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Master Program
on Bio-Based Circular Economy

Course of Renewable Energy Technologies

Renewable Energy Driven Desalination in China

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Content

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1 Background

Water resources are the life source of a country's development. Without adequate water resources to support, agriculture, industry, survival, development will be severely restricted. As we all know, China's water resource reserves are relatively rich in general. But these water resources need to support more than 1.3 billion people, the number after per capita is insufficient. China's total water resources rank sixth in the world, but the per capita share is less than one quarter of the world average.

Table 1 shows the total water resources from 2013 to 2017 and the per capita water resources in 2016 and 2017 in china. It can be seen that the total amount of water resources in China has basically stabilized at 2800 billion cubic meters in the past five years. Due to the progress of science and technology and the increasing awareness of water resources protection, there is even a small increase in the total amount of water resources in some years, but on the whole, it still shows a decreasing trend. However, the per capita water resources are relatively scarce.

Table1 Statistical tables of total water resources and per capita water resources

Time	Total water resources (Unit:100 million cubic meters)	Per capita share of water resources (Unit:100 million cubic meters)
2013	27860	
2014	28370	
2015	28306	
2016	30150	2354.9
2017	28761.2	2074.5

From the perspective of the spatial distribution of water resources, the regional distribution of water resources in China is obviously different. Generally speaking, there are more in the South and less in the north, more in the West and less in the East. From figure 1 and figure 2, it can be seen that the water resources of our country are mainly concentrated in the southwest region, especially in Tibet, Sichuan, Guangxi and Yunnan provinces, and it can be said that the Yungui Plateau is a rich area of water resources in China [1]. In terms of the time distribution of water resources, the seasonal variation of water resources in China is very large, mainly concentrated in the summer and autumn seasons, and even in the area south of the Yangtze River. But the spring and winter season rain is less, the north area often has the drought situation to appear.

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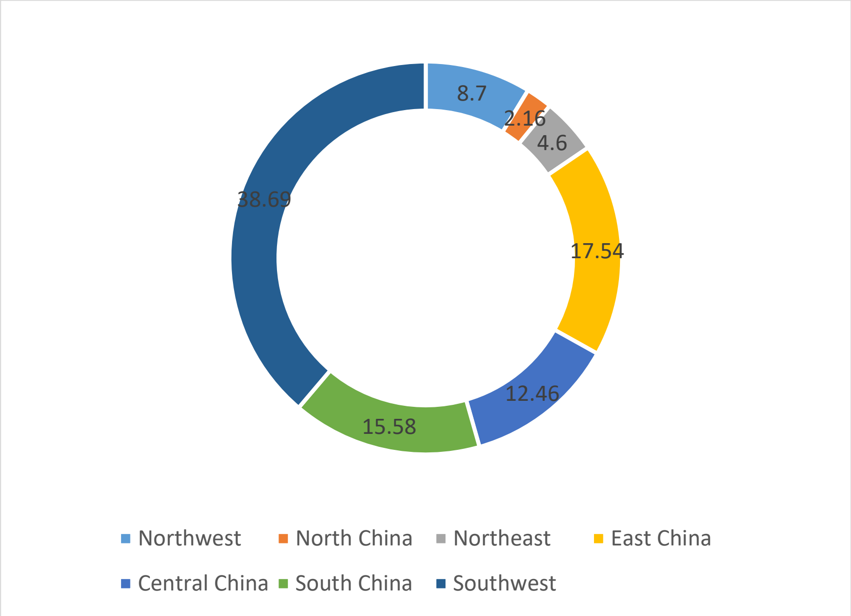

