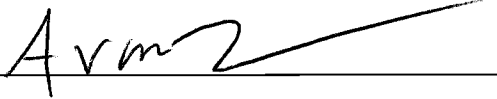


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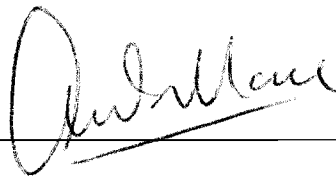
Heng Zhang for the degree of Master of Science in Electrical and Computer Engineering presented on June 27, 2003.

Title: Ocean Electric Energy Extraction Opportunities

Abstract approved:



Annette R. von Jouanne



Alan K. Wallace

The world's oceans contain tremendous renewable energy potentials. It is estimated that if 0.2% of the ocean's untapped energy could be harnessed, it could provide power sufficient for the entire world [1].

This thesis provides a comprehensive description of the state-of-the-art of ocean energy extraction technologies and lessons learned from previous research and projects leading to the development of a model to convert wave characteristics to wave energy potential. A Graphical User Interface (GUI) is developed with Matlab 6.5 to convert wave characteristics to wave energy potential, which can be used to analyze real-time data as well as historical statistics. Issues that need to be considered toward the commercialization of this type of renewable energy are investigated and presented.

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Ocean Electric Energy Extraction Opportunities

by
Heng Zhang

A THESIS
submitted to
Oregon State University


in partial fulfillment of
the requirements for the
degree of

Master of Science

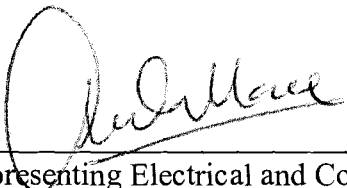
Presented June 27, 2003
Commencement June 2004

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Heng Zhang, Author

ACKNOWLEDGEMENTS

It was not an easy journey for me to come back to school after six years in industry after my undergrad years. However, I believe that there are always ways for a dream to becoming reality. Understanding your deep inner self, and doing your best are two keys to becoming closer to a dream.

I gratefully wish to thank my Co-major Advisors, Drs. Annette von Jouanne and Alan K. Wallace, for bringing me to this program, for their invaluable guidance and support throughout this program, and the close relationships they help build among the members of the Motor System Research Facility (MSRF) group.

I also thank my family, friends, and some of my previous colleagues. Their support has helped me through the applications and the two years master's program at Oregon State University. I believe: we will stay standing together for a better tomorrow.

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DEDICATION

To my parents I dedicate this work.

OCEAN ELECTRIC ENERGY EXTRACTION OPPORTUNITIES

1 Introduction

The solutions to today's energy and environmental challenges need to be found through increased electricity generation using alternative, renewable and clean energy sources. Covering more than 70% of the Earth's surface, oceans are the largest solar collectors and renewable energy reservoirs. It is estimated that if 0.2% of the ocean's untapped energy could be harnessed, it could provide power sufficient for the entire world [1].

The electricity industry is the largest industrial source of pollutants, accounting for one-third of nitrogen oxides (NO_x), two-thirds of sulfur dioxide, one-third of toxic mercury and one-third of carbon dioxide of all U.S. emissions [2]. Since 1989, electric energy consumption has increased by 2.1% annually, which is a challenge to both the electricity production industry and the environment [3]. Ocean energy is one of the most concentrated forms of renewable energy. Electricity generation from the oceans is potentially sustainable and pollution-free. Developing ocean energy will help meet the increasing electricity demands, as well as improve the overall air quality, reduce the nation's dependence on diminishing domestic resources and imported fuels, and therefore, improve the nation's energy security.

Ocean energy exists in different forms including: wave (kinetic and potential energy, utilizing the up and down motions of ocean waves), current (kinetic energy of

flowing ocean currents), tidal (from the rises and ebbs of tides), thermal (utilizing the natural temperature gradient as a function of depth in tropical oceans) and salinity (chemical electric potential formed by the difference in salt concentration between fresh water and sea water).

The main goal of this thesis is to provide a comprehensive review of ocean energy extraction technologies, with a main thrust in wave energy, and develop a model to convert wave characteristics to wave energy potential. In Chapter 2, a comprehensive description of the state-of-the-art of ocean energy extractions is presented. In chapter 3, basic wave terminologies are first introduced to prepare the readers for understanding the wave model, then a Graphical User Interface (GUI) is developed with Matlab 6.5 to demonstrate the conversion from wave characteristics to wave energy potential, which can be used to analyze data in real-time, as well as from historical statistics. Chapter 4 discusses the issues involved in developing and commercializing ocean energy, status of the research in this field, lessons learned from previous research, and perceptions. Chapter 5 summarizes this thesis work and gives conclusions, as well as proposals for future work.

2 Ocean Energy Extraction Technologies

This chapter reviews the state-of-the-art of ocean energy extraction technologies, where wave energy is the main focus considering the relative technological maturity and the wave extraction opportunities in Oregon and plan for future work.

2.1 Wave Energy

Wave energy refers to the kinetic (speed) and potential (height) energy contained in ocean waves.

The world's first wave energy device patent was registered in 1799 by Girard, in Paris. After more than 200 years' development, wave energy has been the most developed form of ocean energy and there are currently more than 1500 wave energy device patents. Historically, there have been two booms of interest in the research of wave energy, corresponding to the 1970's oil crisis and pollution concerns as well as concerns regarding natural resource reserves since the mid 1990's.

According to the distance between the devices and the shoreline, wave energy devices can be classified as shoreline, near shore and offshore devices.

2.1.1 Shoreline Devices

Shoreline devices are devices fixed to or embedded in the shoreline.

a) Oscillating Water Column (OWC)

The Oscillating Water Column system is the most developed of the shoreline devices. An OWC system has a partially submerged hollow air chamber, which opens to the sea under the water line. A wave enters the air chamber and forces the air in the column to pass through a turbine. When the wave retreats, the air will be drawn back and pass through the turbine again (Fig. 1). The turbine can be unidirectional or self-rectified. The unidirectional “Wells turbine” is the best-known turbine for this kind of application.

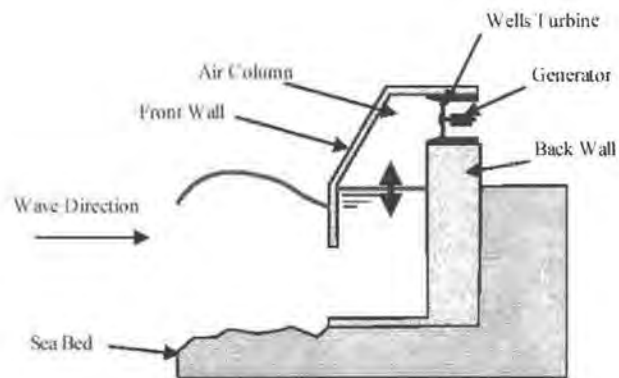


Fig. 1 Working Principle of OWC [4]

Wavegen's LIMPET [5]



Fig. 2 the LIMPET 500

The world's first commercial wave power unit is the LIMPET 500, an OWC system mounted on the cliffs of the Islay island in Scotland by Wavegen (Fig. 2). It generates a peak power of 500 kW, enough to run about 400 island homes. The station has successfully fed electricity into the UK's national grid since November 2000.

The Limpet design was developed for ease of construction and installation with minimal visual intrusion (Fig. 3).



Fig. 3 Construction Sequence of the Limpet

- The Energetech OWC [6]

This is another representative of OWC technology being developed by Energetech in Australia. Compared to the LIMPET, it uses a variable pitch turbine instead of the Wells to achieve higher system efficiency, and it has a relatively cheap parabolic wall behind the OWC to focus the wave energy on to the more expensive collector and associated M&E plant (Fig. 4).



Fig. 4 Artist's Impression of the Energetech OWC

- The European Pilot Plant

This is an OWC system developed by the Institute Superior Tecnico (IST) of Lisbon, Portugal (Fig.5).

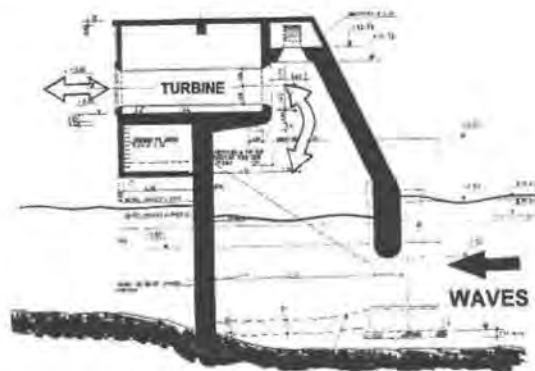


Fig. 5 Schematic of the European Pilot Plant (Drawing by IST)

b) The Pendulum

The Pendulum was developed by the Japan Marine Science & Technology Center (JAMSTEC). It consists of a concrete box with one end open to the sea. A steel pendulum flap is hinged over this opening. Waves cause the pendulum flap to swing back and forth to power a hydraulic pump through a hydraulic system, which supplies a generator (see Fig. 6).

