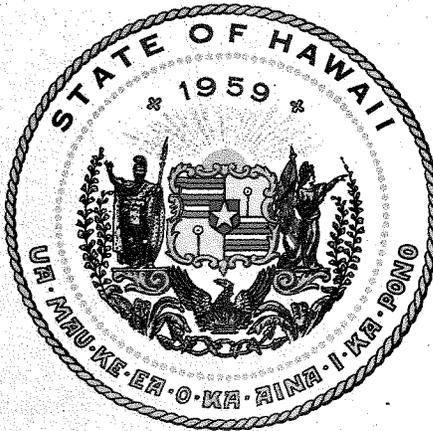


LIBRARY
STATE OF HAWAII
DEPARTMENT OF BUSINESS AND
ECONOMIC DEVELOPMENT & TOURISM
P.O. Box 2359
Honolulu, Hawaii 96804



HAWAII DEEP WATER CABLE PROGRAM

PHASE II-D

TASK 5.5

A SHORE-BASED SEA ELECTRODE SYSTEM FOR A SUBMARINE ELECTRICAL TRANSMISSION CABLE SYSTEM IN HAWAII

TK3351
H35
PIID
T5.5

Department of Business and Economic Development

HAWAII DEEP WATER CABLE PROGRAM

PHASE II-D

TASK 5.5

**A SHORE-BASED SEA ELECTRODE
SYSTEM FOR A SUBMARINE ELECTRICAL
TRANSMISSION CABLE SYSTEM IN HAWAII**

Prepared by

**G. Krasnick and J. Mansur
of Parsons Hawaii**

for

Hawaiian Electric Company, Inc.

and the

State of Hawaii

Department of Business and Economic Development

AUGUST 1988

TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
List of Figures and Tables	iii
1.0 Introduction	1
2.0 Sea Electrode System Description	3
3.0 Siting Procedures	8
4.0 Cost Evaluation	16
5.0 Summary	20
6.0 References	22

LIST OF FIGURES

<u>NUMBER</u>	<u>TITLE</u>	<u>PAGE</u>
1	Preferred Route Map	2a
2	Diagrammatic Section Through Hypothetical Shore Electrode	6a

LIST OF TABLES

<u>NUMBER</u>	<u>TITLE</u>	<u>PAGE</u>
1	Sample Electrode Specifications	6
2	Intermountain Power Project Electrode Costs	19

1.0 Introduction

This report describes the complete sea electrode portion of the electrical power transmission system proposed for the Hawaiian Islands as researched and developed by the Hawaii Deep Water Cable (HDWC) Program.

1.1 The Hawaii Deep Water Cable Program and a Commercial Cable System

The Hawaii Deep Water Cable (HDWC) Program is a research and development effort to determine the technical and economic feasibility of installing and operating a submarine, high voltage, direct current, electrical transmission system from the Island of Hawaii to Maui and Oahu. Actual development of the system would be a commercial venture but would have access to all of the HDWC Program research. Informational reports, such as this, aid in future decision-making regarding the proposed system. The transmission system design presently includes overhead transmission lines across portions of the three islands and submarine cables in the channels between islands. The transmission system has been designed to include a total of 131 miles of overhead lines and approximately 138 miles of submarine cables. Four cable landing sites would be required along the transmission route.

1.2 HDWC Program Phase II-C Sea Electrode Report

A HDWC Program report titled Environmental Constraints to Use of a Sea Electrode in a Submarine Electrical Transmission Cable System in Hawaii described system configuration options available to the HVDC system (Parsons, 1987). The rationale for the sea electrode as the preferred alternative were also discussed. Preliminary information on sea electrodes, such as design considerations, typical locations for siting, criteria for siting, environmental considerations and impact mitigation, was included in the report. The report recommends a shore-based system for the sea electrode. The shore-based system would be buried on dry land with the electrodes reaching a depth below the fresh water lens which underlies each of the islands. Thus, the shore-based system for the sea electrode is not to be misinterpreted as a land-based or ground electrode.

1.3 Preferred Cable Route and Landing Areas on Hawaii, Maui and Oahu

A "preferred route" was chosen to represent a broad path within which many options for future alignment of the electrical system exist. This preferred route is shown in Figure 1.