Figure 1. Distribution pattern of water resources in China in 2017

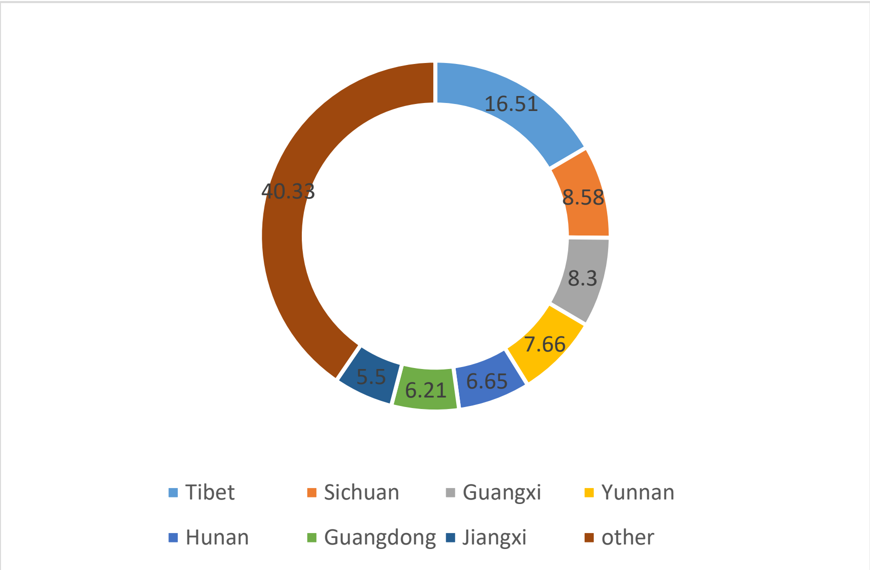

Figure 2. Analysis on the concentration of water resources in China's provinces and cities in 2017

Water resources are indispensable to economic development, which is more and more important to economic growth. The research shows that by 2030 the low demand for water resources in social and economic development will reach 710 billion cubic meters, with an increase of 140 billion cubic meters on the basis of the current water supply capacity. According to expert analysis, after deducting the necessary water demand for ecological environment, the actual amount of water resources that may be used in China is about 800-900 billion cubic meters, and the above estimated water consumption is close to the upper limit of reasonable water utilization. There is little potential for further development of water resources. National flood control security, ecological security, food security, as well as the improvement of people's living standards and sustainable economic and social development put forward higher requirements for water resources security. So the sustainable

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development of water resources is very important for us. As an incremental technology of fresh water resources, seawater desalination technology has been more and more applied, which has effectively alleviated the water dilemma in coastal areas, especially islands.

2 Desalination technology

Desalination is the process by which dissolved minerals, salts, organic matter, bacteria and viruses, as well as solids, are to obtain fresh water. From the point of view of energy conversion, seawater desalination is the process of converting other energy sources (such as heat energy, mechanical energy, electric energy, etc.) into brine separation energy. There are more than 20 kinds of seawater desalination technology. According to the difference of brine separation process, when there are new substances generated in brine separation process, the desalination method belongs to chemical method, otherwise it belongs to physical method. In physical methods, thermal energy is used as the driving force, and phase transitions are classified as thermal methods during brine separation, mainly including multistage flash, multi-effect distillation, steam distillation, freezing, and humidification and dehumidification. brine separation using membranes (semi-permeable membranes or ion exchange membranes, etc.) and not involving phase transitions are classified as membrane methods, mainly including reverse osmosis and electrodialysis. in addition, solvent extraction is included in physical methods. The chemical methods mainly include hydrate method and ion exchange method. Next, I will introduce traditional desalination technology and desalination technology based on renewable energy.

2.1 Traditional desalination technology and its characteristics

The traditional seawater desalination technology was put forward relatively early. After years of development, the commercial application is more mature. This section will introduce traditional desalination technologies such as multi-effect distillation, multi-stage flash evaporation and reverse osmosis.

2.1.1 Multi-effect distillation

The origin of multi-effect distillation (MED) can be traced back to 1830s. In the early stage, Med was always restricted by the easy scaling (scaling) on the heat exchange surface. Until the 1960s, the development of low temperature multi-effect (LT-MED) distillation technology made the scaling and corrosion problems relieved. In LT-MED system, the horizontal tube falling film evaporator can eliminate the static pressure on the evaporation surface, thus increasing the total heat transfer coefficient. The operation at low temperature (the maximum salt water temperature (TBT) is 65~70℃) can also limit the formation of scale on the tube wall. At present, the horizontal tube falling film evaporator has become the industry standard.

MED system is made up of multiple evaporation containers in series. The number of evaporation containers is called effect. The name of multi-effect distillation comes from it. The MED process flow can be divided into reverse feed, forward feed and parallel feed according to the difference of feed seawater and steam flow direction. The Med system widely used in desalination industry is of advection structure.