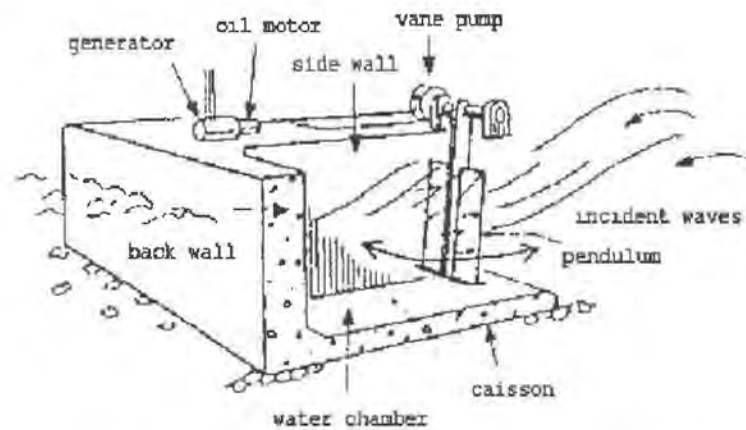


Fig. 6 the Pendulum (Drawing by JAMSTEC)

c) The TAPCHAN

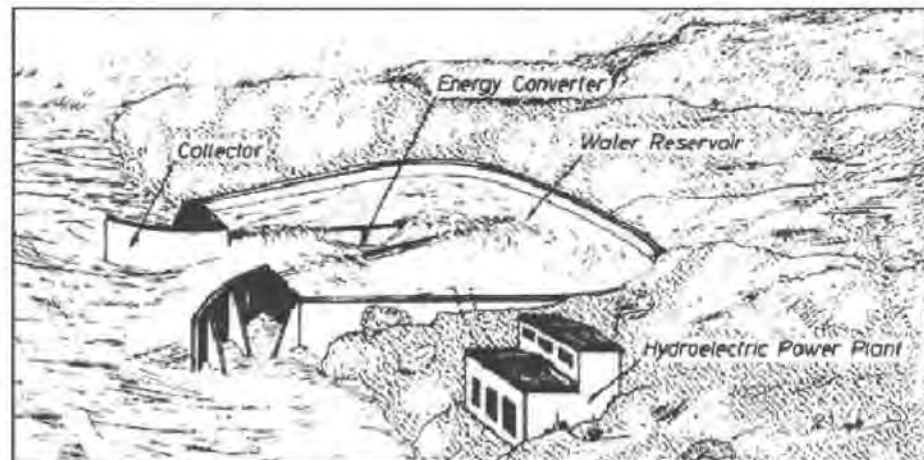


Fig. 7 the TAPCHAN [7]

The Tapered Channel System, or the TAPCHAN, is developed by Norwave AS of Norway. It applies the working principle of a traditional hydroelectric power plant (Fig.7). The seawater is tapered into the reservoir constructed on a cliff and then flows back to the sea through a low-head hydroelectric generator to generate electricity.

2.1.2 Near Shore Devices

a) The OSPREY [5]

OSPREY is the acronym for Ocean Swell Powered Renewable Energy. It is designed to operate in 15m of water within 1km of the shore, generating up to 2MW of power for coastal consumers (Fig.8).

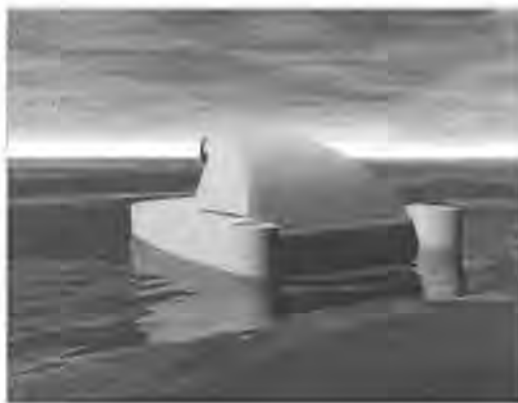


Fig. 8 Artist's Impression of the OSPREY

b) The Mighty Whale

The Mighty Whale is a floating OWC based device developed by JAMSTEC (Fig.9). A 120kW prototype with 3 OWC's in a row has been operating since 1998 in water depths of 40m, 1.5km off Nansei Town in Japan.



Fig. 9 The Mighty Whale Being Launched [8]

c) The WOSP [5]

The WOSP, or the Wind and Ocean Swell Power, is an integrated near shore wave and wind powered station (Fig. 10). It is designed to operate much the same as the Osprey 2000 device, generating 3.5MW of power, and offers major advances in accessing multiple offshore renewable energy resources.

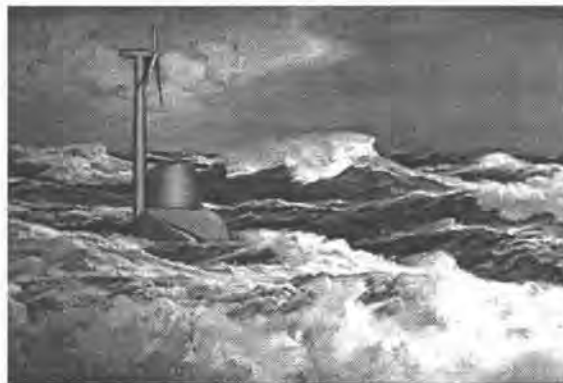


Fig. 10 Artist's Impression of The WOSP

2.1.3 Offshore Devices

a) The “Pelamis” [8]

The “Pelamis” is developed by Ocean Power Delivery in Edinburg, Scotland. This is a semi-submerged, articulated structure composed of cylindrical sections linked by hinged joints (Fig.11). The wave-induced motion of these joints is resisted by hydraulic rams, which pump high-pressure oil through hydraulic motors via smoothing accumulators. The hydraulic motors drive electrical generators to produce electricity. Power from all the joints is fed down a single umbilical cable to a junction on the seabed. Several devices can be connected together and linked to shore through a single seabed cable.



Fig. 11 The Pelamis

b) The AquaBuoy [9]

The Aqua Energy Group of Mercer Island, Washington, are promoting the AquaBuOYs which are moored-buoy devices that transform the vertical component of kinetic energy from the oncoming ocean waves into electrical energy (Fig.12). They are placed in suitable measured locations, up to several miles offshore, where

the water depth is between 150 to 250 feet. The individual sizes of the AquaBuOYs are designed according to the energy content of the prevailing seas at a particular installation site.

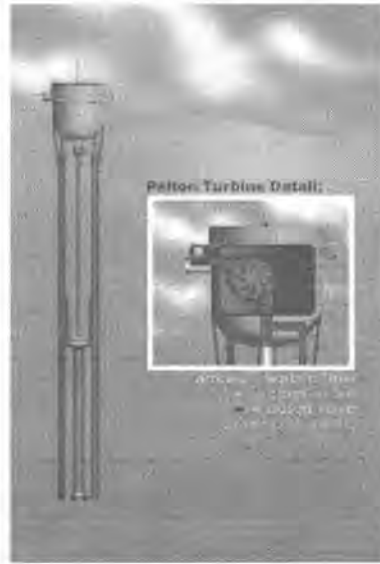


Fig. 12 The AquaBuoy

c) The McCabe Wave Pump [10]

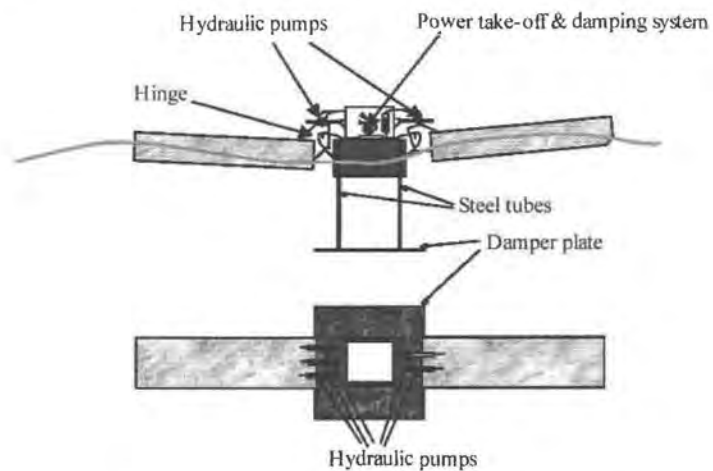


Fig. 13 Schematic of The McCabe Wave Pump

A 40m long McCabe Wave Pump prototype is currently under construction by Haydam Ltd. This device consists of three narrow rectangular steel pontoons, which

are hinged together across their beam pointing into the incoming waves. The fore and the aft pontoons move in relation to the central pontoon by pitching about the hinges, and energy is extracted from this limited rotation by linear hydraulic rams mounted between the central and two outer pontoons near the hinges (Fig.13). This energy can be used either to provide electricity by driving a hydraulic motor attached to a 400kW generator or to produce potable water by supplying pressurized sea water to a reverse osmosis plant.

d) The Archimedes Wave Swing [11]

This device is being developed by Teamwork Technology in the Netherlands. It consists of a cylindrical, air filled chamber (the “Floater”), which can move vertically with respect to the cylindrical “Basement” which is fixed to the sea bed (Fig.14 & 15). The air within the 10m-20m diameters “Floater” ensures buoyancy. When a wave passes over the top of the device, it alternatively pressurizes and depressurizes the Floater, and the buoyancy is changed which causes the Floater to move up and down with respect to the Basement. This relative motion is then used to produce electricity.

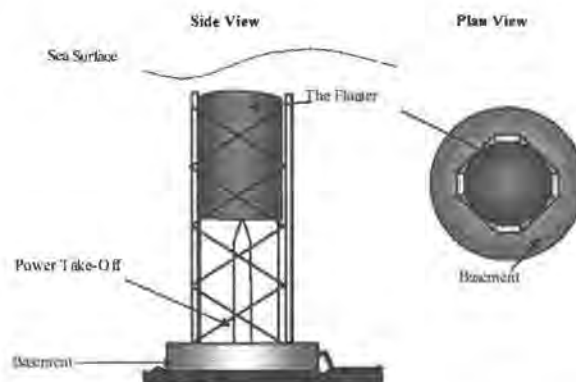


Fig.14 Schematic of the Archimedes Wave Swing



Fig.15 The Archimedes Wave Swing about to be Launched

e) The PowerBuoy [12]

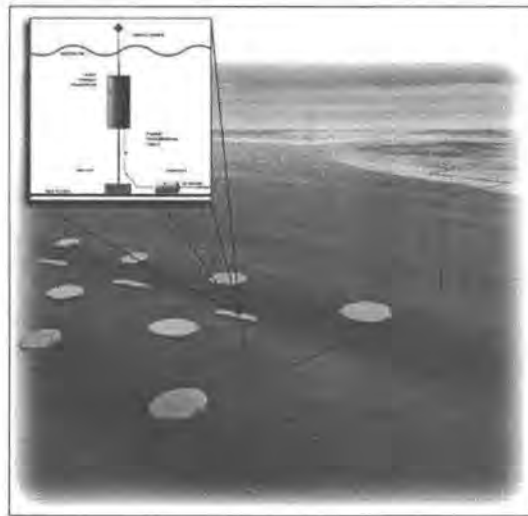


Fig. 16 Artist's Impression of the PowerBuoy

The PowerBuoy is developed by Ocean Power Technology (OPT) in the U.S. The working principle of the PowerBuoy is similar to that of the AquaBuoy (Fig.16).

