Chapter 2
Conceptual Design of Kuroshio Power Plant

The design of a Kuroshio power plant begins with the selection of turbine. Once the turbine is chosen, the turbine anchoring system will be designed accordingly, followed by the designs of construction procedure and relevant equipments. Figure 2.1 shows the conceptual design of the Kuroshio power plant, which was made under a major concern that the design must securely anchor hundreds of turbines in deep ocean under the action of a dynamical force of hundreds of thousands of Newton. This is an unprecedented challenge stemming mainly from the design of an effective anchorage system.

Figure 2.1 shows a power plant being composed of tens of horizontal-axis turbines. As different types of turbine are chosen, such as those given in Appendix A, one may result in a different design in the anchorage system of the power plant. In the figure, a relay platform is used to anchor dozens of turbines. The platform consists of hundreds of hollow floats connected by ball joints, being allowed to deform under the dynamical force applied on the turbines by the Kuroshio. To prevent typhoon-driven waves from damaging the turbines and the platform, the axis of the turbines should be submerged at least 30 m below the surface, and the platform can be submerged to a depth of up to 70 m.

The relay platform serves as an artificial seabed, raising the level of the actual seabed from hundreds of meters deep. The turbine is anchored to the relay platform by a single cable of a length about 20–30 m, allowing the turbines to drift with the ocean current within a limited domain. The platform is anchored to the seabed hundreds of meters deep by tens or hundreds of cables, and the direction of the cables shall be in accordance with the ocean current, so that the whole relay platform will not suffer significant displacement or deformation under the action of the strong current. This approach, simultaneously anchoring the platform by hundreds of cables, can prevent collapse of the platform due to seabed slumping caused by undersea earthquakes. Moreover, not needing to secure the anchors in predetermined positions helps keep overall construction costs down.

However, on the other hand, the anchorage of the turbine to the platform cannot be random, as the anchor position and the platform structure robustness are closely related. One must consider that, with tens of turbines simultaneously operating in

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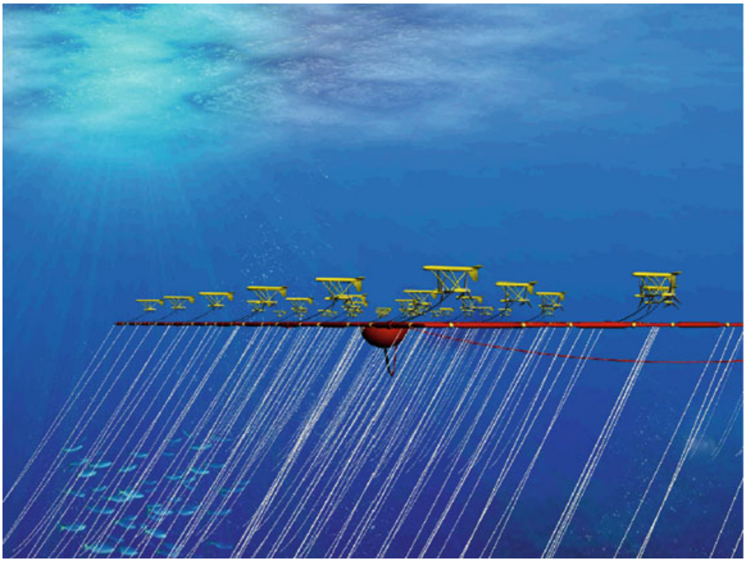


Fig. 2.1 Schematic of a Kuroshio power plant, which shows a so-called turbine cluster having 25 turbines simultaneously anchored to the floating relay platform. Power transmission cables connect different clusters, with each cluster equipped with its own transformer. The floating relay platform is anchored to the seabed by hundreds of cables

the ocean, the entire platform's static tolerance must be kept within a safe range while, at the same time, the overall dynamic reaction of the platform and the turbines must not create a structural fatigue or damage.

On the center of the relay platform, a set of power conversion equipment is deployed, allowing the platform to modulate the power to be transmitted to the land-based grid. To prevent the damage caused by earthquake, the power cable should hang from one platform to the other before finally connecting to power station on land. Without the need to lower the cable to the seabed, the length of the cable can be reduced significantly and the earthquake-caused cable damage can be prevented. The distance between platforms is relevant to the current characteristics and turbine performance. By deploying platforms in different depth, the distance between platforms can be shortened.

Preliminary estimates of construction feasibility, ease of maintenance, cost-effectiveness, and other optimization considerations indicate that a platform should accommodate 25–35 turbines to achieve optimal performance, covering an area of approximately 400 × 700 m^2. With this set up, the movement of the entire turbine cluster is coordinated with that of the floating platform; thus, the reaction force between ocean current and the turbines, and the deformation and displacement of the platform as well, can all be effectively controlled within a safe range.

All of the technologies needed to build a Kuroshio power plant are traditional and mature, but integrating these technologies together to build a Kuroshio power plant is a new endeavor. Currently, tidal power plants have been built in a lot of shallow waters around the world, which is not necessarily applicable to the east coast of Taiwan where the waters are usually of several hundred meters deep, and goes as deep as 3,000 m within a few kilometers from the coast. Deep sea engineering poses very different problems from shallow water engineering. Although the needed technologies are not new (for example, the oil-drilling engineering in the Gulf of Mexico often takes place in depths of over 1,000 m), stably anchoring thousands of turbines to an earthquake-prone sea floor poses various severe engineering challenges.

Based on the deep-sea engineering characteristics discussed above, the engineering design of Kuroshio power plant can be classified into three major categories: the turbine design, the relay platform design, and the construction engineering design. Two more important designs, although may not be so significant as previous ones, are respectively the so-called anchored pile driver design and the site selection of the power plant. The characteristics of these five designs are illustrated in the following.