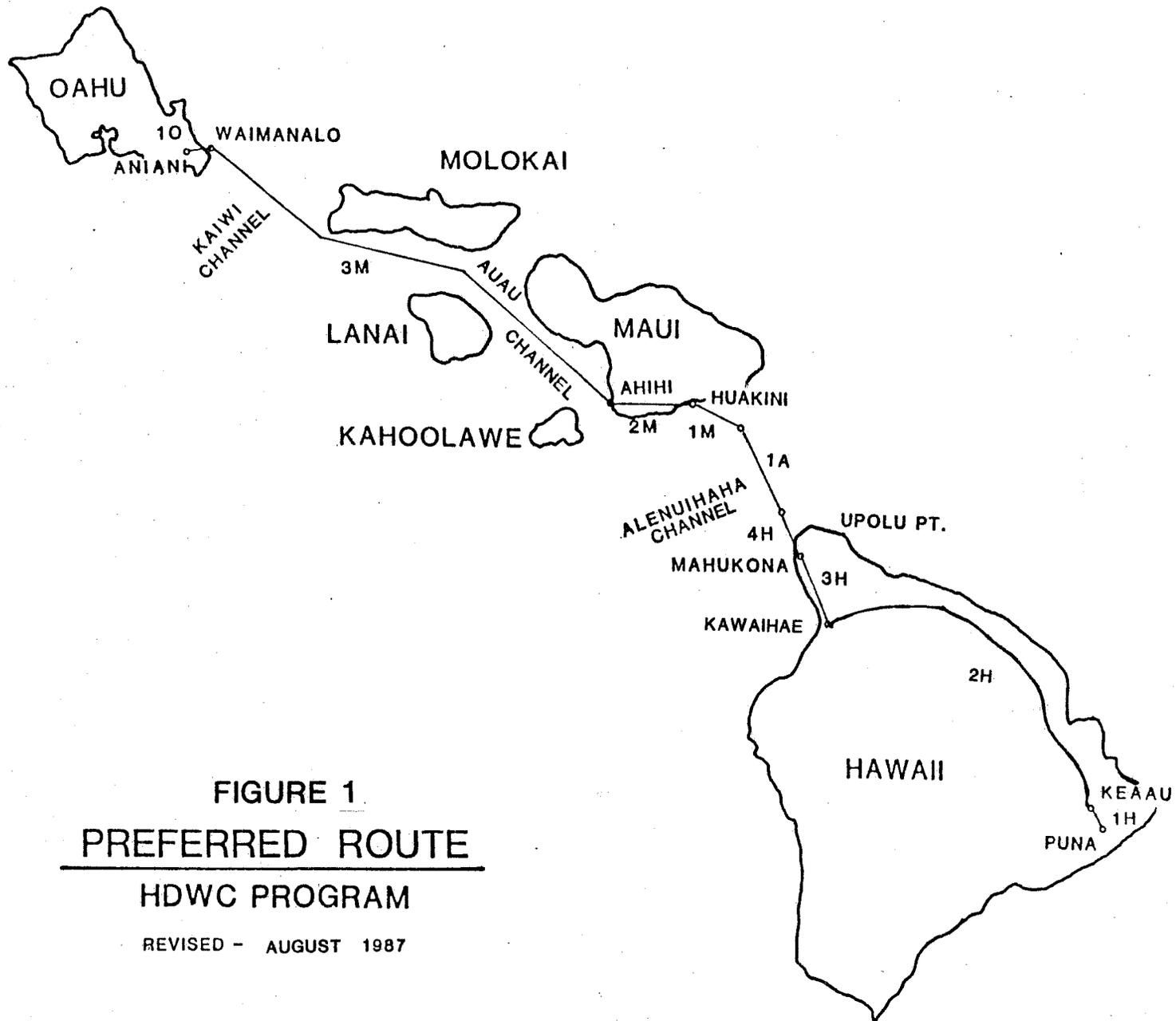


FIGURE 1
PREFERRED ROUTE
HDWC PROGRAM

REVISED - AUGUST 1987

The landing sites, based on the studies discussed above and the results of sea floor mapping also accomplished under the HDWC Program, are at four locations: Makaohule Point, near Mahukona, Hawaii; Huakini Bay and Ahihi Bay, Maui; and Waimanalo Beach, Oahu. These landing sites are also shown on Figure 1.

2.0 Sea Electrode System Description

The sea electrode is described below as it would appear in connection with the cable system which has been developed in the HDWC Program. It may be subject to change if the commercial cable development scenario changes. Three electrode stations would be required, one on each island - Hawaii, Maui and Oahu - using approximately one hectare (2.471 acres) of nearshore land per station.