2.1.4 Comparisons of Different Technologies

Shoreline devices have the advantages of easier access for installation and maintenance and they do not need deep-water moorings or long underwater electrical cable. However, when a wave travels towards the shoreline, its power is greatly

reduced by the friction caused by the rough seabed. This can be partially compensated by siting the devices at locations of natural energy concentration.

Offshore devices can take advantage of the more powerful wave profiles available in deeper water (see definition in Ch.3). In order to extract the maximum amount of energy from the waves, the devices need to be at or near the surface and so they usually require flexible moorings and submarine electrical cables for power transmission. These features cause critical cost issues in construction and maintenance.

Near shore devices exhibit compromises between shoreline and offshore devices, e.g. when there are environmental objections to shoreline devices, near shore devices can provide an alternative solution.

2.1.5 Wave Energy Potential Distribution



Fig. 17 Worldwide Wave Energy Distribution (kW/m)

Waves are generated by winds. In general, the strongest winds blow between the 30° and 60° latitudes. Also, within $\pm 30^{\circ}$ of the equator, there are regular trade winds. These areas therefore have good wave energy potentials. Fig. 17 is a

worldwide wave energy potential map [5]. According to this map, the NW Pacific has rich wave energy potential.

2.2 Ocean Thermal Energy Conversion (OTEC) [1]

The heat from the sun warms the surface seawater, forming a natural temperature gradient with the chilly deep-sea water. When this temperature gradient is 20⁰C or more, it can be used for electricity generation. The potential of ocean thermal energy is estimated to be about 10¹³ watts of base load power generation, according to some experts.

2.2.1 Working Principles of OTEC

Two basic OTEC system designs have been demonstrated to generate electricity: open cycle and closed cycle. The third type is hybrid, which combines open and closed cycles.

a) Open-Cycle OTEC System

In an open-cycle system, the deaeration system (usually a pump) first lowers the pressure inside the chamber to a certain vacuum; the warm seawater is then ‘flash’-evaporated into the chamber to produce steam. The steam expands through a low-pressure turbine that is coupled to a generator to produce electricity. The steam is then condensed by cold seawater pumped from the ocean’s depths through a cold-water pipe (see Fig. 18). The condensed steam remains separated from the cold seawater and can provide a supply of desalinated water if required.

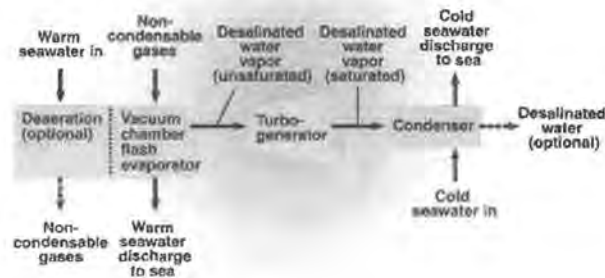


Fig. 18 Schematic of Open-Cycle OTEC System

b) Closed-Cycle OTEC System

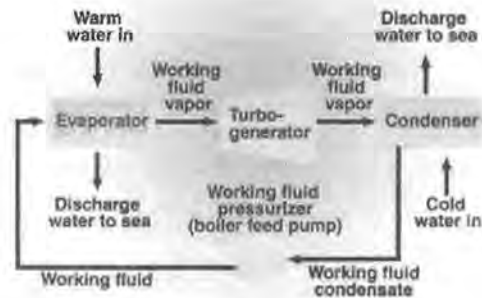


Fig. 19 Schematic of Closed-Cycle OTEC System

In the closed-cycle system, warm seawater vaporizes a working fluid (whose boiling point is very low), such as ammonia, flowing through a heat exchanger (evaporator). The vapor expands at moderate pressures and turns a turbine coupled to a generator that produces electricity. The vapor is then condensed in another heat exchanger (condenser) using cold seawater pumped from the ocean's depths through a cold-water pipe (see Fig. 19). The condensed working fluid is then pumped back to

the evaporator to repeat the cycle. The working fluid remains in a closed system and circulates continuously.

The difference between open-cycle and closed-cycle systems are: in closed-cycle system, the warm seawater itself is not vaporized. Instead, its heat is transformed by a heat exchanger to vaporize the low boiling point working fluid. Due to the introduction of the low boiling point working fluid, the system pressure is improved, therefore the dimensions of the whole system are reduced significantly, especially the turbine generator. But the working fluid will cause pollution.

c) Hybrid OTEC System

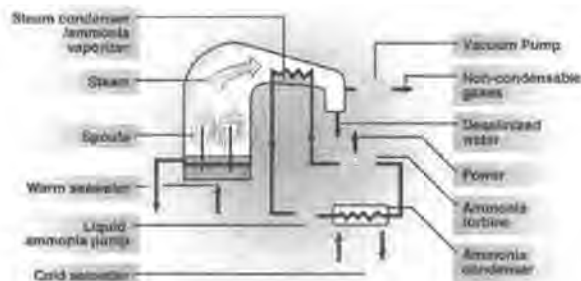


Fig.20 Schematic of Hybrid OTEC System

A hybrid cycle combines the features of both the closed-cycle and open-cycle systems. In such a system, warm seawater enters a vacuum chamber where it is flash-evaporated into steam, which is similar to the open-cycle evaporation process. The steam then vaporizes the working fluid of a closed-cycle loop on the other side of an ammonia vaporizer. The vaporized fluid then drives a turbine that produces electricity (see Fig. 20). The steam condenses within the heat exchanger and provides desalinated water.

2.2.2 Plant Design and Location

Commercial OTEC plants must be located in an environment that is stable enough for efficient system operation. The temperature of the warm surface seawater must differ about 20⁰C from that of the cold deep water that is no more than about 1000m below the surface. The natural ocean thermal gradient necessary for OTEC operation is generally found between latitudes 20 deg N and 20 deg S. Within this tropical zone are portions of two industrial nations-the United States and Australia-as well as 29 territories and 66 developing nations (see Fig. 21). Of all these possible sites, tropical islands with growing power requirements and a dependence on expensive imported oil are the most likely areas for OTEC development.

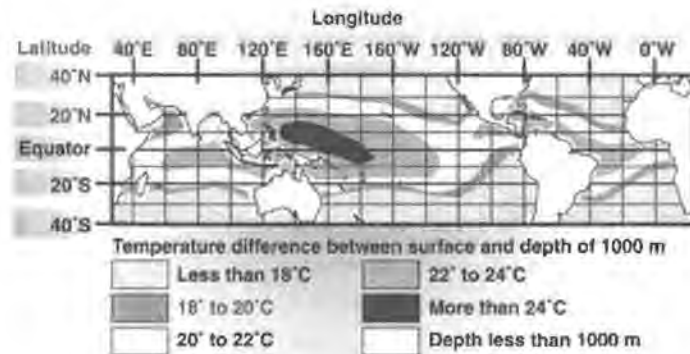


Fig. 21 World's Ocean Thermal Distribution

Commercial OTEC facilities can be built: on land or near the shore, platforms attached to the shelf or moorings or free-floating facilities in deep ocean water.

2.2.3 Applications of OTEC

Besides generating electricity, other applications of OTEC include:

- Helps produce fuels such as hydrogen, ammonia, and methanol
- Produces desalinated water for industrial, agricultural, and residential uses
- Is a resource for on-shore and near-shore mariculture operations
- Provides air-conditioning for buildings
- Provides moderate-temperature refrigeration

However, like every other method of generating power, OTEC is not entirely innocent of environmental consequences. The flow of water from a 100MW OTEC plant would equal that of the Colorado River. And that water would also be some 6⁰C above or below the temperature it was when it was originally drawn into the plant. The resulting changes in salinity and temperature could have unforeseen consequences for the local ecology.

2.3 Ocean Current Energy Extraction Technologies

The working principles of ocean current energy extraction devices are based on that of small wind turbines with the main differences in the working medium and working environment: seawater is 832 times as dense as air, ocean current energy extraction systems work in a submarine environment, which makes corrosion one of the most important issues to be researched. Several technologies are briefly described below:

a) Blue Energy's (Canada) Davis Hydro Turbine [13]

The Davis Hydro Turbine is technically very similar to the large vertical axis wind turbine: it can be used for both ocean current and tidal energy extraction. In this system, the movement of the ocean's currents are captured and used to drive slow-moving blades. These, in turn, power a generator, like an underwater windmill, which is shown in Fig.22. The Davis Turbine unit is anchored to the ocean floor. Four fixed hydrofoil blades are connected to a rotor that drives an integrated gearbox and electrical generator assembly. The whole assembly is driven by water flows to produce electricity. The Davis Turbine unit is now scaled to 250MW/unit ("Mid-Range").

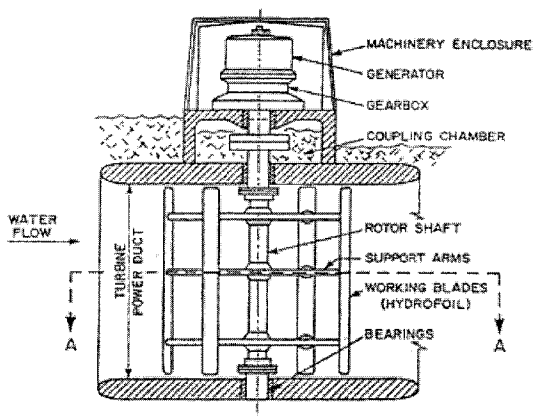


Fig. 22 Davis Hydro Turbine

Multiple Davis Turbines can be arrayed to get the desired output capacity, known as "tidal fence", or "tidal bridge". See Fig. 23.