2.1 The Turbine Design

The principles of ocean turbine to convert current momentum into electric power are similar to those of wind turbine. Both are designed to convert kinetic energy of fluid flow into rotational torque to drive the power generator. But, since the density of seawater is 832 times that of air, the ocean turbine can produce the same amount of electricity by using smaller blades at a slower rate of rotation. Besides, since ocean current flows at a steadier rate than wind, it therefore makes generating capacity larger and more predictable.

Although the energy conversion principle for both ocean and wind is nearly identical, ocean current electrical generation equipment is used in a more extreme underwater environment, requiring more complex construction technology. Also, a higher degree of reliability is needed for ocean turbines, and operations and maintenance costs are higher, thus the costs associated with the early development of ocean current power generation equipment were high, making it hard to compete with other renewable energies or traditional fossil fuels. Recently, however, increased emphasis on upgrading technology for ocean power generation in various countries has reduced the cost, prompting the development of several large-scale underwater turbines in the commercial power generation supply chain [1–3].

In nowadays, most of the commercially available underwater turbines were developed in Europe or the USA, and most models were developed for use in tidal power generation in shallow waters. These turbines can be broadly classified into four types: horizontal axis, vertical axis, reciprocating, and Venturi tube. Online searches found 63 different types of turbines covered by more than 320 patents. The design principles and characteristics of these turbines, along with their development profiles, manufacturers, origin, and relevant patents are organized in Appendix A.

The structure of ocean current turbines can be divided into three large areas (1) the turbine: converts linear kinetic energy into rotational kinetic energy, (2) the generator: converts rotational kinetic energy into electrical energy, (3) the gear assembly: the interface between the turbine and the generator, adjusts the rotation speed and absorbs the axial impact force. Of course, additional gear is needed as well, including electrical power conversion equipment, submarine cables, anchoring devices, etc. In this three-part design, detailed research and development of the following key technologies requires particular attention:

1. Dynamical design of turbine: Turbine performance is determined by the hydrodynamic performance of the turbine body and rotor blades, wherein the average velocity, characteristic velocity of the water, short- and long-term flow velocity fluctuations, typhoon-induced velocity change, and other environmental factors are all important considerations in the design of blade performance. The design of the body of turbine not only must consider the shell shape and structural strength but also the selection of the anchorage point and the design of the cable connector, all of these shall affect turbine performance and safety [4–8].
2. Design of turbine body structure and material selection: Generally speaking, the structure of an ocean turbine is not complex. The key components include the generator, the rotor blades, and the support structure of the frame. The ocean current imposes dynamic stress and strain on the entire turbine structure, requiring the 3D structural mechanical analysis to ensure that the rigidity of the selected materials meets the requirement to survive the dynamic stress imposed by strong current. Regarding component materials, special alloys should be considered for the bearings and brackets, and composite materials for others, such as floats for the body. Fabricating the body from composites in large quantities can reduce the cost but requires mold design and processing techniques, coupled with a production line designed for the designed processing procedures.
3. Generator design: Ocean turbine generators, designed to operate in a low-speed ocean current such as the Kuroshio, should be featured by a large radius and long shaft to output a large torque at a low rotational speed. To maintain optimal efficiency in response to changes of the Kuroshio, the rotational speed of the turbine (and the generator) shall be precisely adjusted through the electronic control circuits.
4. Gear assembly design: Ocean turbines operating at low speed currents is subject to large high torque and axial thrust. These static and dynamic forces are absorbed by the gear assembly which transfers this force from rotor to the generator. Achieving this requires key technologies for variable speed transmissions, force characteristics analysis, anticorrosion, and waterproofing. At the design stage, one needs to consider problems related to maintenance, lubrication, and heat dissipation.
5. Anticorrosion design: The turbines for the Kuroshio power plant will be submerged tens of meters beneath the ocean surface and are thus less prone to oxidation corrosion than shallow-water turbines, but deep water organisms may

adhere to turbines creating the so-called biofouling problem. Previously, biofouling can be prevented by using toxic paints to smear on the turbine. But, nevertheless, this kind of toxic paint is strictly prohibited under marine environmental laws. Therefore, one may need to develop a new type of environmentally friendly paint through a suitable synthesis of chemistry and pharmacology. In addition, some metal parts may require plating and lubrication. The design of anticorrosion process design should take maintenance periods and procedures into account, which will affect operating costs.

6. Maintenance design: All aspects of maintenance contribute to operating costs, and the specific maintenance procedures are closely related to the design of the turbine. Therefore, in the beginning of the design stage of turbine, maintenance procedures and content, such as specific maintenance procedures, frequency, time, replacement parts, and lubrication, must be set out clearly. Ideally, the maintenance shall be done once in a few years. Whether it should be done underwater or above water must be carefully specified.
7. Depreciation: According to the author's understanding after talking with many turbine companies worldwide, the standard can be designed as that no maintenance is required during the first 5 years of service, and the life span can be designed for 25 years. After the first 5 years, the turbine should be able to operate at full load for 10 months out of a year.

As shown in Appendix A, there are over 60 different types of ocean current turbine, covered by more than 320 patents. In which, 20 types have been subjected to long-term full-scale model testing at sea, but only a few have been anchored in deep water to produce electricity. After taking the reliability of anchorage systems and construction procedures, as well as the low construction and operating costs into account, we selected the Gulf Stream Turbine (GST) for use in the Kuroshio power plant. The GST features an auto-stabilizing design, allowing it to be securely anchored on the relay platform by a single anchor. We follow the original design of GST to reproduce the turbine body structure diagram as shown in Fig. 2.2, while detailed specific descriptions can be found in Appendix A, product no. A-1.26.

