HAWAII DEEP WATER CABLE PROGRAM

PHASE II-D

TASK 5.4

FEASIBILITY OF USING UNDERGROUND ELECTRICAL CABLES ALONG PORTIONS OF THE OVERLAND ROUTE OF AN INTER-ISLAND CABLE SYSTEM IN HAWAII

Department of Business and Economic Development

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GLOSSARY

ARC	A luminous discharge of electric current crossing a gap between two electrodes.
ALTERNATING CURRENT (ac)	The voltage or current "alternates" between positive and negative polarity 60 times per second in the United States.
ALIGNMENT	The actual right-of-way of a proposed transmission line within a larger corridor.
BREAKER	A device to interrupt the electrical circuit. All high capacity transmission systems are protected by breakers. For underground systems, breakers may be installed at the terminations, or they may be located in a remote substation and activated by differential relays at the terminations.
BUSHING/POTHEAD	A bushing is a porcelain insulator to connect the cable conductor (or other equipment leads) to open-air conductors or overhead transmission lines. Bushings may be mounted vertically or horizontally, and vary in length according to the voltage. A 500 kV bushing is 10-15 feet long. Potheads are enclosed connectors used between oil insulated cables and gas insulated equipment.
CABLE (POWER)	An insulated current-carrying conductor with shields and coverings used for the transmission or distribution of electric power.
CATHODIC PROTECTION	One or more electrical devices to prevent galvanic action between the cable enclosure and the environment, by maintaining a potential difference of about -1 volt between the enclosure and the environment. The purpose of the cathodic protection system is to protect against corrosion.

COMPENSATION	Correction for cable capacitance. The capacitance of certain underground ac cable designs is large enough to require a significant charging current and to affect the complex impedence of the line, for long distance lines. By installing shunt reactors at critical lengths along the line, the transmission capacity can be maintained.
CIRCUIT	A conductor or system of conductors through which electric current is intended to flow.
CONDUCTOR	The wire or cable suitable for carrying electric current.
CONSTRAINT	A condition which discourages, but not necessarily precludes, a transmission line route.
CONVERTER	Equipment which changes alternating current to direct current or vice versa.
CORONA	A luminous discharge due to ionization of the air around the conductor caused by a conductor voltage gradient in excess of a certain critical value. The corona onset voltage varies with equipment design and condition, system geometry and weather. Corona discharge causes power loss, radio interference (RI), television interference (TVI), audible noise (AN), field effects and creates air pollutants, primarily ozone and oxides of nitrogen.
CORRIDOR	A strip of land which provides ample space for delineating and studying several alternative alignments for a proposed transmission line.
DIRECT CURRENT (dc)	Electricity that flows continuously in one direction has contrasted with alternating current. Unlike alternating current (ac), dc can be transmitted over long distances without special power booster stations. DC requires expensive facilities to raise or lower the voltage or to convert into ac.

DISTRIBUTION	The act or process of delivering electrical energy from the generation and transmission system to the consumer.
INSULATOR	Equipment which attaches a wire to a structure without conducting electrical current.
KILOVOLT (kV)	One thousand volts; a volt is a unit of electrical potential difference and electromotive force.
MEGAWATT (MW)	One million watts.
NOMINAL CAPACITY (of a transmission line)	The load which a line is expected to carry under normal conditions. Transmission lines are designed for a higher than nominal capacity in order to carry higher load under emergency conditions.
PHASE	In this report, the term phase refers to a conductor. AC transmission occurs in three phases, while dc occurs in two, called POLES. An isolated phase system consists of separate cables for each conductor, and thus three cables per AC circuit.
POWER	The unit of measurement of electricity expressed in watts.
REACTOR	In this report, the term reactor refers to a shunt reactor, a device to compensate for the capacitance of certain cable systems, and thus to offset the reduction in power transmission capability that the capacitance would otherwise cause.
RISER	That part of the cable that comes above ground at its termination. The riser is normally vertical, and terminates with an open-air bushing.
SUBSTATION	A subsidiary station in which electric energy is transformed. It is often combined with a switching station.
ROUTE	A broad path with many options for future alignment of an electrical system.