Fig. 23 Tidal Bridge (Concept Design)

b) Floating Rafts

The concept design of the floating rafts is shown in Fig.24 [14]. In this system, floating rafts are secured to the ocean floor, turbines are suspended under the rafts, and flowing ocean currents drive the blades and therefore drive the turbine to generate electricity.

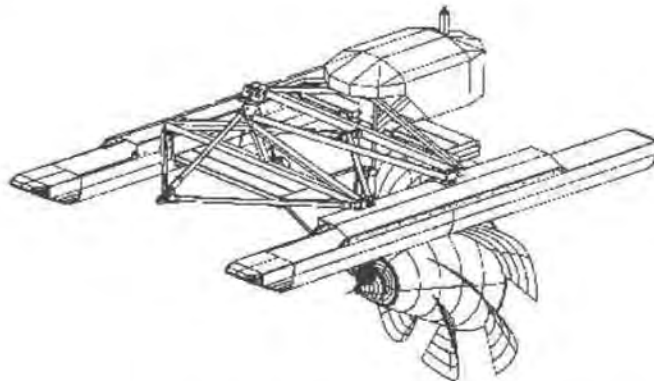


Fig. 24 Floating Rafts (Concept Design)

c) Submerged Hydroplane

The “Stringray” system has been under development since 1997 by the Engineering Business Ltd. This system sits on the ocean bed and oscillates in the tidal

or ocean current (see Fig.25). It is scheduled for experimental deployment in the Orkney & Shetland Islands in 2002.



Fig.25 The Mechanical Design of the “Stringray” [15]

In the United States, the Florida Current and the Gulf Stream are most likely to be explored for ocean current energy extraction.

2.4 Status of Ocean Energy Research

Europe has played an important role in the research of ocean energy. Japan, Australia and Canada have also developed some successful prototypes. India, Indonesia and China are also active countries in the research of this area. The US has developed an OTEC system in Hawaii since 1970’s for comprehensive application including electricity generation, air conditioning, deep sea water desalination, aquaculture, etc., which is the only system that can be self-sustained commercially of its kind in the world, to the best knowledge of the author.

Wave energy has been the most developed type of ocean energy. As for wave energy, most of the recent activities have been concentrated in Europe, India and Japan.

The European wave energy program since 1995 includes developing experimental OWC pilot plants, a European wave energy atlas, evaluation of offshore wave energy converters, evaluating power take-off turbines, designing shoreline OWC and evaluating a novel wave energy conversion system [4].

India built a 150kW prototype OWC with harbor walls in 1991. The prototype has functioned well. The data from this prototype has been used to design and build an improved demonstration scheme.

As can be seen from the technology review, Japan is also active in prototype development. Japan has also built an experimental OTEC system.

For the study reported in this thesis, ocean wave energy extraction technologies will be the focus.

3 Ocean Waves vs. Energy Potential

This chapter first defines some basic terminologies of ocean waves: the mathematical and physical relationships between wave characteristics and wave energy potential are then illustrated. Finally, a dynamic model of ocean waves vs. energy potential is built using Matlab 6.5, and is used to interpret data of waves off the Oregon Coast.

3.1 Nomenclature

The behavior of the waves heavily depends on their characteristics. As a necessary background introduction, the following definitions are given by [16]:

- Deep Water Wave: A wave traveling in water that is deeper than one half of its wavelength, such that the sea bottom does not interfere with its motion. The speed of waves is governed solely by their wavelength, and long waves travel faster and have greater energy.
- Shallow Water Wave: A wave influenced by the sea bottom, usually in water that is shallower than $1/20$ of its wavelength. The speed of waves is governed by water depth. The shallower the water, the slower they travel.
- Significant Wave Height: the average height of the highest one-third of the waves in an area of the ocean.
- Dominant Wave Period: the period with maximum wave energy.

When waves travel toward the shoreline, they become shallow water waves from deep water waves and experience a decrease in speed. However, when the speed decreases, the height increases, the waves get bigger and steeper. However, some energy is lost through friction with the sea bed, causing the wave height to decrease. This is particularly significant where there is a large continental shelf.

3.2 Wave Characteristics & Wave Energy Model

a) Simple Wave Characteristics [4]

- Deep Water Waves

Water waves can be considered to travel along the surface of the sea with an approximate sinusoidal profile. They can be characterized (Southgate, 1981) in terms of the distance between successive crests (the wavelength, λ) and the time between successive crests (the period, T). In deep water these parameters are related as follows:

$$\lambda = \frac{gT^2}{2\pi} \quad (1)$$

where g is the acceleration due to gravity .

The velocity of the waves, C , is given by the following relationship:

$$C = \frac{\lambda}{T} \quad (2)$$

Hence, longer waves travel faster than shorter ones. This effect is seen in hurricane areas, where long waves generally travel faster than the storm generating them and so the arrival of the hurricane is often preceded by heavy surf on the coast. The power (P) in such waves can also be described by use of these parameters and the wave height H :

$$P = \frac{\rho g^2 T H^2}{32\pi} \quad (3)$$

where ρ is the density of sea water and P is the expressed per unit crest length (m) of the wave. Most of the energy within a wave is contained near the surface and falls off sharply with depth. Therefore, most wave energy devices are designed to float (or in the case of bottom standing devices to be in shallow water) and so pierce the water surface in order to maximize the energy available for capture.

- Shallow Water Waves

As waves approach the shore (i.e. $H < \lambda/2$) they are no longer considered to be deep water waves and, as such, they can be modified in various ways (Southgate, 1981 and 1987):

- Shoaling. The height of a wave varies with the depth of water in which the wave is traveling. In very shallow water this can result in an increase in wave height or shoaling. This results in increased energy and power densities in shallower waters close to shore.
- Friction and Wave Breaking. The increase in wave height produced by shoaling can be offset by other mechanisms. As waves become steeper they can break, thereby losing both height and energy in turbulent water

motion. In shallower areas the water disturbance caused by surface wave motion can extend down to the sea bed. In these cases friction between the water particles and the sea bed can result in energy loss.

- Refraction. As the waves propagate into shallow waters near to the coast, the wave fronts are bent so that they become more parallel to the depth contours and shoreline. Clearly this change of direction is of great importance to those shallow water wave energy devices whose capture efficiency is orientation dependent.
- Diffraction and Reflection. The phenomenon of the refraction of sea waves is similar to the optical refraction of light. Other effects analogous to optical behavior occur such as diffraction (waves bending around and behind barriers) and reflection. All these types of behavior are dependent on the detailed variation of sea bed topography and can lead to the focusing of wave energy in concentrated regions called “hot spots”.

b) Real Sea Characteristics

The above description refers to the behavior of simple, monochromatic waves. Real seas contain waves, which are random in height, period and direction. Within a fixed length of time (corresponding to a sea state) the characteristics of real seas remain constant. Statistical parameters must be used in order to describe such sea states and to determine their characteristics which are relevant to wave energy devices.

Wave height and period can be represented by statistical measurements of wave height and energy period. The ones commonly used are the root-mean square of wave height, H_{rms} , or significant wave height, H_s ($\sim 4H_{rms}$), and the wave energy period T_e .

Sea conditions can be calculated from knowledge of the wind climate responsible for the waves (Hasselmann et al, 1976; Darbyshire and Draper, 1963). One such model (Pierson and Moskowitz, 1964) was often used in the UK Wave Energy Program (ETSU, 1985) for programming wave makers in wave tank tests. It describes the distribution of energy, S , as a function of wave frequency, f :

$$S\{f\} = Af^{-5} \exp(-Bf^{-4}) \quad (4)$$

where A is a constant and B is a function of the wind speed.

Some more refined equations (Mitsuyasu et al, 1964) provide descriptions of sea states, which include the spread in wave direction, Θ , and have also been used in wave tank tests (Edinburgh, 1979). The effect of this variation in wave direction is often represented as a directionality factor, DF , which is the fractional amount of power in a random sea, which would be intercepted by a uni-directional wave energy device.

$$DF = \frac{\int P\{\Theta\} \cos\{\Theta\} d\Theta}{\int P\{\Theta\} d\Theta} \quad (5)$$

where $P\{\Theta\}$ is the average power of a wave traveling in direction Θ .

As the waves approach the shore and the shallower waters close to it, the wave modification mechanisms described above lead to a reduction in the angular distribution of wave power and a corresponding increase in directionality factor.

For isolated devices capable of either changing their orientation or capturing waves from any direction, directionality factors are of little relevance. However, for schemes using a line of devices, the directionality factor limits the amount of wave energy intercepted by the devices and hence their output.

The power within a sea state can be estimated by substituting H_s (or H_{rms}) and T_e into equations similar to those describing the power in monochromatic seas, e.g.

$$P(kW / m) = 0.49H_s^2T_e \quad (6)$$

3.3 Wave Characteristics Off the West Coast (US)

A detailed wave energy atlas is necessary for assessing the viability of wave energy plants at a local area, and provides important information for determining “hot spots”. The ocean energy team of the Motor Service Research Facility (MSRF) at Oregon State University is aiming at designing and developing a novel ocean energy extraction prototype. Part of the plan is the comprehensive mapping of wave energy potentials in the US. As an early start of this plan, a Graphical User Interface has been built using Matlab, as the novel contribution of this thesis work.

From Fig. 17, the worldwide wave energy potential distribution map, the Pacific coast of North America has rich wave energy potential. The model is built on the basis of wave data available on the National Buoy Data Center website [16].