2.1 Function and Design of the Sea Electrode in the Cable System

Practically all HVDC systems now operating or which have been designed throughout the world utilize sea electrodes (Bechtold and Smythe, 1968).

A permanent and effective electrical connection between earth and the midpoint of the series of connected valve groups at each converter station is required. This requirement is for the same

reasons as in an alternating current systems i.e. for purposes of stabilization, protection, proper control function, and potential reference. This same connection permits emergency earth return operation (Elder and Whitney, 1968).

Therefore, the sea electrode is a part of the baseline commercial cable system designed as a bipolar configuration of two 300 kV poles with two 125 MW, 12-pulse valve groups per pole. Again, the function of the sea electrode is to complete the electrical circuit, i.e., the "return" of electrons to the source, within the system configuration.

As described in HVDC Ground Electrode Design (International Engineering Company, Inc., 1981), "the design of ground electrodes* is based on the laws of thermodynamics and geophysics as well as on those of conduction of electricity. Electrode design therefore requires a careful consideration of many disparate, but mutually interacting, parameters of the electrical system and of the earth which is used as the current path."

* The term "ground electrode" is used generically to include sea electrodes.

2.2.1 Sea Electrode System Components

The shore-based sea electrode system envisioned for this project would be buried on dry land with the electrodes reaching a depth below the fresh water lens which underlies each of the islands. Therefore, the sea electrode system 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 resistivity (10 to 1000 or more ohm-meters.) As stated in HVDC Ground Electrode Design (International Engineering Company, Inc., 1981), "since sea water offers an optimal path for ground current and water crossings are a prime feature of HVDC, ground electrodes in direct contact with water are important in HVDC systems."

Basic specifications for a typical ground electrode are shown in Table 1. These specifications represent the minimum amount of information necessary for electrode design and are applicable to any type or configuration of electrode, with the exception that the safety requirements would be stated somewhat differently for a sea electrode (International Engineering Company, Inc., 1981).

TABLE 1
SAMPLE ELECTRODE SPECIFICATIONS

PARAMETER	VALUE
1. Current	1250 A maximum
2. Operation Time	Bipolar: Continuously at 50 A Monopolar: 8 hours at 1250 A, followed by 60 days cooling at 50 A
3. Dissipation	Maximum 730,000 Ah per year
4. Lifetime	30 years
5. Polarity	Reversible anode-cathode, equal time
6. Safety	Step voltage $5 \pm 0.03p_s$ volts per meter
7. Reliability	Consistent with system reliability

(International Engineering Company, Inc., 1981)

Design of a typical shore electrode element is shown in Figure 2. 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-based or sea electrode is so much more efficient than a comparable ground electrode, fewer elements of smaller size are required. A linear shore electrode may spread

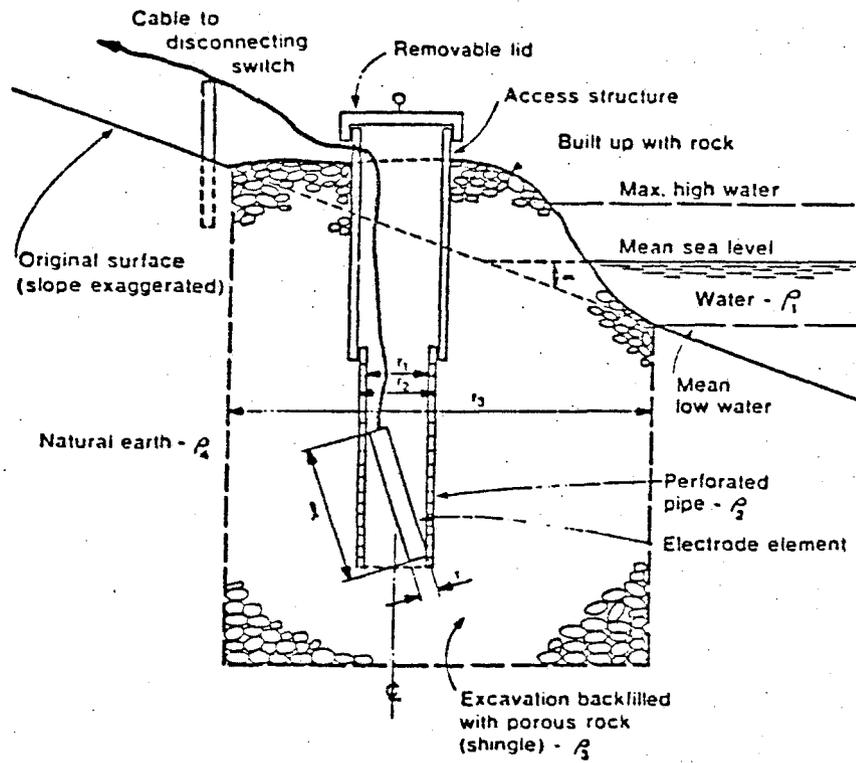


FIGURE 2 Diagrammatic section through hypothetical shore electrode.