SUBTRANSMISSION LINE	A conductor which transmits electric energy from a transmission substation or switching station to a distribution substation.
SWITCHING STATION	A subsidiary station in which electrical energy is switched from one circuit to another. It is often combined with a substation.
TERMINATION	The end of cable, connecting to overhead lines or to other above ground station equipment. A cable termination consists of the riser section, bushing and mechanical support as required.
THERMAL BACKFILL	A soil medium for cable burial, having a low thermal resistivity in order to facilitate cable heat dissipation. Thermal backfill may be a naturally occuring or specially prepared soil mixture, or it may have additives such as concrete or wax. The measure of soil thermal resistivity is sometimes referred to as the "soil ohm" or "soil rho".
TRANSMISSION	The act or process of transporting electrical energy in bulk from a source or sources of supply to other principal parts of the system or to another utility system.
WATT	A watt is the absolute unit of electrical power equal to the rate of work represented by a current of one ampere under a pressure of one volt.

1.0 Introduction

This report examines the feasibility of using underground cables rather than overhead lines for portions of the electrical 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 Big Island to Maui and Oahu. Actual development of the system would be a commercial venture with access to all of the HDWC Program research. Informational reports such as this aid in future decision making regarding the proposed system. This transmission system design concept presently includes overhead transmission lines across portions of Hawaii, Maui and Oahu and submarine cables in the channels between the islands. A total of 131 miles are estimated for overhead lines and approximately 138 miles for submarine cables.

1.2 Rationale for Underground Cable Transmission System

The potential for the overhead transmission lines to be considered a visual intrusion into the landscape has prompted the investigation of placing portions of the system underground. This alternative of underground transmission may mitigate potential negative visual effects in the environment surrounding the project. There may also be areas where placement of the system underground would protect it from elements that affect system reliablity, such as high winds. 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.

It is assumed that the negative visual impact of the 300 kVdc transmission line with the 90 foot high self-supporting lattice towers, spaced at approximately 1300 foot intervals, would not be mitigatable along the entire route. Therefore, the alternative of using an underground system is explored in this report.

1.3 Underground Transmission Experience in Hawaii

Hundreds of miles of underground transmission "lines" exist in the islands as part of the Hawaiian Electric Company (HECO)