The main characteristics of LT-MED technology are as follows[2]: (1) the lower the seawater temperature is, the less corrosive it is to the metal materials, and the higher the solubility of inorganic salt which causes scale formation, so the lower TBT in LT-MED system can slow down the corrosion and scale formation; (2) the seawater pretreatment process is simple, which only needs simple

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screening and adding scale inhibitor; (3) the system has great flexibility in operation, It can operate in the range of 40%~110% of the designed water yield rating; (4) unlike multi-stage flash evaporation, MED does not need a large amount of seawater to circulate in the system, so the power consumption required for transporting seawater is small; (5) there is phase change heat transfer on both sides of the heat exchange tube, and the number of heat transfer systems is high; (6) the steam pressure in the heat exchange tube is greater than the pressure outside the tube, when the heat exchange tube is corroded and perforated, It can only cause a small amount of steam leakage to the outside of the pipe without affecting the quality of product water, so the operation of MED system is safe and reliable; (7) the quality of product water is high, TDS is usually lower than 20 mg/L, and it can be lower than 5 mg/L in special application; (8) because the heat transfer coefficient of phase change increases with the increase of temperature, the lower TBT can slow down corrosion and scaling, However, it also limits the improvement of thermal efficiency; (9) due to the evaporation of seawater on the outer wall of the heat exchange tube, even if the scaling is slowed down, there are still calcium inorganic salts precipitated on the outer wall of the tube, which leads to the formation of scale. It is necessary to clean the outer wall of the heat exchange tube regularly to remove the scale, so as to maintain the efficient and stable operation of the system.

2.1.2 Multi-stage flash

In order to overcome the serious scaling problem in the early Med system, the multi-stage flash (MSF) method was proposed and developed in the 1950s. Because MSF has the advantages of small scaling tendency, it has been developed rapidly since it was proposed and become the most mature and widely used large-scale industrial desalination technology. The technology was first introduced into China in 1989 and successfully applied to the second stage desalination project of Tianjin Dagang Power Plant. The whole set of multi-stage flash units are imported from the United States. So far, it is the only desalination project adopting multi-stage flash technology in China.

Process flow [3]: the sea water is first pretreated by clarification and chlorination, then it is preheated by steam to the steam heater, heated to 90℃~115℃, and then sent to the first flash room. At the same time, the pressure in the flash room is controlled to be lower than the saturated vapor pressure of the sea water, and some of the sea water quickly forms vapor. After the vapor is removed by the demister, it condenses on the surface of the condensation tube bundle, and after collection, it can be diluted water: the temperature of the rest seawater without gasification decreases, flows into the next flash chamber to continue flashing, and repeats the process of evaporation and condensation. A series of flash chambers with gradually reduced pressure are connected in series to continuously produce fresh water. The process flow chart is shown in Figure 3.

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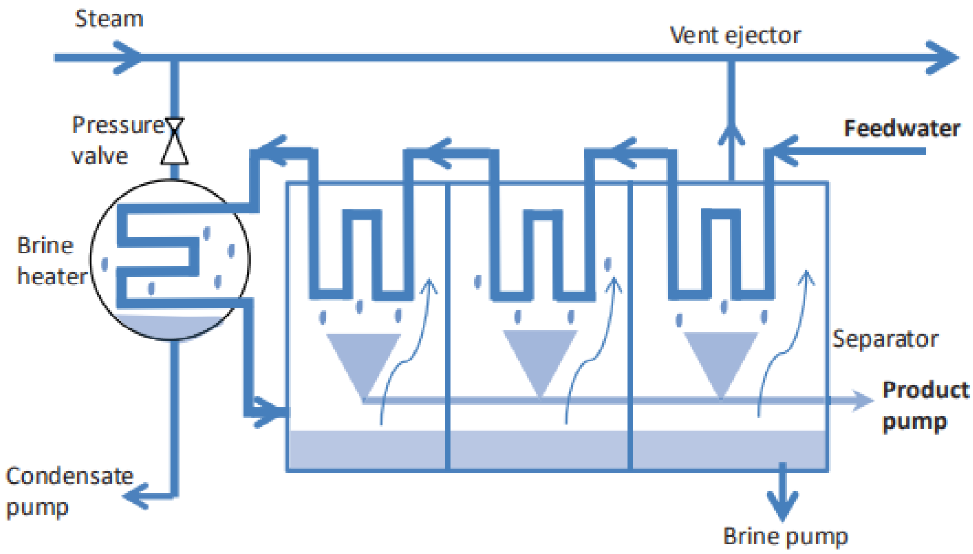

Figure 3. MSF technical process flow chart

The main advantages are large single unit capacity, good effluent quality (the product water salinity is generally 3-10mg/L), long service life, high water production ratio (the water production ratio of the unit with a scale of 40000-50000m^3/T is 13-14), high thermal efficiency, etc. The disadvantage is that the operating temperature is mostly 110℃~120℃, the equipment and materials are mostly stainless steel and copper nickel alloy with good corrosion resistance, which has high engineering investment, generally 2 times of that of reverse osmosis technology. In addition, the operation flexibility of the equipment is relatively small, generally 80%-110% of the design value, so it is not suitable for projects with large changes in water production.