This turbine was first demonstrated by Robson in 2003 (see Appendix B) and is mainly used for ocean current power generation. The device consists of two sets of counter-rotation rotors, a triangular structure supporting a main pontoon made of carbon or fiberglass to strengthen the fuselage structure and prevent corrosion. The two multiblade rotors are positioned at the rear of two watertight nacelles, generating rotational torque in opposite directions. The generators are contained within the watertight nacelles, and the weight of the generators acts as ballast for the triangular structure. The upper middle part of the body features a torpedo-shaped main pontoon with a tail stabilizer to maintain the turbine to face against the ocean current, keeping it level and aligned with the flow. The main pontoon and the watertight nacelles are connected by numerous linkages. The bulk and shape of the linkages are designed to not affect turbine performance. The cable anchor is connected through a ball joint onto the connecting rod below the main pontoon.

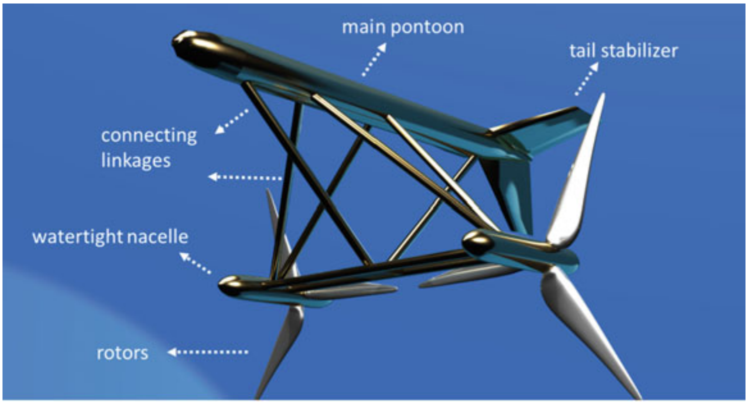


Fig. 2.2 Schematic of the Gulf Stream Turbine (GST), which has been modified by present study in line with the purpose of the dynamic analysis

The GST design features four mechanical stability mechanisms to keep the fuselage level and aligned with the current, while balancing the fuselage against sudden impacts:

(a) Tail stabilizer:
The tail stabilizer features two horizontal tail wings and a vertical rudder. The tail wings ensure that, during yawing, the fuselage can quickly regain its current-facing alignment. The rudder acts to restore the fuselage's horizontal posture when the pitching angle changes.

(b) Resistance center located behind the anchor point:
This works like an arrow's fletching; when the fuselage pitches or yaws, it acts to quickly produce a corrective torque, thus restoring the original attitude and keeping the turbines faced against the current.

(c) The center of gravity located below the center of buoyancy:
This works on the same principle as "Weeble" toys in that, when the fuselage pitches or rolls, immediate compensation restores the turbine to its original attitude.

(d) Symmetrical design:
The design contains a pair of counter rotating rotors and generators, mutually offsetting the force and torque under the flow action on the turbine. However, the operation of the blades of the two rotors is not necessarily in the same phase (commonly referred to as the dual-rotor effect), which will be discussed in greater detail in Sect. 3.5.3.

With these stability mechanisms, the GST design does not require additional balance control systems, thus reducing to some extent the maintenance difficulty and the construction cost. In Sect. 3.7, we discuss the functions of these four stabilization mechanisms, based on the design of the tail stabilizer of the GST.

The dynamic reaction force on the fuselage of GST will be analyzed in Chap. 3, based on which viable anchorage system and components are designed. Of course, some other turbine models are also operable in the Kuroshio. But the dynamic behavior is highly likely to be different from GST, which requires another analysis to be done as shown in Chap. 3.

2.2 The Relay Platform Design

The design of the relay platform is done with a single purpose in mind that one shall deploy the GST at a predetermined position in deep waters and ensure it to stably operate under the action of the Kuroshio. With the relay platform, dozens of turbines can be deployed as a cluster to simplify the engineering procedure to construct the power plant in deep waters. Besides, the relay platform can also comply with the rationality of construction, operation, and maintenance costs. Conceptually, in brief, the relay platform is composed of hundreds of buoyant pontoons connected by universal joints. Above the platform, there are dozens of turbines anchored stably on the platform. Below the platform, hundreds of cables serve to anchor the platform unto the seabed at a depth of several hundred meters.

After tried with several different designs, an assembly for the relay platform (Fig. 2.3a) made up of 66 individual unit platforms (Fig. 2.3b) is developed. Each unit platform measured 70 × 70 m^2, with each side made of three components: a primary linkage (30 m) in the middle, an auxiliary linkage (15 m) on each side, and a cross (or a cruciform) joint (10 m). The side facing against the current has a width of 11 unit platforms, while the side being parallel with the current is six unit platforms wide, giving the relay platform an overall area of 770 × 420 m^2. The turbines above the platform are arranged in a form of staggered grid, anchored by cables of about 50 m long. Each relay platform is able to support a total of 39 turbines. The installed capacity of each GST turbine is 0.5 MW, giving each relay platform a total installed capacity of 19.5 MW.

To ensure sufficient buoyancy to support the platform in the Kuroshio, the primary linkage and the auxiliary linkage are made of hollow floats, with dimensions dictated by the size of the platform. These floats can be made of composite materials or rust-proof metal. All floats are connected by universal joints, giving the platform a flexible structure. The turbine anchor point can be rotated with a hollow sleeve jacketing on the primary linkage. This sleeve is installed at the middle of the primary linkage and can move around the primary linkage, but its lateral movement along the linkage is prohibited. The platform's cable anchor point is located on the bottom of the cross joint, which is connected to the cable by a ball joint. To prevent significant drift in the current, the anchor point of each cross joint is attached to two cables anchored to the seabed, thus restricting the platform's displacement. One cable drops vertically to restrict the platform's vertical displacement, while the other falls diagonally to restrict downstream displacement (Fig. 2.3c).