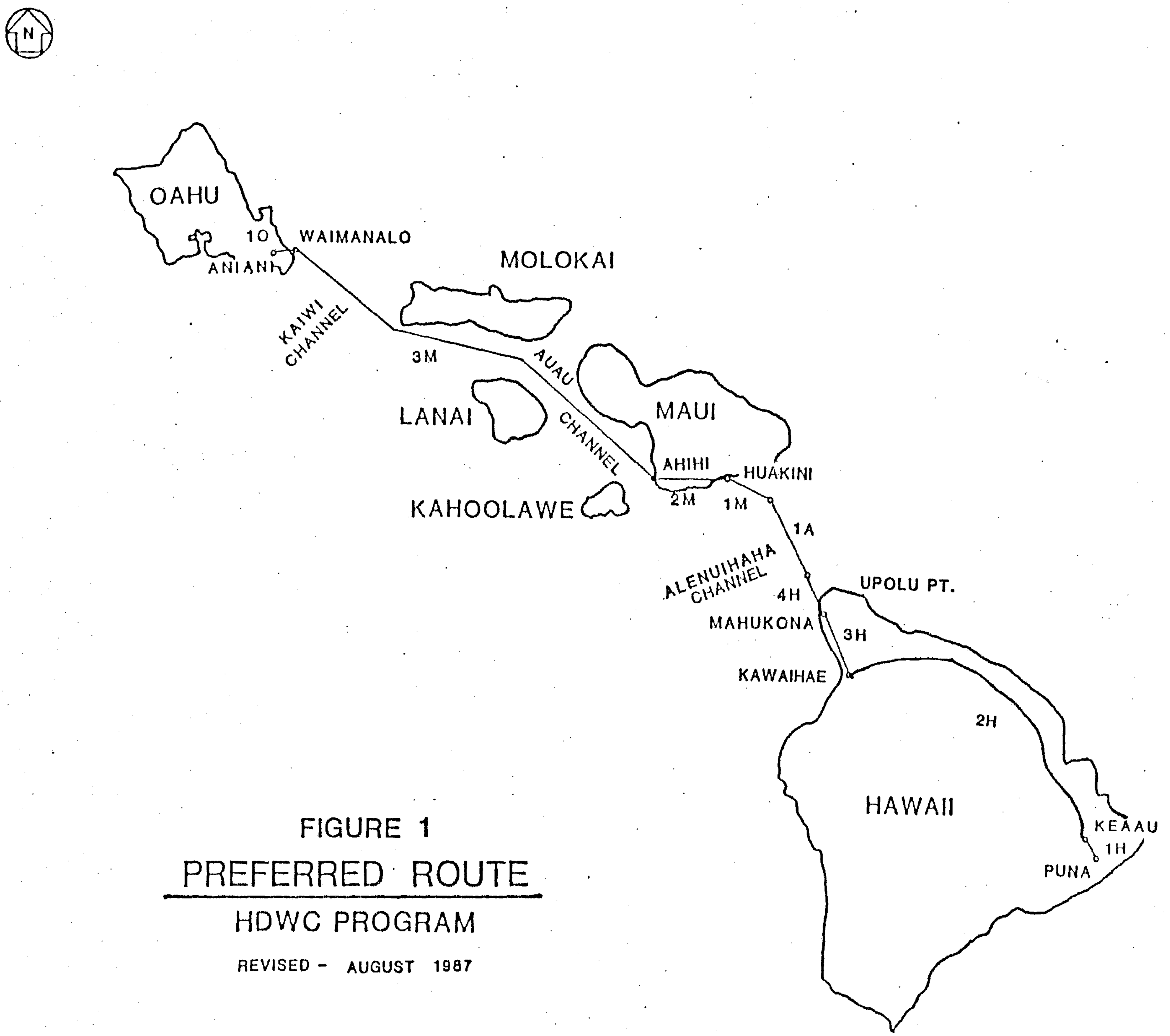


FIGURE 1

PREFERRED ROUTE

HDWC PROGRAM

REVISED - AUGUST 1987

system. (The term "line" is used to describe the conductor wires or cables that carry electric current.) These lines are either transmission or subtransmission lines, not distribution lines. The voltage of these underground lines is 46 kV, and they are used in urban areas almost exclusively.

Transmission lines are placed underground either through a duct system or by direct burial. For a duct system, the conductor lines are run underground through plastic or fiber tubes which protect them from the elements. The direct burial method consists of trenching and burial of cables shielded from the elements by protective outer layers. Construction practices involve standard trenching and burial techniques. The underground route usually follows public streets and property lines to help minimize impacts to land owners and disruption of land use.

2.0 Underground Cable Characteristics

The underground cable portions would be a part of the proposed high voltage direct current system transmitting up to 500 MW of electric power through overhead lines at 300 kV and two submarine cables at 250 MW per cable. The underground cables would also be transmitting direct current power at 300 kV. There are no hVdc underground cables in the United States at the present time. All underground transmission cables in the U.S. are ac. The most common voltage is 138 kV, but there are significant installations at 230 kV and 345 kV as well.

A report titled Underground Electric Power Transmission System Environmental Impact Assessment (Dames and Moore, 1982), summarizes that "while the technology involves a high level of sophistication, there are relately few impacts to the environment that are potentially significant, and of these none are inherently non-mitigable. Route planning, system design, and methods of construction and accident response can be pursued in order to minimize impacts where strict constraints are appropriate." Therefore, environmental impact of the underground system has not been evaluated in this report. Environmental impact of the overhead transmission system is discussed in Hawaii Deep Water Cable Program, Phase II-C, Environmental Assessment (Parsons Hawaii, 1987b).

To determine what type of underground cable would be compatible with the system proposed by the HDWC Program, assistance from Power Technologies, Inc. (PTI) was obtained. Their technical guidance for the analysis of implications of underground cables included cable options and selection, system configuration, reliability considerations and costing information. PTI performed System Studies for HECO under the HDWC Program, and are therefore qualified to lend their expertise to this part of the project.

2.1 Cable Requirements

The underground cables must match the rating of the rest of the system: 500 MW at +/- 300 kV, which gives 833 amperes each for two pole conductors. As indicated in Section 2.4, additional circuits are installed for reliability so the current per conductor would be less during normal operation.

For the purposes of this analysis, the cables were assumed to be buried 42 inches deep in soil having an ambient temperature of 27 degrees centigrade with a fairly poor thermal resistivity (Williams, 1988). Information on Hawaii soil types indicate that special trench backfill may be required.

2.2 Cable System Types

There are three types of underground cables that can be considered technically feasible for the potential route applications:

- Solid-type cable, which is insulated with oil-impregnated paper but requires no pressurization source. This cable is stated to be acceptable to 270 kV, probably acceptable at 300 kV, and requires development above 300 kV (Luoni, G. et al, 1983).