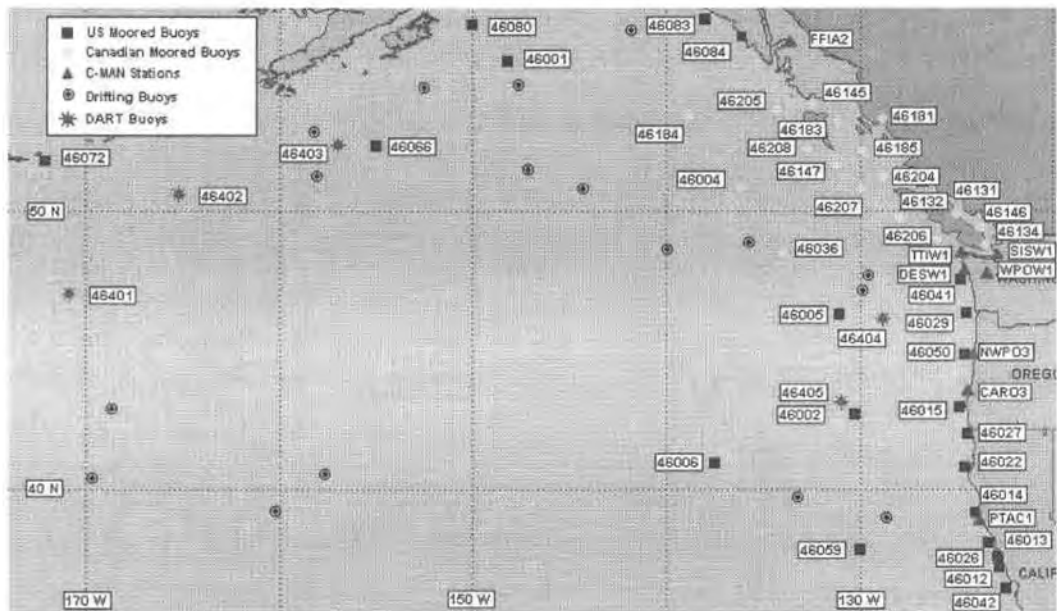


Fig. 26 Buoy Allocations of the NW Pacific (US)

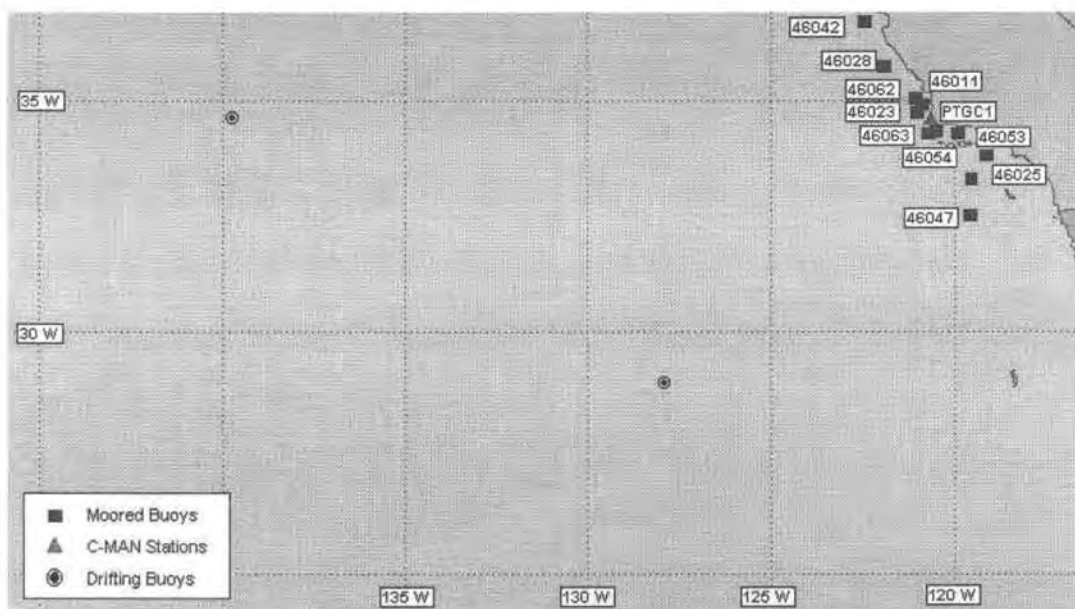


Fig. 27 Buoy Allocations of the SW Pacific (US)

Fig. 26 and Fig.27 are the data buoy allocations off the Pacific coast of North America. In this thesis, data of stations 46002, 46005, 46015, 46029 and 46050 off the Oregon coast are used to demonstrate recent real-time observation. For statistical purpose, data is taken from as many stations as possible, provided that their information is available.

3.2 Matlab GUI

3.4.1 User Guide

This GUI is built with Matlab 6.5 on the basis of the wave model discussed in 3.1 and the data available from the National Data Buoy Center website. When running the program, the first user interface is shown as Fig. 27.

This interface consists of three plot windows: wave height (meter), wave period (second), and wave energy potential (kW/m). The user first chooses if recent or historical data needs to be displayed. For example, if the user clicks on the “Recent” popup button, a list of stations will appear, a click on the number station will then tell the program which station needs to be observed. If station 46002 is selected, clicking on the button “Plot Recent” will activate the program and the interface is now changed to Fig. 28.

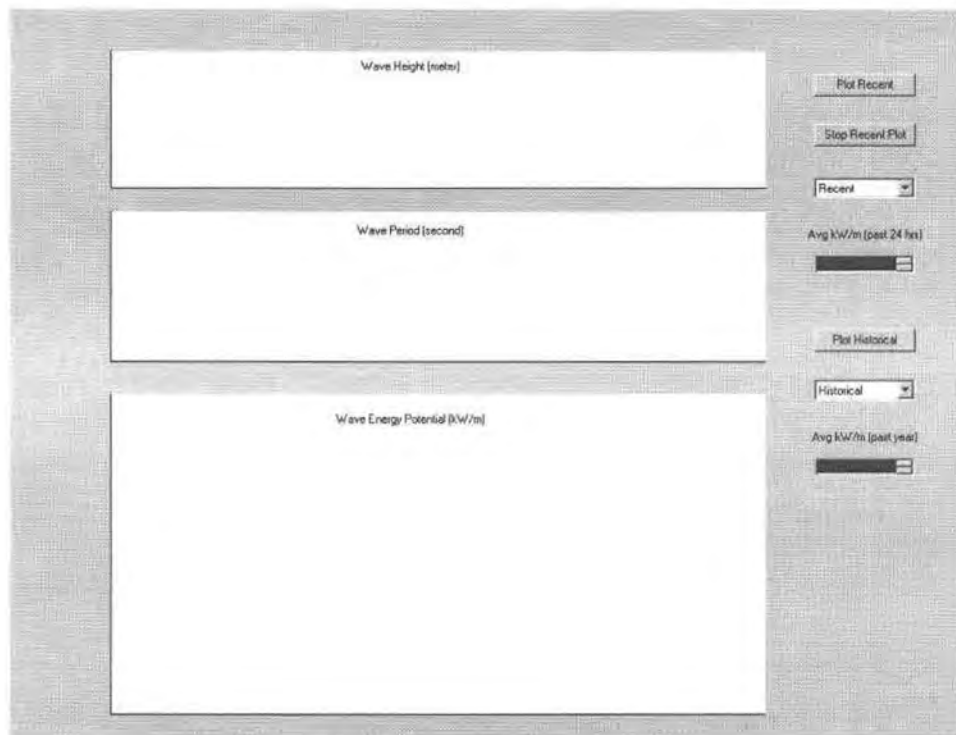


Fig. 28 the Start-off User Interface of the Matlab GUI

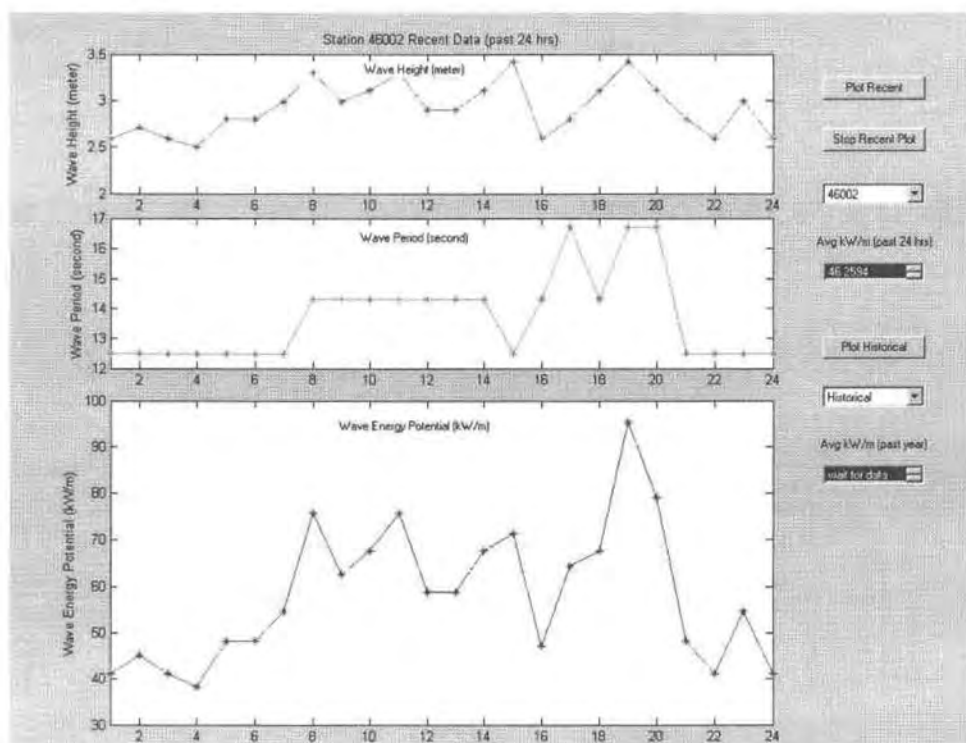


Fig. 29 Sample Recent Data Display

In this interface, the plots can be updated dynamically according to the real-time data input. Displayed range of the plots is set to be the past 24 hours but can be changed to any other range with minor modifications of the program. The list box under text “Avg kW/m (past 24 hrs)” displays the average wave energy potential of the selected station of the past 24 hours dynamically.