over 100 meters or less. A primary design criterion is that the electrode elements always be in contact with the water. Where there is the possibility of the electrode drying out, for example from excessive heating, a pumping system may be necessary. Also, the terminal conversion equipment should employ dc filters on the line side to reduce or eliminate harmonic current components.

The electrodes would be tied to the converter stations' neutral bus by an inexpensive overhead pole line with minimal insulation requirements. Land for a transmission line right-of-way from the converter station to the electrode would be required. 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.)

As of 1981, only twenty-six HVDC ground electrodes were in commercial operation throughout the world. Of the nine operators/owners who responded to the question of system reliability in a recent survey, all reported 100% reliability (International Engineering Company, Inc., 1981).

3.0 Siting Procedures

According to HVDC Ground Electrode Design (International Engineering Company, Inc., 1981) "the process of siting ground electrodes is a complex procedure of searching, finding, evaluating, and finally choosing those plots of land or water which offer the most advantageous combination of desirable physical characteristics and lowest total cost. The nature of the siting process imposes a general order of procedure, in which one step follows another." These steps, or activities, are as follows:

Siting Activities

- o Define the system requirements and ratings of the electrode (determined during the system studies).
- o Decide on general areas where the electrode could be located (determined together with location of the converter station).
- o Collect maps, existing aerial photos and published data for the areas of interest.
- o Mark maps with location of converter station, possible electrode line routes and all known points of possible interference.
- o Plan campaign of site investigations; obtain instruments or hire measurement contractor(s).
- o Develop first estimate of space requirement from preliminary information.
- o Search maps, aerial photos and published data to locate areas likely to contain sites meeting requirements of available space, resistivity (estimated), terrain,

water content, access and distance from possible points of interference.

- o Preselect a number (recommended minimum three) of areas for investigation.
- o Conduct an aerial reconnaissance to evaluate and/or eliminate map-selected areas.
- o Reevaluate areas on basis of first reconnaissance and select other areas if necessary.
- o Conduct air-borne resistivity measurements (land sites).
- o Conduct surface reconnaissance for further evaluation.
- o Conduct aerial photogrammetry or preliminary surface surveys of selected sites; set control points.
- o Produce preliminary site plans.
- o Make preliminary inquiries about availability of selected sites.
- o Make preliminary evaluation of sites and decision on which sites are to be investigated more thoroughly and which sites are second choices.
- o Determine availability of sites under consideration and obtain permission to survey.
- o Produce detailed mapping of selected sites with surface contour lines (line) or depth contours (shores and sea).
- o Plan the measurement program for each site and locate test points on site maps.
- o Take resistivity, thermal conductivity and earth temperature measurements.
- o Measure earth moisture content and water table levels (land sites) over at least a 3-month interval.
- o Measure water resistivity and temperature (shore and sea sites) at least four times in a year.
- o Investigate tide and water current fluctuations (shore

and sea sites).

- o Revise estimate of space required for electrode in light of information obtained by investigations.
- o Conduct detailed investigation of possible objects of interference (pipelines, buried and marine structures, generating plants and substations, railroads, telephone cables, etc.).
- o Investigate possible routes for transmission line(s) from the converter station to the ground electrode.
- o Evaluate means of access to sites.
- o Estimate the cost of construction for each site, considering all factors investigated under previous steps.
- o Estimate the cost of controlling interference to external objects and evaluate the differences between sites.
- o Obtain statements of environmental and legal constraints.
- o Compile the information.
- o Evaluate the data, cost estimates, constraints and other factors for all sites under consideration.
- o Select the site(s) for development.

Just the first four steps in the list above are covered in this report. It is important to note that several of the steps require techniques using special equipment over long periods of time. Developers of the commercial cable system should allow a minimum time span of 15 months to complete the process of selecting an electrode site. It is assumed that all electrode sites can be researched simultaneously.