- High pressure fluid-filled, which is also insulated with oil-impregnated paper; but the cables are installed in a steel pipe which is pressurized with dielectric fluid to about 200 psig. This cable system is currently under test at 600 kVdc at the Electric Power Research Institute's (EPRI) Waltz Mill cable test facility. Although this type of cable has not been used commercially for underground dc operation (all current underground dc cables are long underwater crossings which are not suited to pipe-type cables) most cable engineers would not question the acceptability of the underground cable system for 300 kVdc.

- Self-contained fluid-filled. This cable type, which is recommended for the underwater portions of the system, has a central duct containing pressurized fluid. For underground cables the fluid pressure is typically 30 to 60 psig in contrast to the 450 psig required for an underwater cable.

The fluid pressurization for underground cables is supplied from small reservoirs about the size of oil drums, located two or three miles apart (depending upon elevation changes) and placed in manholes used for cable splices.

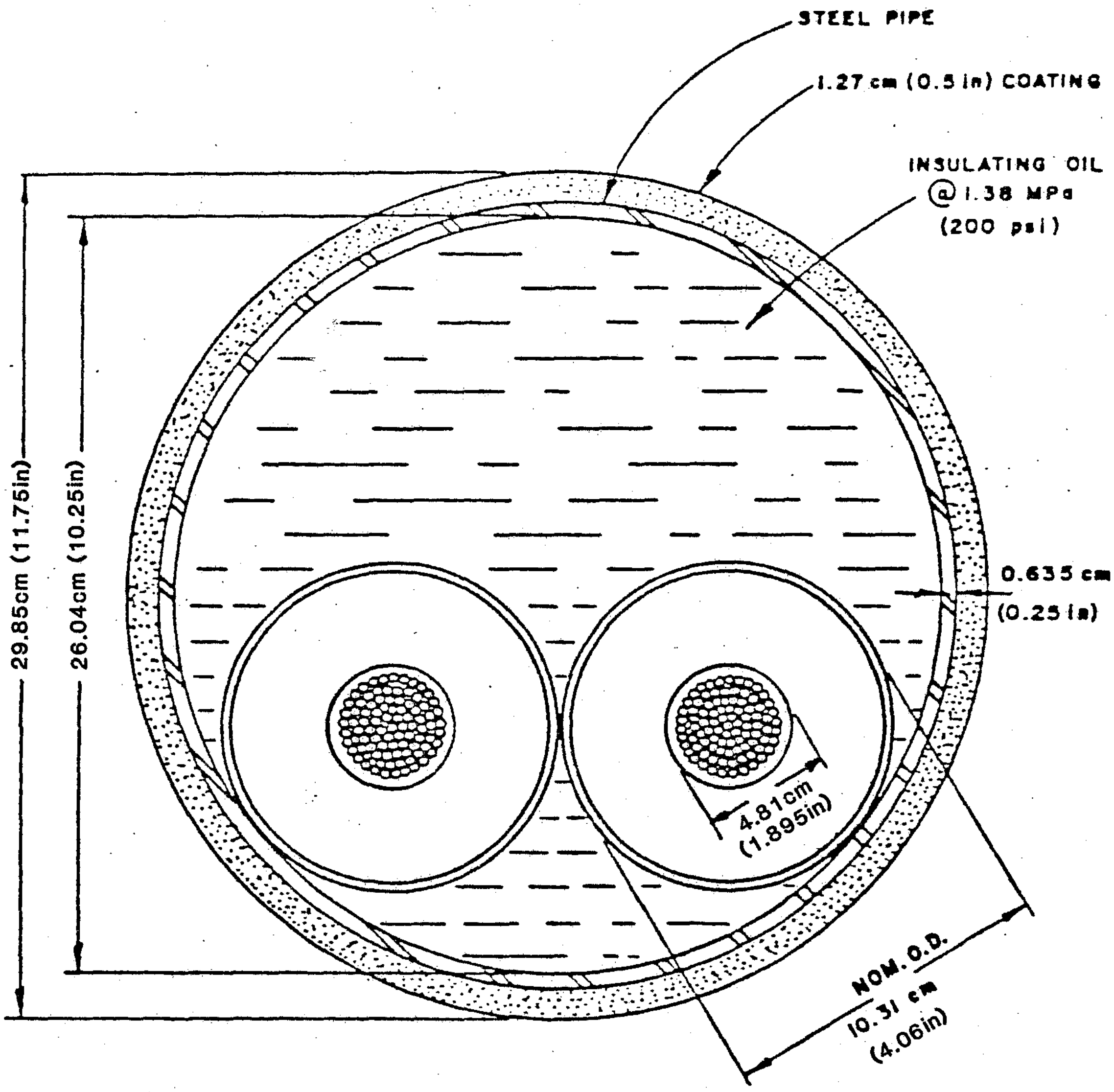
After review of each of these systems, high pressure fluid filled (HPFF, also called pipe-type) cable was selected for further analysis for several reasons. First of all, this is by far the most common type of underground cable installed in the U.S.: more than 85% of U.S. underground transmission cables are pipe-type. Hawaiian Electric Company is planning the installation of a 138 kVac pipe-type cable in Honolulu in 1990, so would have experience with this type of cable. Another important reason for this recommendation is that an underground cable system is very rugged and reliable. Also, a brief costing study showed this cable type to be about 10% less expensive than the self-contained cable for the island of Hawaii application.