When the user wants to look at the recent data of other stations or historical statistics of a station, a click on the “Stop Recent Plot” will stop loading current data to let the user make a different choice. If the user wants to display the historical data of station 46005, a selection of “46005” and click on “Plot Historical” will change the interface to Fig. 29.

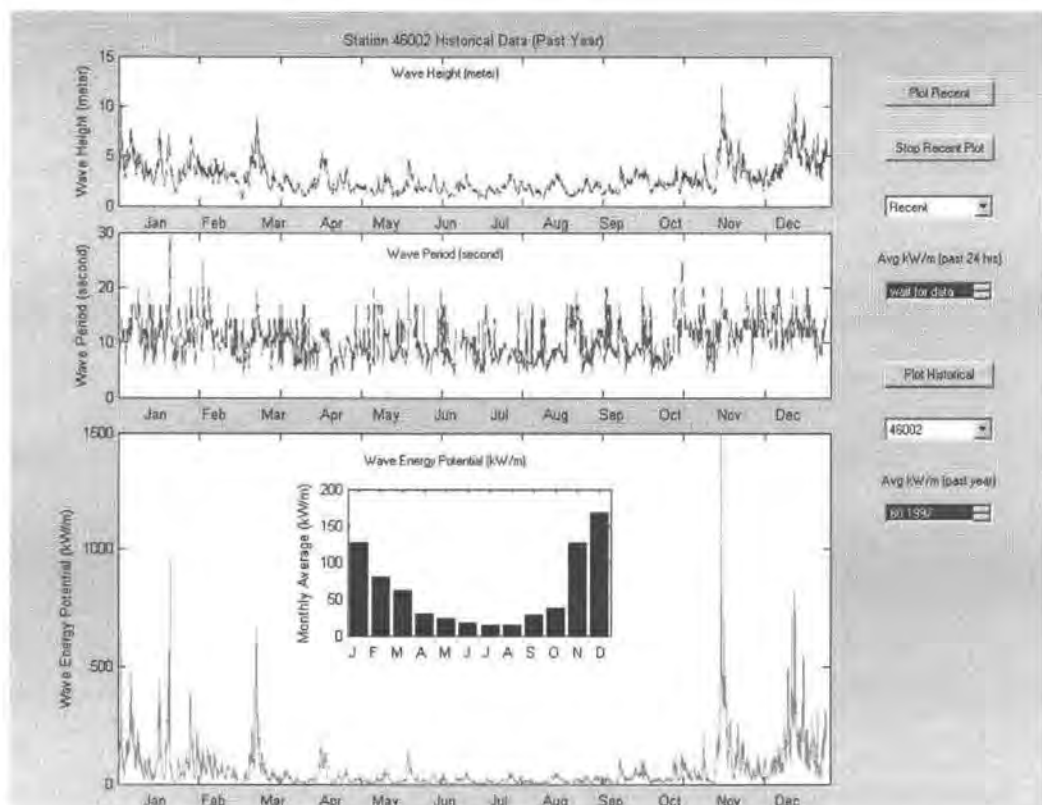


Fig. 30 Sample Historical Data Display

The acquisition step of historical data is one hour, a bar plot of monthly average over the year is shown.

3.4.2 Notifications

- This GUI needs to run under Matlab 6.5 or higher version.
- In the “Recent” plots, the data is “pseudo” real-time. Due to the availability of data, the program actually only reads in data that was saved in advance.

3.5 Data Analyses

By analyzing the available historical data, Fig. 26 and Fig. 27 can be revised to the following wave energy potential maps (Fig. 31 and Fig. 32), where the numbers in bigger font size are the energy potential of the corresponding spots (kW/m).

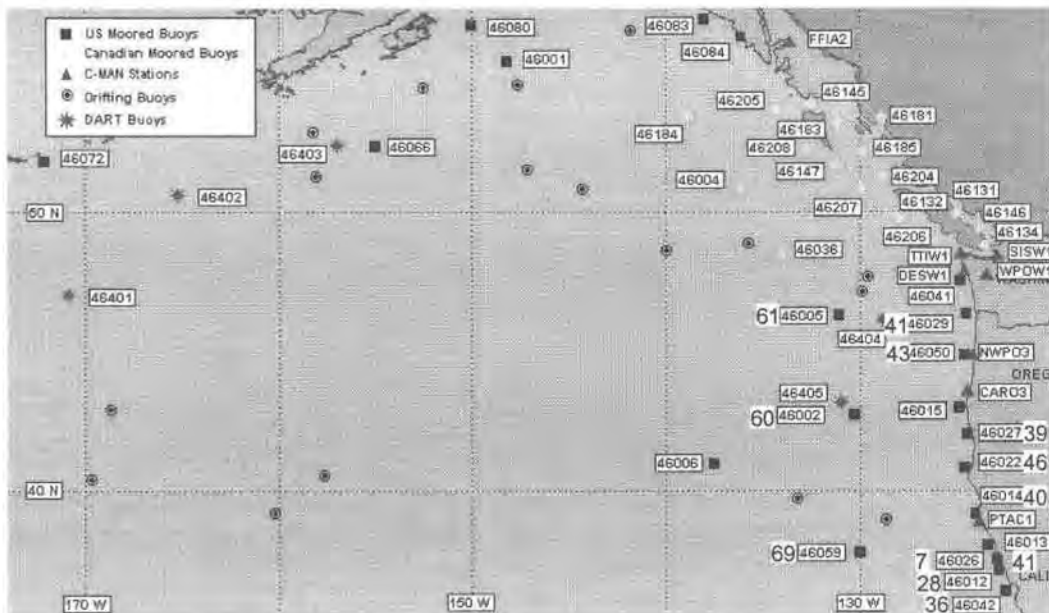


Fig. 31 Wave Energy Potential off the NW Pacific

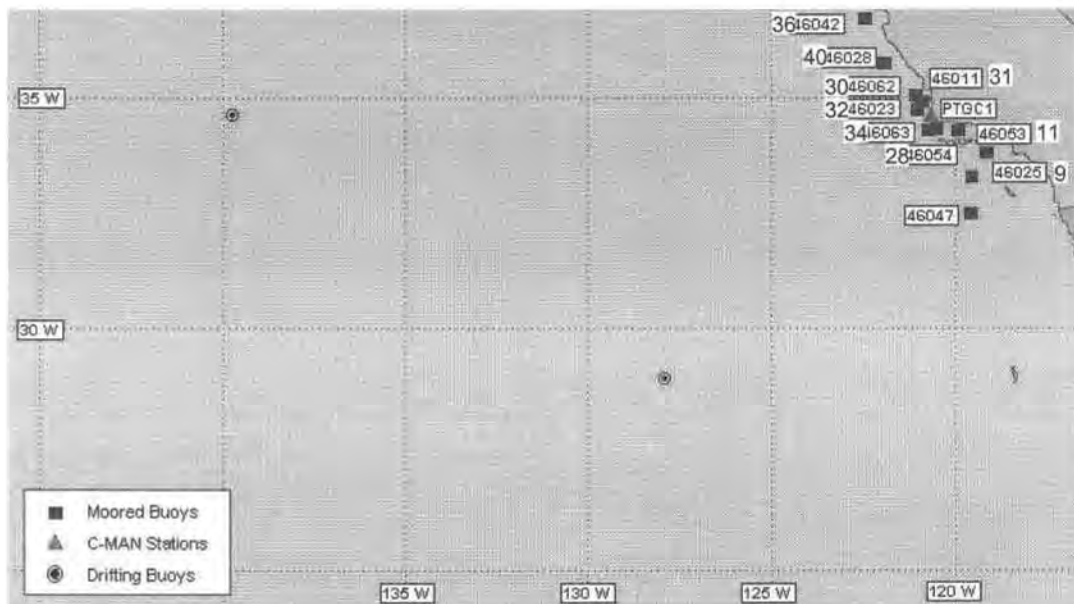


Fig. 32 Wave Energy Potential off the SW Pacific

It can be generally concluded that offshore spots such as 46002, 46005 and 46059 have much higher energy potential than spots that are much closer to the shoreline. This is because there is much less energy losses caused by the friction of the sea floor. The energy concentrations of the spots that are closer to the coast are much lower, and differ in a wide range.

An ideal site for an ocean energy plant is a spot that has deep water-depth, and is close to the shoreline: for better energy concentration, and lower costs in construction, power transmission line, and maintenance. According to these criteria, most of the marked spots have wave energy potentials above 30kW/m.

Spots that are far away from the shoreline are of little meaning in the sense of supplying power to local grids commercially, at least at this point. The prohibitively high cost of submarine devices, construction, maintenance, etc. make it non-realistic.

However, floating devices such as oil rigs may take the advantage of this high energy potential if some suitable floating devices can be invented.

In some area, energy demands is higher in the winter for heating, whereas some other areas require more power in the summer for air conditioning. This uneven distribution may or may not fit the load changes. A hybrid energy system, which consists traditional electricity generation and renewables would be an ideal solution for meeting power demands.

Let us now consider the capacity that wave energy devices can capture from the oceans at these spots. There is not published information of the tested prototypes, such as their dimensions, efficiency, etc, therefore only estimates can be made in this thesis. The Limpet 500 can generate 500kW from 25 yards of coastline (= 22.86m), so it is reasonable to assume that the spots be conservative, we assume that the spots in the above maps have the potential of generating 400 ~ 500kW electricity from 30m of coastline.

