a pumping system may be necessary.

Where a shore electrode is undesirable because of the lack of a suitable site or other reason, the electrode may be situated at any distance offshore. Enclosures would be required to protect fish.

## Siting Criteria

- Resistivity - For shore electrodes it is necessary to measure the resistivity of the surrounding water and the adjacent earth. Flux of fresh or brackish groundwater past the electrode would imply a medium of much greater resistivity and less efficient electrode operation than one immersed in seawater. For electrodes farther than about 400 m from shore, the resistivity of the seabed may be neglected, as nearly all ground current will flow in the seawater.

- For shore electrodes, physical factors of the site, including effects of wave action on the structures and tidal changes, must be determined. Also necessary would be screening the site against fish, and fencing it against intrusion by human or animal life.

- For shore or sea electrodes, the presence of marine structures within range of corrosive effects of the ground current must be determined. (See sample calculation below.)

- For sea electrodes, the direction and speed of water currents, scouring action of sand, presence of aquatic flora, location with respect to established shipping routes and fishing operations, and the possible effect on aquatic life must be considered.

- Site accessibility for construction and maintenance must be considered.

- Relative economics of the site must be investigated.

- Geophysical factors to consider in initial siting of submerged electrodes include:

    - Composition of the earth at the shoreline (for shore electrodes)

- Composition of the sea bottom (for sea electrodes)
- geologic hazards
    - -- Erosion potential
    - -- Earth or rock slides, on the surface or underwater
    - -- Subsidence
    - -- Earthquake hazards

## ENVIRONMENTAL CONSIDERATIONS AND IMPACT MITIGATION

### Corrosion Effects

There are two concerns for metallic structures located in the field of an HVDC electrode: corrosion and coating damage (IEC, 1981).

Metallic ions are positive and move through an electrolyte in the direction of electric current. Where current leaves a metallic object, metal ions flow into the electrolyte where some of them combine with negative ions.

The formation of ions liberates electrons which may flow to some other point on the metal object through the metal itself to where current enters the metal from the electrolyte. Here the electrons combine with positive ions. This reaction coats the metal object with a layer of hydrogen which protects it from further corrosion or oxidation. This is where the distinction between anode and cathode lies: metal from which current flows into the electrolyte is an anode, and metal into which current flows from the electrolyte is a cathode. From the previous discussion it is clear that cathodes are not subject to corrosive action, whereas anodes are.

The most satisfactory methods of decreasing the effects of ground current from an HVDC electrode on buried objects are to maintain maximum separation, minimize the magnitude of current discharge, and minimize the operating time of the HVDC electrode. Tests conducted prior to installation of the Los Angeles Sea Electrode confirmed, however, that corrosion effects are markedly less for an ocean electrode than for a comparable land electrode (Elder and Whitney, 1968). Calculations presented in the next section show why this is the case.

## HVDC Effects on Telephone Cable

An important form of interference on telephone systems is the corrosion of cable sheaths. Most cable sheaths are of lead material. The lead sheath corrodes until it is penetrated and the cable loses the protection afforded by the sheath.

Some simple concepts of electrical current flow will serve to explain why HVDC ground currents may result in corrosion. Electrical current always flows through all paths of conductance, and the magnitude of the current is directly proportional to the length of the conductance path between two points. In the case of HVDC earth return currents, this path is generally through a large volume of low resistivity earth between two electrodes. In the vicinity of these electrodes, however, the current must concentrate itself near the surface of the earth to be collected by, or discharged from, the electrode. Nearby buried pipelines or other structures often present a lower resistance path to the current as it flows near the earth's surface than does the earth itself. The pipeline will collect current some distance from the electrode and discharge it as the pipeline nears the electrode, resulting in corrosion of the metal at the point of discharge.

With certain simplifying assumptions, it is possible to make a preliminary analysis of the distance at which HVDC ground currents may cause interference problems. In a paper by Fiorito (1968), a procedure is outlined by which the minimum desirable separation between a lead-sheathed cable and an HVDC electrode can be calculated. This separation will result in leakage currents low enough to keep the corrosion of a lead sheath to acceptable limits.