2.3 Description of the Proposed Cable System

The pipe-type cable system for dc application consists of two copper conductors, 1500 kcmil (1.4 inches diameter) in this case, insulated with about 0.45 inches of wrapped oil-impregnated paper insulation with outer metallic shield and skid wires to protect the cables during pulling into the pipe. The coated and cathodically protected 8-inch pipe is pressurized to a nominal 200 psig with a high quality dielectric fluid similar to that proposed for the HDWC underwater cables.

Two cable pipes, with a positive and negative conductor in each pipe, are suggested to provide the necessary redundancy as described in Section 2.4. This system would require a trench 42 inches wide by 56 inches deep.

Figure 2 shows a cross-sectional view of a potential 600 kVdc cable system. Figure 3 shows these cables in a typical trench. Both figures were taken from a comprehensive study of dc cables by Philadelphia Electric Company prepared for the U.S. Department of Energy. These figures of the 600 kVdc high pressure oil pregnated type cable (HPOPT) illustrate the closest equivalent to the proposed 300 kV electrical system. The dimensions for the conductors, pipes and trenching would be smaller for the 300 kV system. For example, the conductors would be only 1500 kcmil, the pipe's diameter would be only 2.66 inches and the trench would be approximately 56 inches in depth.

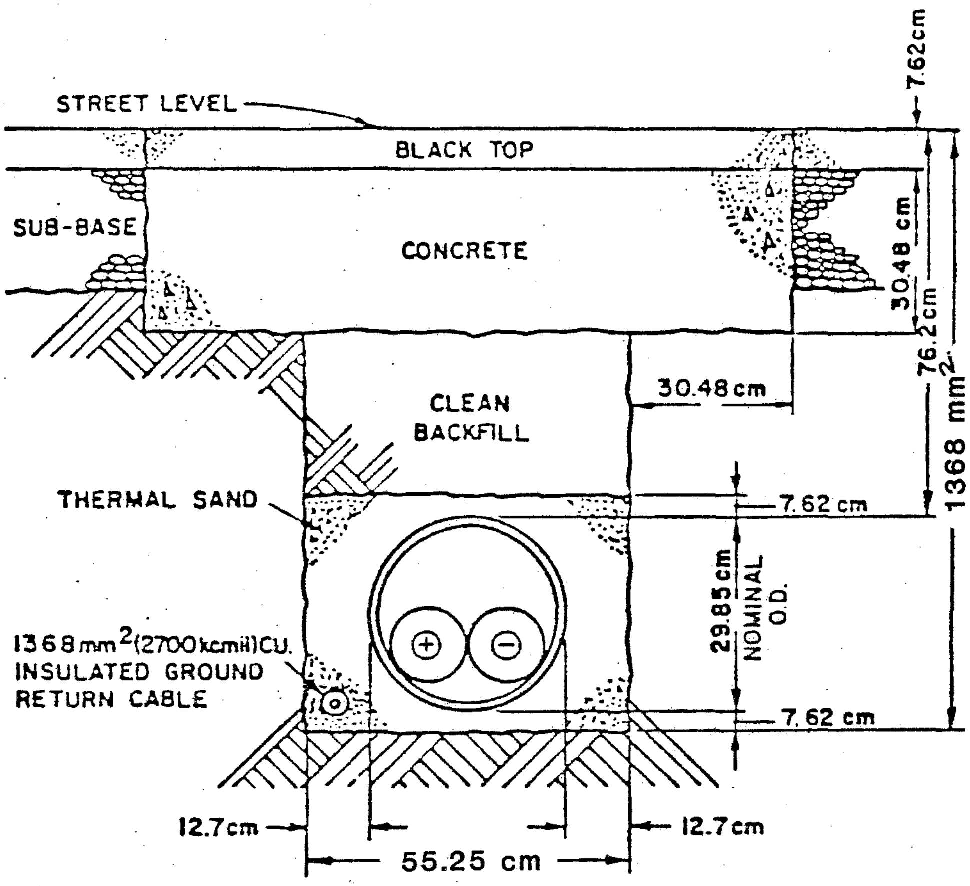


CONDUCTORS ARE 1368mm^2 (2700kcmil) COPPER, COMPRESSED

Ref: Philadelphia Electric Company, 1983

Figure 2 Internal Cross Sectional View

600 kV dc HPOPT CABLE



STREET RIGHT-OF-WAY

NOTE: TRENCH ℄ SEPARATION IS 3 METERS MINIMUM.

Ref: Philadelphia Electric Company, 1983

Figure 3 Typical Trench Cross Sectional View

600 kV dc HPOPT CABLE

The cable system would consist of the following major components:

Table 1

Cable System Components

Item	Amount
Cable	633,600 ft
Pipe	316,800 ft
Normal Joints	112 two cable
Stop Joints	6 two cable
Potheads (terminations)	8 each
Surge Arresters	8 each
Dielectric fluid	720,000 gal
Pressurizing plants	2
Reservoir Size	40,000 gal
Alarms, cathodic prot., etc.	2 sets

The numbers given above assume a spacing of 3000 feet between splices, which is reasonable for the fairly straight route. The stop joints are to isolate the circuit into five mile long sections to reduce loss of fluid during contingencies or maintenance. (The majority of utilities using pipe-type cables have never experienced a loss of fluid.) A two-cable joint refers to the joining of adjacent positive and negative pole cables at each splice location. Surge arresters must be installed in the termination stations to protect the cable from lightning or other surges. The cost analysis assumed one arrester per cable per end; detailed design analysis may show that two or more arresters must be installed in parallel to accept the high stored energy of a long dc cable.