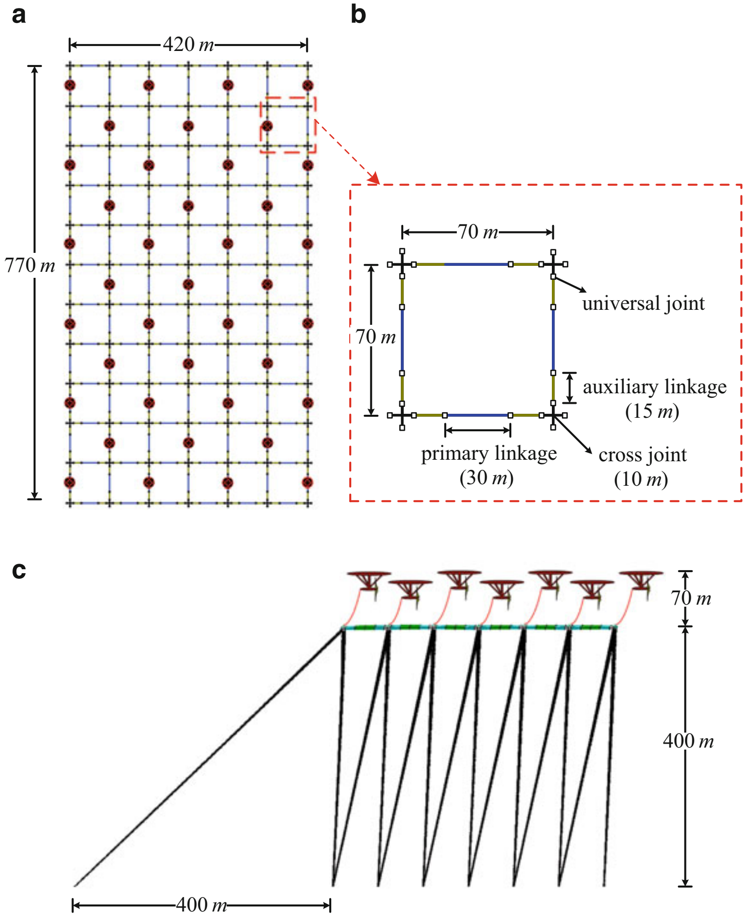


Fig. 2.3 Schematic of relay platform components and overall structure. (**a**) The complete platform is made up of 66 unit platforms, with a total of 39 turbines arranged in a staggered formation and anchored to the upstream primary linkage of the unit platforms. (**b**) The unit platform—a square structure with each side constituted by one 30-m-long primary linkage, two 15-m-long auxiliary linkages, and two cross joints, with each component connected by universal joints. (**c**) Side view of the complete Kuroshio power plant, with the platform secured to the seabed by two sets of cables (vertical and inclined) and the turbines anchored to the relay platform with the central axis of the rotors positioned 30 m above the platform. Note: the current moves from left to right, with the left-most cable at a 45° angle. The turbines are not drawn to scale, and the second, fourth, and sixth turbines in (**c**) appear lower to indicate the staggered configuration

The universal joint connecting the primary and auxiliary linkages is the key design focus of the relay platform. This universal joint not only controls the deformation of the entire platform but also absorbs high frequency vibrations caused by the current, thus reducing the risk of damage to the power plant's structure from deformation strain or fatigue. At the same time, both the level of platform deformation and the degree of linkage rotation can be controlled by selecting a proper stiffness of the rotating spring of the universal joint.

The relay platform has four major elements: the floats that make up the main structure of the platform, the universal joints which connect the floats, the cross joints that bear the cable anchors, and the anchors and the cables. The key technologies involved include the mechanical design and material selection of the floats, the force specifications and deformation limitations of the universal joint, the stress and strain analysis of the cable and the anchor, and the force distribution, the deformation and displacement analysis of the platform in the Kuroshio. Other technologies required include the design of the anticorrosion treatment, warranty, and maintenance of the aforementioned elements, along with depreciation estimates. The work content of the above mentioned is as follows:

1. Platform dynamic design: The relay platform, supporting tens of turbines, is anchored to the seabed by hundreds of cables. The operation of the overall structure reflects complex and dynamic changes in the Kuroshio current, leading to deformation and displacement of the platform. These forces and their action on the platform components are the key focus of analysis and technology application for power plant design. This work begins from establishing a theoretical model for use in conducting reliable numerical computations to analyze the stress and strain on the overall structure.

   Only in this way can we determine the required mechanical strength for the platform components, effectively select appropriate materials, and properly predict the structural rigidity and apparent stability of the overall power plant structure. The selection of materials for the platform's buoyant linkages requires combining material mechanics analysis and structural analysis with other mature techniques in assembly and manufacturing [9–12]. The platform can be made of composite or plastic steel materials. Assembly shall be completed on land before installation at sea.
2. Cable material: Traditional anchor chains are typically made of steel, which is heavy and prone to corrosion and is possibly unsuitable for use in anchoring the turbines to the relay platform. There are cables made of composite materials or polymer compounds, which is light and strong and their bristly surface capable of helping to reduce low-frequency swinging or high-frequency vibration caused by the current [13, 14] and is optimally suitable for use in Kuroshio power plant. In particular, the sea off the coast of Tai-Dong in southeast Taiwan is hundreds of meters deep, requiring cables as long as 1 km. As such the weight and strength of the cable are key engineering concerns.
3. Anchor specifications: There is a wide selection of existing anchors [15, 16] including caissons, pilings, screws, etc. The choice of anchor is directly influenced by the local seabed geological conditions. As discussed in Chap. 1, the geology of the seabed at Taiwan's east coast is generally made up of solid igneous rock, covered by a layer of sediment up to several meters in depth. Using caisson anchors under these conditions would require the weight of the caissons to be highly large, and its shape also requires special consideration given the

adhesiveness of the sediment layer. Using piling anchors requires detailed mechanical data for the geology below the sediment layer, which show that the seabed geology of eastern Taiwan is primarily made up of igneous rocks in a compact structure, so permanently anchoring the cables by screws would be a more viable approach. Finally, the depth to which the anchor should be set and the required tension resistance are important issues that shall be clarified during the design phase.