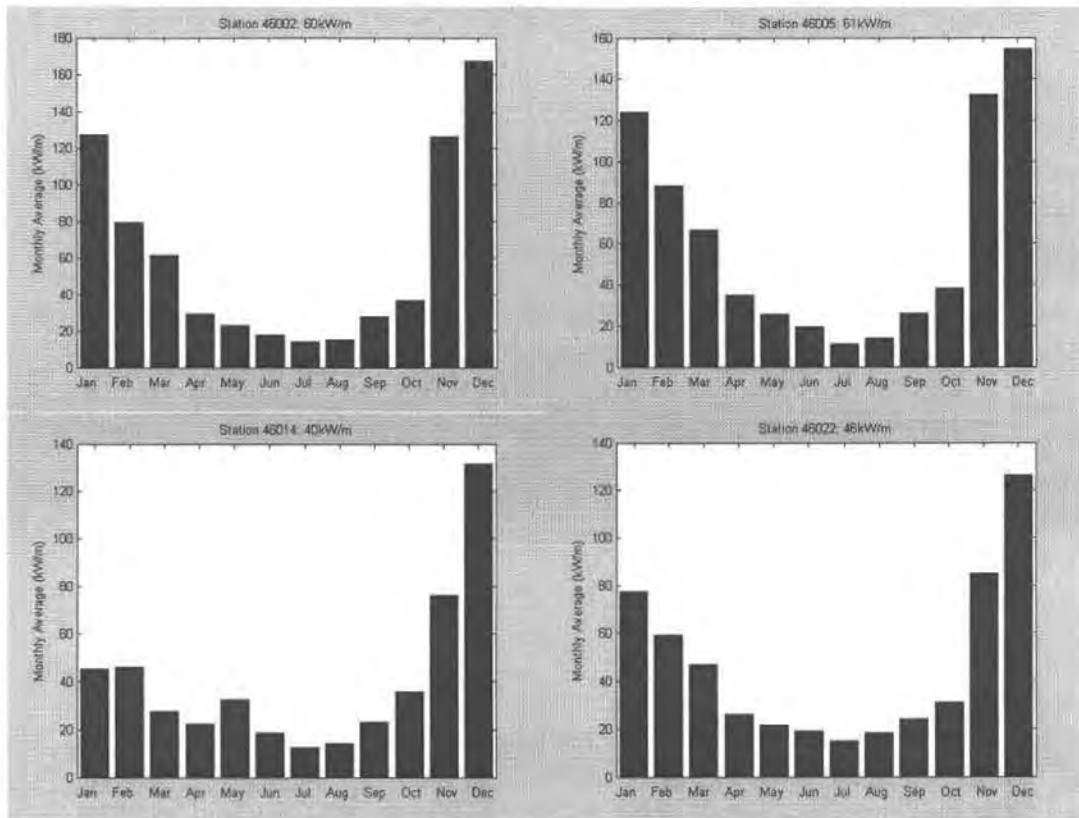


Fig. 33 Monthly Wave Energy Potentials

It is impossible for the author to make better or more estimates from the information available about the current technologies.

4 Discussions

The previous chapters have discussed the state-of-the-art of ocean energy extraction technologies, and a model was developed to provide wave characteristics vs. wave energy potential information. In this chapter, issues related to commercialization of ocean energy extractions (at this point, wave energy is the main focus) will be discussed.

4.1 Important Issues in the Development of Ocean Energy

4.1.1 Technological Viability

Among the devices reviewed in Chapter 2, some have already been built as full-scale prototypes, while others still require years of further research. The Limpet is the most developed wave energy device, which has successfully fed electricity to the UK's grid since November 2000. AquaEnergy is currently designing and permitting a 1MW demonstration power plant for commercial utilization using "AquaBuoys".

Besides device technologies, other technical issues that are important in the development of ocean energy extractions include:

- a) Power quality/service reliability

Power quality requirements need to be met by all units that supply power to the grid, a wave energy plant needs to meet these specifications, too. Compared to conventional power plants, the output of a wave energy plant is variable due to the variable nature of ocean waves. Energy storage system may be necessary.

Currently, there is no national standard available for the grid connection of ocean energy plants. The standard for small wind farms [18] can be used as reference. According to this standard, the power quality factors of a wave energy plant output including service voltage, flicker, frequency, harmonics and power factor need to be maintained within local utility regulatory authority limits.

b) **Survivability**

Intense storms have destroyed many ocean-facing systems including the collapse of a wave energy project in Norway in 1988, showing the importance of the capability of a system to survive in the marine environment.

c) **Anti-corrosion**

The ocean environment is highly corrosive. For the systems to achieve an economic lifespan, good anti-corrosion solutions need to be found. Research in advanced materials, chemical erosion needs to be performed.

4.1.2 Economic Viability

Cost has been the most critical issue in developing ocean energy extraction technologies. Some patent owners claim that the rate of electricity generated from the

oceans can be from 3 to 7 cents/kWh, but detailed justifications are not available. When considering the economical viability of an ocean energy plant, the following cost issues may be important:

The premature status of device technologies determine that large amount of investment is required for research and demonstration before an ocean energy plant can be commercialized. Sufficient governmental support is necessary at this stage.

Grid Connection of off shore plants is sometimes cost-prohibitive, especially for small-scale plants. The connection between a wave energy extraction device and the grid involves two stages: the submarine connection (not required for shoreline devices) and the landline connection. Submarine connection in some cases requires large flexible cables, the shorter this connection is, the lower the cost. Therefore, sites with deep water close to the shore are preferred, and large-scale installation is preferred over small-scale installation.

Accessibility to a spot determines the cost of installation and maintenance. This condition leads to the same conclusion of the last paragraph, e.g., sites with deep water close to the shore are preferred.

4.1.3 Environmental and Other Considerations

All forms of electricity generation have impacts upon the environment, so does ocean electricity.

From wastes, emissions point of view, the pollutions of ocean energy extractions are mainly caused during the manufacturing of the devices. During operation, the only pollution sources can be found from maintenance, possible

leakage from lubricants, working fluid of OTEC systems, etc. Compared to conventional non-alternative power plants, ocean energy plants can be claimed to be “pollutant free”.

Other impacts that ocean energy plants may have upon the environment include:

- Hydrodynamic Environment: Wave energy converters may affect the wave climate, patterns of vertical mixing, tidal propagation and residual drift current.
- Devices as Artificial Habitats: The devices would represent new habitats sea creatures. Anti-fouling measure would be necessary for some devices.
- Noise: some wave energy devices are likely to be noisy, especially in rough conditions. Noise travels long distance underwater and this may have implications for the navigation and communication system of certain animals.
- Navigation: Wave energy devices may have potential effects on shipping as their low freeboard could result in their being difficult to detect visually or by radar. Measure like proper markings (lights, transponders, etc.) should be taken to minimize the effects.
- Visual Effects: When wave energy devices are close to the shoreline, they may cause visual effects, especially in areas of designated coastline and those used for recreational purposes.
- Local Fisheries: The devices could limit access to fishing/crabbing areas, especially during the installation phase.

There is no simple conclusion can be made whether the above effects are good or not. It is not easy to judge the complex interactions between human activities and the environment. However, it can be concluded that the electricity generated from the oceans results in negligible pollutions in conventional meaning. Impacts upon marine habitats could not be determined until actual large-scale commercial plants have been in operation for sufficiently long time.

4.1.4 Benefits

On the other hand, ocean energy plants can benefit the local grids, coastal communities, and the environment in a variety of ways including:

- Reinforce the local grids: A lot of the “hot spots” with high ocean energy concentrations are at remote ends of main grids. By supplying locally generated pollutant free, fuel free energy from the oceans, these remote ends can get more reliable power supply, and the grids could be reinforced by the removal of strains from their remote ends.
- Coastline protection: By absorbing the damaging waves, ocean energy devices can protect the coastline from erosion without changing the physical scenes dramatically (let us remember the structure of the Limpet 500). Many coastal communities have suffered from the coastline erosion problem. One of the traditional ways to improve the condition has been to build harbor walls, which reflect waves to adjacent areas. The erosion of the unprotected coastlines therefore gets worse, because the energy has to be released, here or there.

- Tourist attraction: The novel technologies may attract tourists from other places, which can improve the local tourism, bring more job opportunities.
- Market potential: Let numbers speak: “Denmark is home to 60 percent of the world’s wind turbine manufacturing capacity. Presently about 2/3 of production is exported.” [19] The U.S. Department of Energy estimates that the demand for power will exceed 1,100,000MW, and 81% percent of it is expected to be from non-petroleum burning facilities. The estimate of this increase represents a \$17 billion per year industry.

4.2 Lessons Learned from Previous Research

Previous research projects have provided valuable experience for ocean energy researchers and designers. These lessons include:

- A reasonable plan: There was a great deal of interest in ocean energy in Europe throughout the 1970’s. Scientists devoted nearly a decade to developing large-scale, 2000 MW wave energy plants. These programs collapsed due to overly ambitious goals or a weakening of financial support, and the low after-war oil prices did not stimulate basic research in this area, either. A reasonable goal is the very first thing that researchers need to define before actual work starts.

- Survivability, reliability, maintainability: The collapse of some early projects due to extreme storm has told designers to pay enough attention to the devices' capability of surviving extreme storms with reasonable technologies.
- Comprehensive Applications: Low efficiency is one of the key features of ocean energy extraction devices. Comprehensive applications may make this disadvantage less significant. The OTEC system at Hawaii [1] has proved this.

5 Conclusions

The tremendous energy potentials have made the oceans attractive to researchers. More and more advanced technologies have made it possible for commercialization of ocean energy plants to provide a sustainable, clean energy supply. However, issues including grid connection, survivability, reliability, maintainability, corrosion, etc., device erosions need to be solved. Environmental impacts need to be further investigated.

The Matlab GUI developed as part of this thesis work is a start of the MSRF ocean energy team's next step of research. In the future, more functions can be added to this model, such as statistics of output capacity, displays of different stations simultaneously, acquiring "true" real-time data for dynamic display, and more options for users.

The MSRF has been funded by an NSF grant since March 2003. The main focuses of this project include determining the most promising ocean energy extraction technologies, system design and optimization, etc. The MSRF group has also been seeking funding for prototype development and testing.

Based on this comprehensive research investigation, the MSRF researchers are ready to investigate the most promising and appropriate technologies including OWC wave chambers (modular, adjustable and portable and exploring advanced corrosion free composite materials) as well as more direct and efficient buoy systems,

which will springboard the prototype design, testing in the MSRF, the Hinsdale Wave Research Lab and critically demonstration sites off the Oregon Coast.