3.1 Locational Factors

Many locational factors must be considered in the siting of the electrode system. The first factor is the electrode system's relationship to the other accessory structures, such as the substations, in the overall electrical power transmission system. Another factor is the ability to identify onshore locations that would meet the siting criteria and not interfere with existing or planned urban uses. Additionally, the rights-of-way between the electrodes and the substations need to be identified on each island. These factors are discussed below.

3.1.1 Substation Locations

A substation is where electric energy is transformed and switched from one circuit to another. There are several substations in use on each island as a part of the existing electrical power

transmission system. A converter station, which changes alternating current to direct current or vice versa, would be required on each island of the proposed interisland system. On the Big Island, the converter station would most likely be built in the Puna District near the geothermal subzones where the electricity would be generated or at the Kaumana substation outside of Hilo town (PTI, 1986). On Maui, the converter station would preferably be close to the Wailea substation which is tied to the 69 kV networks out of the Maalaea generating station (PTI, 1986). On Oahu, Hawaiian Electric Company owns land for a utility function at Aniani, behind Waimanalo. This site could be used for the converter station where the electric power from the Big Island could be accepted into the HECO grid system (PTI, 1986).

Given these general areas, the electrode systems would best be sited within an approximate three mile radius for economic reasons. The criteria described below further define the locational factors to be considered in siting the electrodes.

3.1.2 Siting Criteria for Sea Electrode

Potential sites for the sea electrode need to be chosen with an understanding of the siting criteria discussed below:

Corrosive Effects

The presence of marine structures and buried metallic structures within range of corrosive effects of the ground current must be determined. Such structures include transmission line tower footings, telephone lines, pipelines and other structures. 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. This field was determined to be approximately 4.5 meters from the electrode (Krasnick, 1987). The most satisfactory methods of decreasing the effects on buried structures of ground current from an HVDC electrode are to maintain maximum separation, minimize the magnitude of current discharge, and minimize the operating time of the HVDC electrode.

Resistivity Characteristics

"In the case of an electrode to be constructed on the shoreline of a body of water, it will be necessary to measure the resistivity of the surrounding water as well as that of the

adjacent earth. Since the resistivity of seawater is much lower than the average resistivity of earth, and therefore the effect of the earth will be proportionately less, earth resistivity measurements for shore electrodes may not need to be as elaborate as those for land electrodes. However, attention must be paid to the effect of water infiltration into the earth, since a wide variation of resistivity will occur depending on whether the infiltration comes from the sea or land side. Seasonal changes in shore land resistivity may occur. In any area, resistivity measurements of the surrounding water should be made at regular intervals over a period of at least two years" (International Engineering Company, Inc., 1981).

Geophysical Factors

Geophysical factors to consider in initial siting of submerged electrodes include composition of the earth at the shoreline and geologic hazards (the latter are discussed in the next section). The effects of wave action, if near the shoreline, and tidal changes on the electrode structure must be determined. It would be necessary to fence off a small area around the electrode to protect it against intrusion by humans or marine animals.

"A shore electrode should not be located in a natural drainage course, where runoff water from a storm might wash through the

electrode. It is also preferable not to locate a shore electrode in a percolation channel, where the infusion of fresh water from the land side would lower the salinity, and thus raise the resistivity, of the water around the electrode elements" (International Engineering Company, Inc., 1981).

Geological Hazards

Areas with geological hazards such as erosion potential, earth or rock slides, subsidence and earthquake hazards should be avoided where possible, or considered in the design of the electrode system when necessary.

Climatic Data

Weather data covering rainfall, hours of sunshine, solar heat gain, ambient temperature variations, and possibly wind intensities should be consulted in designing the electrodes.

Site Accessibility

Site accessibility for construction and maintenance must be considered. A site with good access would minimize the costs associated with construction and maintenance. However, the site

must be in an area where it can be secured and protected from vandalism.

Existing and Planned Land Use Patterns

Each electrode station would only use approximately 1 hectare (2.47 acres) of land and would be fenced off or otherwise secured, as described above. Operation of the electrode station and connecting powerline would not interfere with urban, agricultural or industrial land uses. "Objections to ground electrodes for aesthetic reasons should be minimal, since there is very little visible evidence of any type of electrode, except for the line termination" (International Engineering Company, Inc., 1981).