Pressurizing plants are required to maintain the necessary 200 psig fluid pressure and accommodate fluid expansion and contraction due to heating and cooling of the system during changes in cable loading. These plants are normally installed in self-contained enclosures resembling large outdoor food coolers. The plants require a distribution power supply and connection to the utility's control center for monitoring and alarms. One plant should be installed in each transition station, and should be capable of pressurizing both pipes should the plant in the other station fail.

In addition to the pressurizing plants, the transition stations would consist of deadend towers for the overhead lines, surge arresters, potheads, buswork for connection of components and to permit disconnecting and grounding a cable when required for maintenance while maintaining power flow through the companion circuit. A small control room should be supplied for alarms, relays, etc.

The transition station would be about an acre in size and should be fenced. As noted above, a distribution power supply and communication equipment must be supplied to the substation.

2.4 Reliability Considerations

It is commonly accepted that underground cables have a far lower outage rate than overhead lines, but the repair time could be significantly longer for the cables.

All of the presently-operating dc cables of this design are part of long underwater crossings; the only land segments are those required to go from shore to the transition station. (The only all underground dc circuit, the Kingsnorth line in Britain, was reportedly decommissioned a few years ago when the associated generating plant was decommissioned.) Failures of the cables have almost always been due to external causes: principally ships' anchors or sleds from trawlers' nets. Neither of these hazards exists on land.

It is more relevant to evaluate the reliability of ac underground cables, where far more data are available. Again, many of the failures are due to external causes such as dig-in. A tabulation of failure data shows an historical average of one or two failures per hundred miles of cable per year, and these data are weighted toward older cable systems. It should be noted that many utilities have had dozens of miles of pipe-type cable in service for more than thirty years, and have <u>never</u> experienced a failure.

Typical repair time is two weeks for an electrical failure. In view of the remoteness of the Hawaii cable circuits and mobilization time for contractors with the proper equipment, a one-month repair time should be assumed.

One failure mode for either pipe-type or self-contained cables is a fluid leak. The circuit must be removed from service to repair the leak, and the outage time would range from a few days to a few weeks depending upon cause of the leak, need for extensive repairs to a pipe damaged by excavation equipment, etc.