If it is assumed that the earth is uniform everywhere, the expression for the earth potential resulting from a current, $I_o$, injected into the earth from an HVDC electrode can be stated as:

$$V_y = \frac{I_o p}{2\pi y} \text{ volts}$$

where $V_y$ = earth potential at distance y from electrode, volts

$y$ = perpendicular distance from electrode, meters

$I_o$ = electrode current, amperes

$p$ = earth resistivity, ohm-meters

Assuming a lead-sheath cable separated from an HVDC electrode by a large distance y (several miles) and further assuming a low contact resistance, the current flowing on the cable is:

$$I(x) = \frac{I_o p x}{2 \pi R \, (X^2 + y^2)^{3/2}} \text{ amperes}$$

where $R$ = cable sheath resistance, ohm-meter

$x$ = length of cable from point opposite electrode, meters

$I(x)$ = current on cable at point x, amperes

The maximum leakage current density on the cable will occur at $x = 0$, where:

$$i_{max} = \frac{I_o p}{2\pi^2 \; dRy^3} = \frac{dI(x)}{d_x}\Bigg|_{x = 0} \quad \frac{\text{amperes}}{\text{meter}^2}$$

where $d$ = cable diameter, meters

$i_{max}$ = maximum leakage current density at $x = 0$, amperes/meter$^2$

Assuming an original lead-sheath thickness of 100 mils with a 10 percent uniform sheath loss over 40 years, the maximum allowable leakage current density is approximately $2 \times 10^{-7}$ amperes per square centimeter. Assuming a typical large lead cable with $d = 0.0645$ meter and $R = 0.36$ ohm/km, an earth resistivity of 100 ohm-meters and an electrode current $I_o = 1{,}000$ amperes, the minimum separation "y" is:

$$y = \left[\frac{I_o p}{2\pi^2 \; dRi_{max}}\right]^{1/3} \text{meters}$$

$$y = 4{,}778 \text{ meters} = 4.778 \text{ km}$$

This type of calculation is only valid for cases where the assumption of uniform earth holds true. In practice, this will seldom be the case. However, the procedure outlined may be used to arrive at a preliminary range where corrosion problems may result and where field testing should be considered. It should be pointed out that in the case of cables with an insulated sheath or insulated pipelines, a small hole in the insulation will result in current densities of up to 100 times that for bare systems. This is due to leakage current being concentrated at the hole in the insulation.

Corrosion is not limited to structures buried in the earth. Similar structures are sometimes used in a marine environment and are also subject to corrosion. Any object in the field of HVDC ground current which presents a lower resistance path than the surrounding soil or water is subject to corrosion problems.

However, applying the same set of equations and assumptions to our sea electrode and substituting 833 amperes maximum current and a seawater resistivity of 0.2 ohm-meters for the earth resistivity of 100 ohm-meters yields a minimum separation distance of only 4.5 meters. In other words, communications cables with the assumed specifications located at distances greater than 4.5 meters from the electrode would not experience unacceptable accelerated corrosion.

## Electrical Effects

Corrosion is not the only adverse effect that HVDC ground currents may have on external installations. The dc current, along with the many harmonic components created by the terminal conversion equipment, may also cause electrical interference problems. It should be noted that it is possible to greatly reduce the magnitude of the harmonic components with dc filters on the line side of the terminal. Typically, three areas must be investigated in connection with this electrical interference:

(1) railway signaling, (2) transformer magnetization, and (3) ac transmission effects. We will not have to worry about the first in planning a system for Hawaii, and the latter two are primarily of concern with a ground electrode system, but brief discussions of these two follow.

## AC Transmission Effects

AC electrical substations are grounded directly to the earth as a means of overvoltage control during lightning strokes and faults. If two such grounding points are in the field of HVDC ground current, a potential difference may exist between the two points, and direct current may flow in the ac transmission conductors. If the ground current is of a sufficient magnitude, it will affect the accuracy of relaying and metering current transformers, or, result in transformer magnetization.