4. Anchor system: The overall anchoring system consists of the anchors, the cables and the relay platform. The movement of each component influences the others, and the ocean current will cause the overall structure to vibration and deformation [17–19], potentially affecting the overall safety, lifespan, the efficiency, and performance of the turbine. Therefore, the structural design of the anchoring system is essential to the power plant design, along with static equilibrium calculations and dynamic vibration analysis [20]. However, in terms of mechanical analysis, these processes all draw on mature technologies, and assembly techniques are existent in engineering market.
5. Anti-biofouling: Similar to the turbine, the three major components of the anchoring system above are subject to biofouling. Special attention shall be paid to the universal joints, since sever biofouling on the joints will make them broken, leading to the disintegration of the platform. The biofouling on the pontoons and the cables shall also be prohibited, since the weight of the platform will increase gradually. The overall buoyancy of the power plant is then reduced and, if no attention is paid, the platform will sink to the deep sea eventually.
6. Maintenance: One maintenance run per year is taken as a rough standard, primarily for removing biofouling and inspecting the structure robustness. Maintenance and repair work would primarily occur on site, but the design needs also to consider the difficulty of maintenance work at deep sea. Specialized submersibles (ideally remote controlled) will be required. Key technologies will be required for clearing biofouling and repairing structural damage.

2.3 The Construction Engineering Design

Construction engineering for the Kuroshio power plant is divided into four major stages: anchoring the platform, deploying the turbines, laying submarine cables and installing power transmission equipment, and power transmission and distribution on land. The first two tasks are highly complex, but the key challenge lies in the deep sea engineering required. The last two tasks involve mature undersea technology, and engineers can reference many previous projects; thus this discussion shall focus on the first two stages. The work content of these two tasks is explained in the following (illustrated in Fig. 2.4).

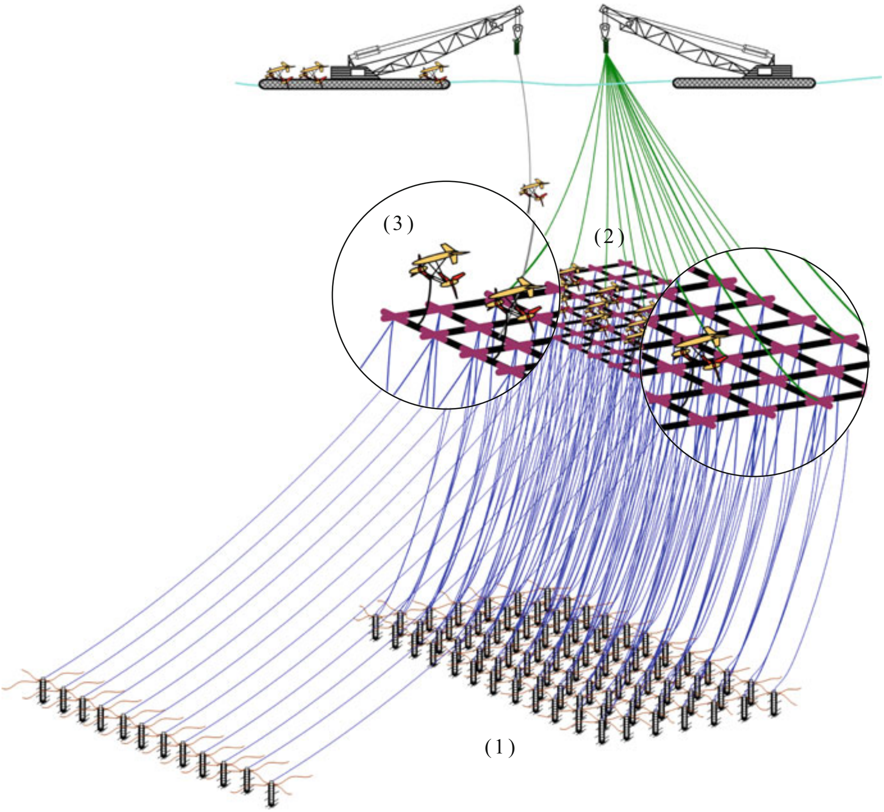


Fig. 2.4 Schematic of Kuroshio power plant construction. The construction procedure is designed to be three steps (1) anchoring the cables to the seabed, (2) anchoring the relay platform in place, and (3) installing the turbines on the relay platform. Each turbine is anchored to the platform by a single cable, while the platform is anchored to the seabed by two sets of cables: vertical and inclined

1. Anchoring the cables to the seabed: The seabed geology off of Taiwan's east coast consists primarily of igneous rock, covered by several meters of sediment. Combining screw-type anchors with pilings provides a more suitable means of anchoring the cables to the seabed [21, 22]. Installation will require the design of a deep sea piling device (see Sect. 2.4), which is remotely controlled by engineers on the barge at sea surface. This installation does not require exact precision in placing each anchor in advance, providing additional flexibility in terms of anchor type, number of required anchors, and the extension angle of the cables, thus significantly reducing installation complexity.
2. Anchor the relay platform to the sea bed: Once several hundred cables have been anchored to the sea bed, the cables are attached to their corresponding anchor points on the relay platform. The relay platform initially floats on the surface but,

as the cables are attached, it gradually sinks until the platform assumes a horizontal attitude at a predetermined depth. Finally, the tension of each cable is individually adjusted to compensate for the buoyancy of the platform, ensuring the platforms stable positioning. The area of the relay platform may cover tens of thousands of square meters, supporting dozens of turbines, each of which is exposed to hundreds of thousands of Newtons (see Chap. 3 for analysis).

Given the large size of the platform, its dynamical variations of stress and strain will be quite intense. Thus, the number of cables securing the platform to the seabed should include a suitably broad margin to enhance the overall safety of the structure [23]. The relay platform is constructed of many floats of varying sizes, shapes, and hollowness which can be used to adjust the structural strength and buoyancy. Each float should be able to swing freely, but the platform's overall deformation should be restricted within a small range to prevent the turbine groups from swinging excessively. This can be accomplished through the designing rigidity of the universal joints.