Because there is a chance of cable failure or fluid leak that could cause a month-long outage, a redundant cable is recommended to ensure continuity of power flow. If one of the two cables in the pipe fails, the other cable must also be taken out of service during repairs. A second pipe should contain both a +300 and -300 kV cable to permit full power transfer during the contingency.

A cable conductor size of 1500 kcmil (1.4 inch diameter) would permit full 500 MW power transfer for a month through one cable pipe. Cables in the two pipes should be connected in parallel during normal operation to halve the current in each conductor and therefore reduce the ohmic losses.

Factors that enhance reliability of the underground cable alternative in comparison to the overhead line transmission include the maintenance factors which affect the cost, complexity and frequency of maintenance for overhead transmission lines. These are wind, salt spray, forest vegetation, range fires, dust, hurricanes and vandalism. The underground cables are free from these hazards that affect reliability.

3.0 Underground Cable Segment Criteria

As shown in the preferred route (Figure 1), the overland portions of the transmission system traverse three islands: Hawaii, Maui and Oahu. The following criteria should be considered when choosing underground segments:

A. Where preferred route corridor passes through urban centers or rural residential areas; and

B. Where an overhead transmission line would be highly visible.

3.1 Other Environmental Considerations

As stated earlier, Hawaii soils information indicate that special backfill materials may be needed to correct their poor thermal diffusivity. This refers to the response of a soil type to a cable heat load under changing conditions. Use of special backfill materials in the trench may create a stablized thermal soil condition, thus correcting this potential problem.

Another environmental consideration is that the Big Island may experience seismic vibrations. This occurs in the southern half of the Big Island and is due to the active volcano. Proper construction techniques for the cable system would reduce potential damages from this natural hazard. Such techniques include well-compacted backfill, careful design of substations, and "bracing" of pressurizing plants. However, discussions were held with an engineer who was responsible for design of most of the transmission cable systems in San Francisco and it was his opinion that tremors such as those found on Hawaii Island would have no effect on any of the cable types that are discussed in this report. This is because California earthquakes are of a higher amplitude than those common to Hawaii. The California underground pipes have not experienced any problems resulting from earthquakes. Futhermore, the recent Mexico City earthquake, which was quite severe, left the areas underground cable system intact.

4.0 Economic Implications

A comparison of costs for overhead lines and underground cables was performed. The overhead transmission costs involve towers and lines, land acquisition, and planning and engineering. The underground alternative costs involve the cable and pipe, installation, trenching, accessory structures, engineering and construction supervision, and land acquisition.

The placement of overhead lines through the proposed segments may have hidden costs related to public opposition, however, these costs have not been factored into this analysis (Parsons Hawaii, 1987a).

The following overhead line cost figures were taken from _Submarine Vs. Overhead Routing: A Cost Comparison for Molokai_ (Parsons Hawaii, 1987a), where costs for submarine and overhead transmission were compared. The same cost figures for the overhead lines were applied to this scenario and altered to reflect a thirty-mile route distance. The thirty miles represents the minimum length of underground cable that would be installed to grant visual relief from overhead transmission lines.

4.1 Overhead Line Transmission Costs

Overhead Lines and Towers

Based on cost data provided by HECO to Power Technologies Inc. (PTI) and stated utility preferences for tower design and spacing (PTI, 1986), the following summarizes the costs for the overhead lines. The analysis assumes use of self-supporting steel lattice towers and 1,300 foot spans. Costs per tower for hardware and installation are as follows:

foundation excavation	$ 17,892
foundation materials	3,560
foundation assembly	16,082
tower materials	12,145
tower erection	13,097
tower set up	11,211
insulator hardware	600
	$ 74,587

The thirty miles of route would require 122 towers, or a total cost of $9,099,614. To this must be added the costs for two conductor wires, one shield wire and stringing. Stringing costs are estimated in PTI's latest report (PTI, 1986) at $32,000 per mile, or $960,000 for the thirty miles. Conductors were optimized by PTI according to tower type and fuel oil price escalation rate (PTI, Inc. 1986). For a self-supporting steel tower and a medium oil price escalation rate, the optimum conductor is an "AAC, 3,500 Kcmil" design.

This conductor costs $0.64/lb and weighs 3,350 lb/1,000 ft. One conductor per pole is required, so for a 30-mile long bipole, the conductor cost would total $679,219. A single 3/8-inch galvanized EHS shield wire would cost $0.57/lb and weigh 273 lb/1,000 ft. For a 30-mile length, the total cost would be $24,649. The total cost for conductors and shield wire would be $703,868.