Tests by the Bonneville Power Administration (BPA) in 1963 have shown that installations with grounded neutral power transformers are the most vulnerable to HVDC ground current. The primary means of avoiding this type of interference has been to locate the HVDC ground electrodes a sufficient distance from grounded electrical equipment to limit the magnitude of ground currents in the neutral system.

## Transformer Magnetization

A related problem arising from dc currents in neutral circuits is that of transformer magnetization. One method of alleviating transformer magnetization, other than relocating the ground electrode, is to insert a small resistance in the grounded neutral connection. Care must be taken, however to assure that subsequent fault currents will not cause dangerous voltage levels in the substation. Another method which has been successful in mitigating direct current flow in the distribution transformers is to separate the neutrals. By separating the neutrals and using separate ground rods, the direct current flow is reduced and transformer saturation is not a problem.

## Other Effects

As the system is presently envisioned, electrodes would be required on Oahu and Hawaii and if a Maui tap is built, an electrode would be needed on that island as well. Each of these electrode systems would require nearshore land (on the order of one hectare in area), and additional land for a transmission line right-of-way from the converter station to the shore. This right-of-way can be relatively narrow as this portion of the system is low voltage. Single, wooden poles carrying a pair of conductors rated at approximately 11 kV would be adequate. (The size of the conductor must be large enough to carry a lightning strike.)

In addition, if a true sea electrode is employed, there would be offshore impacts associated with emplacement of conductors, electrodes and protective barriers. Trenching of each conductor wire (one per electrode element) would likely be required.

An electrode discharging current into the ocean and the cable feeding current to it would produce magnetic fields which may deflect compass needles in passing ships or magnetize a metallic hull if a ship stops within the field (Bechtold, 1968). In the latter case, compass recalibration or degaussing of the hull might be necessary.

## CONCLUSIONS AND RECOMMENDATIONS

- In previous HDWC Program planning related to system configuration, metallic return has been specified based on assumed unacceptability of environmental impacts. This has been shown invalid. Potential impacts include accelerated corrosion of nearby metallic structures and risks of shock to humans and animals at close range. Neither of these potential impacts are significant at distances of more than a few meters from the electrode.
- ← Either a shore electrode system or a sea electrode system is feasible. The impacts associated with burying the disconnect cables through the nearshore environment, potential security problems, etc. argue against a sea electrode, and a shore-based system is recommended.

- The shore electrode should be sited away from sources of fresh or brackish water runoff or seepage. This may be accomplished by burying the electrodes to depths below the fresh water lens which underlies each of the islands.
- The electrode should be located away from anchorages or shipping lanes.
- The maximum distance possible should be maintained between the electrode and other metallic structures.
- The electrode should discharge the minimum amount of current for the least possible time.
- The terminal conversion equipment should employ dc filters on the line side to reduce or eliminate harmonic current components.

# References

Bechtold, I.C. 1968. "Ground Current Patterns of the Southern California HVDC Sea Electrode." Paper No. 38, National Association of Corrosion Engineers Conference. Cleveland, Ohio.

Elder, G.R. and D.B. Whitney. 1968. "The Los Angeles HVDC Ocean Electrode." Paper No. 39, National Association of Corrosion Engineers Conference. Cleveland, Ohio.

Fiorito, L.E. 1968. "Corrosion Aspects of HVDC on Buried Telephone Plant." IEEE Transactions on Power Apparatus and Systems. 87: 35-40.

International Engineering Company, Inc. 1981. HVDC Ground Electrode Design. Prep. for Electric Power Research Institute. Res. Proj. 1467-1. EPRI Rept. No. EL-2020.

Power Technologies, Inc. 1986. Hawaii Deep Water Cable Program, Phase II-B: Final Report. Prep. for Hawaiian Electric Co., Inc. and the Hawaii Dept. of Planning and Economic Development.