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APPENDIX

Appendix: Matlab GUI Code

```

function varargout = My_Gui(varargin)

% MY_GUI M-file for My_Gui.fig
% MY_GUI, by itself, creates a new MY_GUI or raises the existing
% singleton*.
%
% H = MY_GUI returns the handle to a new MY_GUI or the handle to
% the existing singleton*.
%
% MY_GUI('Property','Value',...) creates a new MY_GUI using the
% given property value pairs. Unrecognized properties are passed via
% varargin to My_Gui_OpeningFcn. This calling syntax produces a
% warning when there is an existing singleton*.
%
% MY_GUI('CALLBACK') and MY_GUI('CALLBACK',hObject,...) call the
% local function named CALLBACK in MY_GUI.M with the given input
% arguments.
%
% *See GUI Options on GUIDE's Tools menu. Choose "GUI allows only one
% instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help My_Gui

% Last Modified by GUIDE v2.5 10-Jun-2003 22:23:32

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',    mfilename, ...
                  'gui_Singleton', gui_Singleton, ...
                  'gui_OpeningFcn', @My_Gui_OpeningFcn, ...
                  'gui_OutputFcn', @My_Gui_OutputFcn, ...
                  'gui_LayoutFcn', [], ...
                  'gui_Callback', []);
if nargin & isstr(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else

```

```

    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT

% --- Executes just before My_Gui is made visible.
function My_Gui_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   unrecognized PropertyName/PropertyValue pairs from the
%           command line (see VARARGIN)
handles.recent_data = [];
handles.historical_data = [];

% Choose default command line output for My_Gui
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

% UIWAIT makes My_Gui wait for user response (see UIRESUME)
% uiwait(handles.figure1);

% --- Outputs from this function are returned to the command line.
function varargout = My_Gui_OutputFcn(hObject, eventdata, handles)
% varargout  cell array for returning output args (see VARARGOUT);
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;

% --- Executes on button press in plot_recent.
function varargout = plot_recent_Callback(hObject, eventdata, handles, varargin)
% hObject    handle to plot_recent (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

```

```
uiresume
```

```
mm = 1; ss = 'wait for data';
set(handles.historical, 'Value', mm);
set(handles.avg_historical, 'String', ss);
str = [];
zz = handles.recent_data;
str1 = handles.str;
str = ['Station ' str1 ' Recent Data (past 24 hrs)'];
[m,n] = size(zz);

for ii = 1:24
    xx(ii) = ii;
end

timedelay = .5;
axes(handles.axes1); cla;
axes(handles.axes2); cla;
axes(handles.axes3); cla;
axes(handles.axes4); cla;
set(handles.axes4, 'Visible', 'off');

clc;

for ii = 1:m-23
    axes(handles.axes1);
    plot(xx, zz(ii:ii+23, 1), 'r-*');
    title(str); ylabel('Wave Height (meter)');
    xlim([1 24]);
    axes(handles.axes3);
    plot(xx, zz(ii:ii+23, 2), 'm-*');
    xlim([1 24]); ylabel('Wave Period (second)');
    axes(handles.axes2);
    plot(xx, zz(ii:ii+23, 3), 'b-*');
    xlim([1 24]); ylabel('Wave Energy Potential (kW/m)');
    if (ii <= 24)
        avg = zz(1:ii, 3);
    else
        avg = zz(ii-23:ii, 3);
    end
    avg = sum(avg)/length(avg);
    avg = num2str(avg);
    set(handles.avg_recent, 'String', avg);
end
```

```

        pause(timedelay);

end

% --- Executes during object creation, after setting all properties.
function recent_CreateFcn(hObject, eventdata, handles)
% hObject    handle to recent (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: popupmenu controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc
    set(hObject,'BackgroundColor','white');
else
    set(hObject,'BackgroundColor',get(0,'defaultUicontrolBackgroundColor'));
end

% --- Executes on selection change in recent.
function varargout = recent_Callback(hObject, eventdata, handles, varargin)
% hObject    handle to recent (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns recent contents as cell array
%       contents{get(hObject,'Value')} returns selected item from recent

val = get(hObject, 'Value');
str = get(hObject, 'String');
handles.str = str{val};
str = handles.str;
handles.recent_data = load(['s:\Thesis\recent\data' str '.txt']);
% handles.recent_data = load(['c:\Temp\data' str '.txt']);

zz = [.3048*handles.recent_data(:,5), handles.recent_data(:,6)];
zz(:,3) = .49 * (zz(:,1).^2) .* zz(:,2);
handles.recent_data = zz;
guidata(hObject, handles);
% --- Executes on button press in plot_historical.
function varargout = plot_historical_Callback(hObject, eventdata, handles, varargin)
% hObject    handle to plot_historical (see GCBO)

```

```

% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
mm = 1; ss = 'wait for data';

set(handles.recent, 'Value', mm);
set(handles.avg_recent, 'String', ss);
axes(handles.axes1); cla;
axes(handles.axes2); cla;
axes(handles.axes3); cla;
axes(handles.axes4); cla;

zz = handles.historical_data;
[m,n] = size(zz);
str1 = handles.str;
str = ['Station ' str1 ' Historical Data (Past Year)'];
axes(handles.axes1)
cla;
plot(zz(:,1), '--');
title(str);
% xlim([0 8800]);
ylabel('Wave Height (meter)');
label1 = ' Jan Feb Mar Apr ';
label2 = 'May Jun Jul Aug ';
label3 = 'Sep Oct Nov Dec ';
label = [label1 label2 label3];
xlabel(label);
set(gca,'XTickLabels',[])
axes(handles.axes3);
cla;
plot(zz(:,2), 'r--');
ylim([0 30]);
% xlim([0 8800]);
ylabel('Wave Period (second)');
xlabel(label);
set(gca,'XTickLabels',[])

axes(handles.axes2);
cla;
plot(zz(:,3), 'm');
avg = sum(zz(:,3))/m;
avg1 = round(avg);
avg = num2str(avg);
avg1 = num2str(avg1)

```

```

set(handles.avg_historical, 'String', avg);
%ylim([0 550]);
%xlim([0 8800]);
ylabel('Wave Energy Potential (kW/m)');

xlabel(label);
set(gca,'XTickLabels',[])
avg_month = zz(:,3);
m = length(avg_month)
n = floor(m/12);
nn = (n+1)*12 - m;
avg_month = [avg_month zeros(1,nn)];
m = length(avg_month)/12;
avg_month = reshape(avg_month, m, 12);

avg_month = sum(avg_month)/m;
avg_month(12) = avg_month(12)*m/(m-nn);
avg_month
axes(handles.axes4);
bar(avg_month);
xlim([0.5 12.5]);
xlabel('J F M A M J J A S O N D');
set(gca,'XTickLabels',[])
ylabel('Monthly Average (kW/m)');
figure;
bar(avg_month);
xlim([0.5 12.5]);
xlabel('Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec');
stitle = ['Station ' str1 ': ' avg1 'kW/m'];
title(stitle);
set(gca,'XTickLabels',[])
ylabel('Monthly Average (kW/m)');

% --- Executes during object creation, after setting all properties.
function historical_CreateFcn(hObject, eventdata, handles)
% hObject handle to historical (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: popupmenu controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc
    set(hObject,'BackgroundColor','white');

```



```

else
    set(hObject,'BackgroundColor',get(0,'defaultUicontrolBackgroundColor'));
end

% --- Executes on selection change in historical.
function varargout = historical_Callback(hObject, eventdata, handles, varargin)
% hObject    handle to historical (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns historical contents as cell array
%        contents{get(hObject,'Value')} returns selected item from historical

val = get(hObject, 'Value');
str = get(hObject, 'String');
handles.str = str{val};
str = handles.str;
handles.historical_data = load(['s:\Thesis\Historical\data' str '.txt']);
% handles.historical_data = load(['c:\Temp\data' str '.txt']);
zz = [handles.historical_data(:,8) handles.historical_data(:,9)];
[m, n] = size(zz);
for ii = 1:m
    if zz(ii,:) == [99.00 99.00]
        zz(ii,:) = zz(ii-1,:);
    end
end
end
zz(:,3) = .49 * (zz(:,1).^2) .* zz(:,2);
% for jj = 1:m
%     if zz(jj,3) > 2000
%         zz(jj,3) = 2000;
%     end
% end

handles.historical_data = zz;
guidata(hObject, handles);

% --- Executes on button press in stop_recent.
function varargout = stop_recent_Callback(hObject, eventdata, handles, varargin)
% hObject    handle to stop_recent (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB

```

```

% handles    structure with handles and user data (see GUIDATA)

uiwait
handles.current_data = [];
% --- Executes during object creation, after setting all properties.
function avg_recent_CreateFcn(hObject, eventdata, handles)
% hObject    handle to avg_recent (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: listbox controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc
    set(hObject,'BackgroundColor','white');
else
    set(hObject,'BackgroundColor',get(0,'defaultUicontrolBackgroundColor'));
end

% --- Executes on selection change in avg_recent.
function avg_recent_Callback(hObject, eventdata, handles)
% hObject    handle to avg_recent (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = get(hObject,'String') returns avg_recent contents as cell array
%    contents{get(hObject,'Value')} returns selected item from avg_recent

% --- Executes during object creation, after setting all properties.
function avg_historical_CreateFcn(hObject, eventdata, handles)
% hObject    handle to avg_historical (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: listbox controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc
    set(hObject,'BackgroundColor','white');
else
    set(hObject,'BackgroundColor',get(0,'defaultUicontrolBackgroundColor'));
end

```

```
% --- Executes on selection change in avg_historical.  
function avg_historical_Callback(hObject, eventdata, handles)  
% hObject    handle to avg_historical (see GCBO)  
% eventdata  reserved - to be defined in a future version of MATLAB  
% handles    structure with handles and user data (see GUIDATA)  
  
% Hints: contents = get(hObject,'String') returns avg_historical contents as cell array  
%        contents{get(hObject,'Value')} returns selected item from avg_historical
```