3. Anchor the turbine to the relay platform: One should not underestimate the difficulty and complexity of installing dozens of turbines safely in the ocean, which shall float stably at a distance of 50 m or more above a relay platform covering tens of thousands of square meters. The turbines can only be installed once the relay platform has been erected. Given that the side of the relay platform facing the current is subject to the greatest force of the current, the components of this side requires the greatest structural stiffness. Therefore, turbine installation should begin at the upstream side of the platform and gradually shift towards downstream. Once the turbines are fully deployed, the buoyancy and tensile strength of the anchor cable for each turbine needs to be adjusted to ensure the turbine will float at the predetermined depth and will not swift out of position due to the turbulence in current flow.

Although not shown in Fig. 2.4, submarine cables and electrical transmission engineering are still key technologies for power plant engineering [24]. The decision regarding whether AC or DC power is transmitted should be made first. Additionally, evaluations on what voltage level suits the Kuroshio power plant, how to maintain the voltage level of the power collection system in the event of malfunction or momentary power outages, and locations of the offshore and onshore power substations are also crucial issues for the power plant engineering. In fact, the location of the substations affects the costs for power generation and construction, and thus must be determined in the early planning stages. The choice of AC and DC power transmission entails a tradeoff between increased construction costs and increased transmission capacity. Cost estimates must be based on the scale of the ocean current's generating capacity and the transmission distance. Data for AC and DC power transmission must be collected and analyzed to establish a reference for future AC and DC transmission designs.

Regardless AC or DC, the output needs to be collected together to one or several locations and then transmitted through a system of AC or DC parallel submarine cables to shore. The power collection system can be used as a power bus function for each generator, thus collecting together the power output to the interconnecting point for the power system. In addition to collecting power, the system should also be able to control the switching equipment for each turbine group, allowing for easy isolation of malfunctions to prevent damages from overload and short-circuit. Moreover, the possibility of system-wide failure should be reduced, and equipment failures that could potentially affect other facilities should be prevented.

Finally, the seismic-related risk such as the possibility of severe underwater landslides in off Taiwan's east coast shall be investigated. On this account, recommendations are made that power conversion be completed on the relay platform before transmission to the land substation by cable to improve safety and efficiency, and to lower installation costs.

2.4 The Anchor Pile Driver Design

Due to the geology makeup of hard andesite off Taiwan's east coast, screw-type anchors are recommended to secure the Kuroshio power plant. Initial estimates show a 0.5 m diameter steel screw anchor embedded 5 m into the rock would withstand a force several times that it needs to stably hold the platform (see Sect. 4.3.1 for analysis). In addition, to adapt to the rugged seabed geomorphology and reduce the cost of the anchor engineering for hundreds of buried anchor points, we have designed an unmanned deep sea anchor installation device, referred to as the Anchor Deployment Machine (ADM). The ADM allows for the remote installation of anchors through a simple and quick procedure with little environmental damage and well suited to the installation of a large number of anchors.

As shown in Fig. 2.5, the body of the ADM consists of three main parts: the housing, the anchor carrying plate (in the center), and the pressurized gear set (on the right). The housing supports the other two parts and is hold by a cable to connect to the surface barge, while using another cable to transmit power and signal between ADM and the surface barge.

Figure 2.5 also shows a sequence of nine images illustrating the anchor installation process. Once the housing is stably positioned on the seabed (Fig. 2.5a, b), the burial engineering at the heart of the ADM design uses the anchor carrying plate and the pressure gear set to individually install each screw anchor. The gear set engages the anchor and the motor drives the anchor's rotation under pressure to screw the anchor into the seabed (Fig. 2.5c–f). Once the anchor is completely buried, the ADM moves to another anchor point and repeats the process until all anchors are installed. It is then raised to the surface to be loaded with another set of anchors (Fig. 2.5g–i). The operation of the ADM is remote controlled by technicians on the barge.