4.0 Cost Evaluation

A number of factors need to be considered in the cost evaluation of an electrode system, including its relationship to the overall electrical transmission system researched under the Hawaii Deep Water Cable Program, determination of the electrode's function in terms of time and current flow, location of the system (soil and terrain factors), need for special technical expertise, importation of equipment and materials, and implementation costs (construction, planning and engineering, site studies,

environmental impact reports). It is difficult, therefore, to estimate the cost of an electrode system when much of the critical information is yet undetermined. However, using cost data from another electrode system while pointing out the differences and similarities between the two may result in an approximate price range or cost figure to consider in future planning. This form of cost evaluation is used herein and described below.

4.1 Intermountain Power Project

A consortium of utilities, including the Los Angeles Department of Water and Power, has recently completed a ground electrode system as a part of the Intermountain Power Project. This system carries 500 kVdc of electrical power between Delta, Utah and Adelanto, California - a total of 489 miles. Two ground electrode systems were required for this project, one at each end. The electrodes are located in the desert on government-owned land. They use several acres of land each. These are "huge" electrodes, able to carry 26,000 amperes for an eight hour period and higher amperages for shorter periods of time when necessary.

The electrodes are buried in wells in a circular configuration. For example, the Utah electrode has a 3000 foot diameter with a

total of sixty wells. These wells are in ten groups of six, equally spaced, and fed by cables out of a terminal house built in the center, resulting in a wagon wheel configuration. The terminal house is approximately 12 x 10 x 10 feet and roofed to protect the main bus and switches.

The wells in Utah are each 285 feet deep with 15 feet of backfill on top and the remaining 270 feet filled with coke breeze. The California wells are only 230 feet deep. The wells (14 inch diameter) each hold anode bars. The Utah wells hold 17 anodes, and the California wells hold 11 anodes.

These two electrode systems, designed for a 35 year lifespan, have the following major cost components:

TABLE 2

INTERMOUNTAIN POWER PROJECT ELECTRODE COSTS

FACTOR	COSTS (1984 dollars)
<u>Materials:</u>	
anodes	381,000
feeder cable	151,000
coke breeze	568,000
other hardware	150,000
<u>Implementation:</u>	
construction	2,026,000
engineering/planning	700,000
site studies	350,000
environmental reports	<u>700,000</u>
Total:	5,026,000 =====

(Los Angeles Department of Water and Power, 1988)

The cost, approximately five million dollars, for two very large land electrodes is not that great considering their vital function in the transmission of electrical energy. The Intermountain Power Project, of course, is significantly different from the proposed cable project in Hawaii in several ways which would affect our cost estimate. Some, such as land costs, are hard to estimate. The Hawaii project would use a shore-based electrode system requiring less land but may be on private land purchased at market value. The Intermountain Power Project obtained a right-of-way grant for the government land used. The factors that would affect the relative costs of the two systems are as follows:

- o Three electrode systems would be required for the Hawaii project, increasing the price;
- o The HVDC voltage is lower for the Hawaii project, thus requiring a smaller electrode system decreasing the price;
- o Special expertise and materials would need to be imported to Hawaii, increasing the cost; and
- o The 1984 dollars cited in the cost table above would not be equivalent to the 1995 dollars when the Hawaii project may be implemented, increasing the cost.

Taking these considerations into account, a rough cost estimate of three to five million dollars for the Hawaii project's three electrode system is projected.

5.0 Summary

The sea electrode system is a vital part of the overall interisland electrical transmission system proposed for Hawaii, Maui and Oahu. Its function is to "return" the electrons to the source within the cable system configuration. Approximately two

and one half acres of land would be needed for each electrode site - one each on Hawaii, Maui and Oahu. Siting procedures are very detailed and data collection may take up to fifteen months. The costs of the three electrode system is projected to be between three and five million dollars.

6.0 References

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

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

International Engineering Company, Inc. 1981. HVDC Ground Electrode Design. Prepared for Electric Power Research Institute.

Krasnick, George. 1987. Hawaii Deep Water Cable Program, Phase II-C: Environmental Constraints to Use of a Sea Electrode in a Submarine Electrical Transmission Cable System in Hawaii. Prepared for Hawaiian Electric Company, Inc. and the State of Hawaii Department of Planning and Economic Development.

Los Angeles Department of Water and Power. Personal communication with Thomas J. Taylor, August 29, 1988.

Power Technologies, Inc. 1986. HDWC Phase II-B Studies - Final Report. Prepared for Hawaiian Electric Company, Inc. and the Hawaii Department of Planning and Economic Development.