Land Acquisition

As background data for PTI's Phase II-B study, HECO provided the following information:

> "HECO does not normally include the cost of the right-of-way and/or the cost of clearing the right-of-way in the cost for a transmission line. For the purposes of this study, a right-of-way cost of approximately $5,000 per mile for a 150-foot wide right-of-way can be utilized. The cost of clearing the right-of-way will be negligible since minimal clearing is usually required" (July 28, 1983 letter from G. Okura to J. Mountford).

The right-of-way is estimated at only 135 feet in width, but these cost estimates are also nearly five years old. Assuming these factors offset, ROW costs would total $150,000.

Planning and Engineering

A number of different activities are included in this category. All data were provided by HECO based on in-house experiences.

route selection, environmental studies, EIS preparation and permitting @ $34,900/mile	$ 1,047,000
photogrammetric survey and mapping @ $8,000/mile	240,000
engineering @ $21,500/mile	645,000
survey easement document preparation @ $1,000/mile	30,000
survey construction stakeout @ $1,800/mile	54,000
	$ 2,016,000

Total Costs for Overhead Line Transmission

Towers and Foundations	9,099,614
Conductor and Shield Wires	703,868
Stringing	960,000
Land	150,000
Planning and Engineering	2,016,000
	$ 12,929,482

Therefore, the final total cost for the overhead transmission lines is $12,929,482.

4.2 Underground Transmission Alternative

Cost Assumptions

The process used for estimating the costs of the underground transmission alternative is different than the process used for the overhead transmission lines. The overhead transmission line cost information is more readily available from HECO, whereas the proposed underground cable cost information had to be generated from a scenario never before implemented. The two final total costs, however, can be compared and are found in Section 4.3.

The cost per mile for this cable is difficult to estimate because of changing copper prices and the lack of commercial experiences with pipe-type dc cables. Although the cable resembles a 138 kV ac cable in dimensions, the cost for a 345 kV cable of about $30 per single conductor foot delivered to Hawaii, was assumed for this study. Cable cost is therefore $120 per trench foot (two cables per pipe, two pipes).

There are significant costs associated with cable accessories and costs were again assumed to be the same as for conventional 345 kV ac cable.

Installation costs were based on conventional ac cable, and trenching costs were based on calculated trench dimensions and a trenching cost of $50 per cubic yard. Half of the route was assumed to be under pavement for costing purposes.

Cable System Cost Estimates

Based upon these assumptions and applying typical percentages for engineering and construction supervision, plus a 15% contingency on materials and a 20% contingency on labor, a total cost of

$70,000,000 was calculated for the thirty mile circut. Both of these costs include transition stations. Less conservative assumptions on cable and accessory costs would reduce these figures by about 15%.

Land Aquisition

Purchase of right-of-way would not be required for the underground alternative, but a fee for easement rights may be extracted by the highway owners (the State of Hawaii in this case). This fee is not included in cost calculations.

Additional land of one-acre at two sites would be required for the terminations and transition between overhead lines and underground cables. For these we estimate a cost of $10 per square foot. Total costs would thus be $871,200 for the two transition sites.

Total Costs for Underground Alternative

The sum of the two costs, $70,000,000 for the cables circuit and $871,200 for the transition sites, equals a total of $70,871,200 for the underground alternative.

4.3 Costs Comparison

The total of the overhead transmission lines - $12,929,482 and the total of the underground cable transmission alternative - $70,871,200 may be compared. In the absence of environmental or land use concerns causing expenses related to schedule delays or mitigation measures, the overhead transmission would be almost sixty million dollars cheaper ($57,841,718 rounded off). This six to one ratio (the underground cables being approximately six times more expensive than the overhead transmission lines) reflects what experts in the field of electrical power transmission generally believe to be accurate for cost comparisons (pers. comm., Jay Williams, July 1988).

5.0 Conclusions

In summary, high pressure fluid-filled cable circuits would meet the requirements of the land portions of the Hawaii deep water commercial cable system. Intrusion on the visual quality of a route or through urban areas may be avoided by substituting the underground cables for overhead transmission lines. However, this alternative could be approximately six times more expensive.

The underground cable alternative may have the advantages of being unseen in form and very reliable in function compared to the overhead transmission lines, but they have a longer repair period than the overhead lines which are more readily accessible above ground.

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