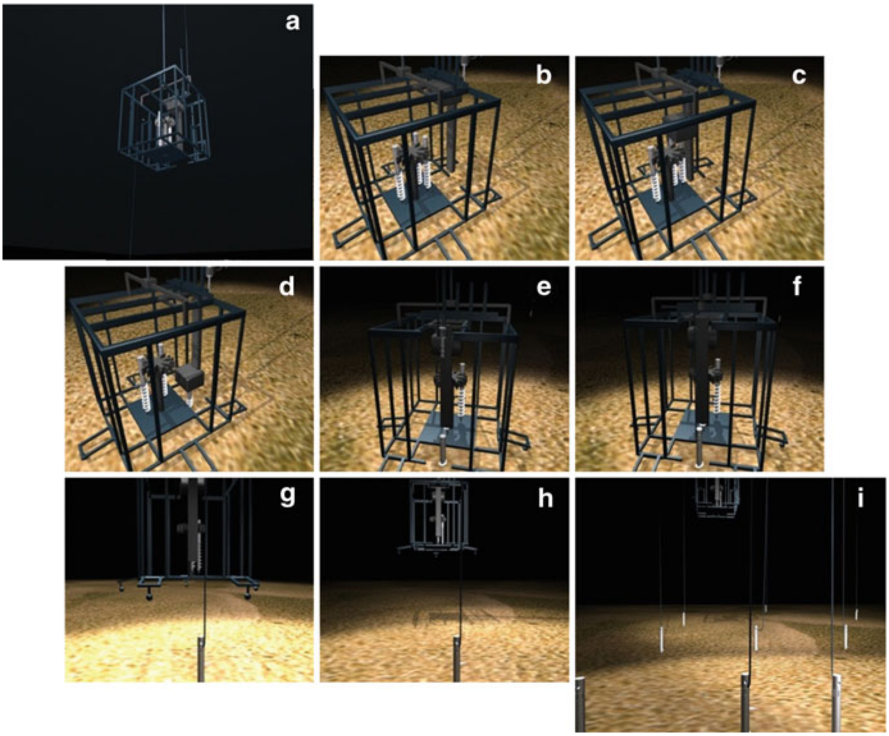


Fig. 2.5 Schematic of ADM construction procedure. (**a**) ADM hanging from the operations platform into water. (**b**) When ADM reaches the seabed, four legs extend to support the device. (**c**) The gear set on the right moves to the left to combine with the anchor set. (**d**) The gear set with the anchor moves laterally to the right to a position rotatable with pressure, where the anchor is screwed into a seabed. (**e**) Connecting the cable to the top of the anchor. (**f**) The gear set is removed after the cable is connected. (**g**) The ADM is removed, leaving the anchor and cable. (**h**) The ADM is moved to the next anchor position and repeats the aforementioned process. (**i**) With eight anchors installed, the ninth anchor is being fixed.

In brief, the ADM has three special features:

1. The body is capable of simultaneously carrying multiple anchors and cables, allowing it to complete multiple anchor installations without surfacing.
2. When the system approaches the seabed, landing brackets around open out, each supported by spherical contact points, thus allowing it to cope with uneven seabed conditions.
3. How anchors connect cables are specially designed: The end of the cable is fitted to a key-shaped retainer ring on shore. Once the anchor is secured to the seabed, the retainer ring is fixed to the anchor.

2.5 Site Selection for the Power Plant

The site selection of Kuroshio power plant is crucial. Location conditions for deep sea Kuroshio power plants are different from those for shallow water ones. Existing marine and geological data shall be used to evaluate the quality of the proposed location, wherein the type of plant—commercial or pilot—shall also be taken into account.

For a commercial power plant, there are five conditions to be considered (1) the current is strong and stable, (2) the depth of seabed shall not be large, (3) the seabed geology shall be stable and of high strength, (4) the location shall be close to coast, (5) turbine deployment shall not influence the robustness of the Kuroshio.

For a pilot plant, a sea area with various geological and marine features should be selected, so that several test units can be deployed in areas of different features, in order to carry out tests for different functions of the power plant at the same time. However, criteria for the two types of plants are not necessarily exclusive.

Figure 2.6 shows the average energy density of Taiwan's Kuroshio current at a depth of 50 m in summer 2003, which shows the Kuroshio flowing strongly northward from the Philippines to Taiwan's east coast, producing a high level of energy density as it passes Lan-Yu and Lu-Dao.

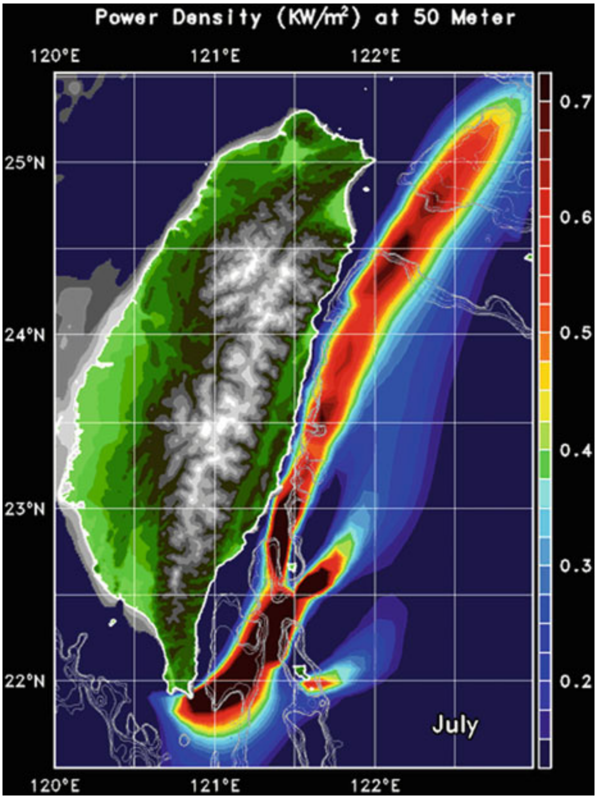
As the current passes the seas off Hua-Lien, it slows down a little bit, but then picks up again as it turns northeast towards Okinawa. An overall assessment of the current strength indicates three sites worth considering:

1. The sea between Lan-Yu and Lu-Dao: As the Kuroshio flows north from the Philippines, the current is fast and stable, but the far offshore location and deep seabed entails higher construction costs and more difficult maintenance.
2. The sea between Lu-Dao and Taiwan: As the Kuroshio passes between Lu-Dao and Taiwan, both the width and the depth of the current diminish. Squeezed by land and lifted seabed, the Kuroshio current accelerates, resulting in a strong and stable flow. Besides, the "proximity to land" and "the shallow seabed" characteristics make construction and maintenance easy, hence lowering cost. However, the forces that keep the Geostrophic Current in balance are likely to be influenced by Lu-Dao, making it difficult for the Kuroshio current to restore the kinetic energy lost. In addition, the deployment density of turbines should not be over-high to prevent a possible turn-away of the Kuroshio towards the east of Lu-Dao.
3. The sea between Hua-Lien and Yi-Lan: Here, the current is strong and wide, with a clear balance among the three balance forces to maintain the strength of the geostrophic current. However, the location is far offshore with a deep seabed, and is in an area where the current is often weakened by northeast winds.

Based on the discussion above, the optimal layouts of the site selection are prioritized as follows:

1. The sea between Lu-Dao and Taiwan
2. The sea between Lan-Yu and Lu-Dao
3. The sea off the east coast of Hua-Lien and Yi-Lan

Fig. 2.6 Average energy density of the Kuroshio in July 2003 at a depth of 50 m. The highest (*darkest*) energy density is found in three areas: between Lan-Yu and Lu-Dao, between Lu-Dao and Taiwan, and between Hua-Lien and Yi-Lan (courtesy of Professor Shenn-Yu Chao [Exploring Kuroshio's energetic cores with an ocean nowcast/forecast system. Private communication, University of Maryland, 2008])



The seabed in these three areas is largely formed of hard igneous rock, covered by a layer of sediment of varying thickness. The seabed topography near Lu-Dao and Lan-Yu changes more drastically. To their west the seabed becomes shallower as getting closer to Taiwan, making it be suitable for the Kuroshio power plant. To their right the depth of seabed drops to 3,000 m, making it more difficult to construct the Kuroshio power plant. The seabed of the third candidate, the sea near Hua-Lien and Yi-Lan, often falls below 1,000 m, leading to difficult installation and high costs. In terms of seabed conditions, the said order of priority can be justified.

The Kuroshio at Taiwan is wide and broad; harnessing the Kuroshio power in such a wide area requires a systematic assessment, whereby an overall strategy for long-term stability shall be formulated. Four key points for this purpose are as follows:

- A detailed investigation of the economic value and technical feasibility of plant development within the Kuroshio waters, including the current's fluid dynamical characteristics, seabed engineering characteristics, and sea (and seabed) ecological and environmental characteristics.

- Estimation of the installation and generation capacity of the potential sites.
- Estimation of the development costs and cost of electricity for the proposed sites and the lease value for each site as well.
- Development priorities of potential sites based on the above-mentioned characteristics for each site.

2.6 The Design Features of the KPP

This chapter presents a novel and unprecedented design for a Kuroshio power plant: a group of 39 GSTs, each having an installation power of 0.5 MW, is anchored on a $770 \times 420\ m^2$ relay platform, which is a flexible marine structure stably anchored by hundreds of vertical and inclined cables to the seabed hundreds of meters below.

Conceptually speaking, the relay platform serves as an artificial seabed on which tens of turbines can be anchored safely and stably in the deep ocean. In engineering terms, it can help eliminate the high frequency forces caused by the interaction among the Kuroshio, the turbines, and the platform, providing the power plant structure with significant advantages in combating fatigue and failure.

Overall, the current design offers the following advantages:

1. Anchoring the turbine to the relay platform by a single cable of a length less than 50 m can significantly reduce the lateral drift of the turbine.
2. The relay platform is anchored to the seabed by hundreds of cables. As a result, the position where the cable is anchored is not required to be preciously accurate comparing with the predetermined one. Moreover, this design also offers significant flexibility in several parameters including anchor type, number of anchors, and angle of cable extension.
3. Taiwan's east coast experiences frequent earthquakes and undersea landslides which could easily loosen the anchors. To cope with this potential situation, the design calls for hundreds of cables, providing sufficient redundancy that allows some unexpected anchoring damages, enhancing the safety and reliability of the power plant.
4. The flexible relay platform structure, combined with the features of using a single cable to anchor each turbine, allows the overall power plant structure to effectively eliminate the high-frequency forces caused by the impact of the current, significantly reducing the likelihood of component fatigue and damage.
5. The design of the relay platform ensures the accurate positioning of the turbines in deep water, increasing the reliability of the power plant engineering. It also eliminates the need of anchoring the turbine directly in the seabed, which reduces overall costs for construction, operations, and maintenance, and increases the power plant's life span as well.
6. The turbines and platform feature simple mechanical and structural designs by making use of mature technologies. The anchoring system for the relay platform is simple and does not require a high degree of positioning accuracy on the

seabed. The single-cable anchoring for turbines offers accurate positioning and simple engineering of turbine deployment. These factors all result in a significant reduction in costs for construction, operations, and maintenance.

7. Although each sub-construction employs mature technologies, these are combined into new products and a brand new design. This is a new form of marine engineering, represents a significant change in human energy development and marine engineering technology, and should have an inspiring and enlightening influence.

However, there are also some drawbacks:

1. It is a novel and unprecedented design, leaving much to be explored and higher R&D costs.
2. The flexible structure reduces turbine efficiency; the degree of reduction needs a reassessment.
3. The construction is complex, including setting the anchors in the seabed, erecting the cables, installing the platform, anchoring the turbines, testing and starting the power plant, and so on. This entails many procedures, each of which requires careful planning and design.
4. Many construction procedures are unprecedented; the construction equipment and rigging may require a new design.
5. Finally, the novelty of the engineering design and the nature of deep sea engineering entail high costs and considerable risk. In early development stages, one needs to proceed cautiously, wherein each likely problem should be investigated and solved step by step. The turbines should not be installed underwater until all engineering procedures are well designed and clarified.

Recently, the engineering design for the harness of ocean power has been ascendant [25], but that for deep ocean is indeed rarely seen. There are three cases that can be representative: the case for the Gulf Stream at east Florida, the case for the Agulhas Current at southeast Africa, and the case for the Kuroshio at south Japan. All cases had created new designs for the power plant in deep ocean. For the Gulf Stream [7, 8, 26], they design a twin-rotor turbine to be anchored directly onto the seabed. For the Agulhas Current, Wright et al. [27] studied the feasibility of employing the SeaGen developed by MCT company of Scotland. For the Kuroshio [28], the Industrial Technology Development Organization (or NEDO) has proposed to build a 850 MW Kuroshio power plant in the Kuroshio waters at south Shikoku and the Kii Peninsula. The power plant is composed of hundreds of turbines; each turbine has two counter-rotating rotors of 40 m in diameter and is anchored to the seabed at 100 m deep by a single cable.

Similar to the present KPP design, because of the deep water, all cases use flexible cables to anchor turbines in the ocean. The major difference stems from that they did not consider a design like the relay platform to create an artificial seabed closer to the surface. Accordingly, it is implied that the length of anchoring cable of the turbine of these three cases shall be much longer than the present one, so will the drift of the turbine be of a larger amplitude, causing great difficulties for power plant operation and maintenance.

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