Scope of application: the multi-stage flash technology generally uses the low-level steam of the power plant as the heat source to reduce the operation cost. It is mostly used in large-scale desalination projects, providing high-quality fresh water for coal-fired boilers, and also can be used for domestic water.

2.1.3 Reverse osmosis

Reverse osmosis (RO) originated in the 1950s, and began to be used in business in the 1970s. Because of its low energy consumption, it has been developed rapidly. At present, its installed capacity plays a leading role in the global total installed capacity of desalination, and it has become the most successful desalination technology.

Reverse osmosis (RO) technology is to apply pressure greater than the osmotic pressure to the water on one side of the reverse osmosis membrane. Water molecules continuously pass through the reverse osmosis membrane by using the selective permeability of the reverse osmosis membrane. After being collected on the outlet side of the reverse osmosis membrane, they finally flow out at the outlet end, while the impurities in the inlet water are trapped on the inlet side of the reverse osmosis membrane, and then flow out at the outlet end of the concentrated water. Figure 4 shows the schematic diagram of RO process flow [4].

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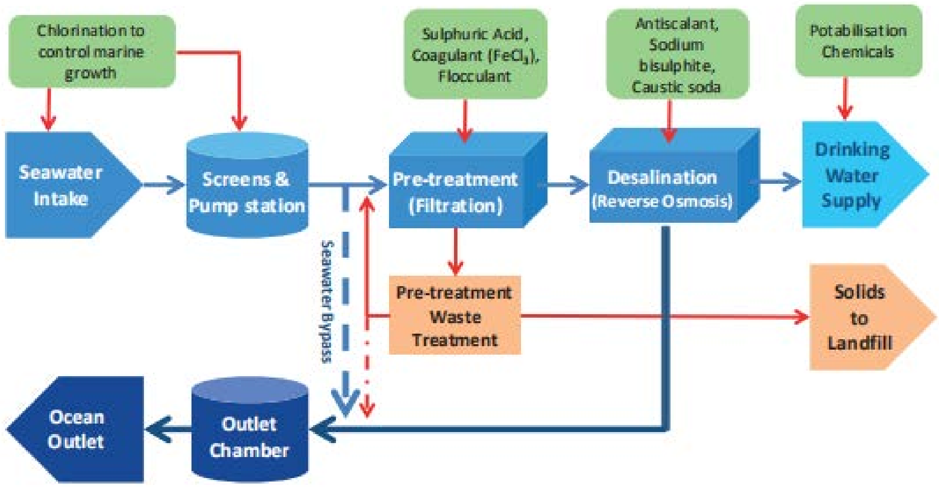

Figure 4. RO Desalination Process

Compared with multi-stage flash distillation and low-temperature multi effect distillation, reverse osmosis technology does not need to consume steam, and has the advantages of high efficiency, low energy consumption, compact and beautiful equipment, easy automatic control, etc. At present, most of the equipment of the technology system has been localized, but the technology of high-pressure pump, energy recovery device and some membrane components is still in the exploratory stage, and the equipment needs to be imported. The disadvantage is that the membrane flux is more sensitive to temperature, especially in winter when the water temperature is low, the membrane flux will drop significantly.

2.1.4 Vapor compression

Vapor compression (VC) is similar to LT-MED. The difference is that VC combines with heat pump to drive brine separation process by compressing steam.

The main features of VC technology are as follows: (1) compared with MED and MSF, VC system only needs to provide power source, no additional external steam heat source, and no cooling water; (2) Seawater Pretreatment process is simple and insensitive to seawater pollution; (3) the structure is simple and compact, easy to modular structure, which can be designed into portable devices such as shipboard and vehicle; (4) The whole system constitutes a closed cycle, and the latent heat of steam is recycled in the system, with high energy utilization rate and good economy; (5) the fresh water quality of the product is high, with TDS lower than 10 mg / L; (6) the evaporation of sea water on the outer wall of the heat exchange tube bundle is easy to cause the corrosion of the tube wall and the formation of scale.

2.1.5 Other methods

In addition to the above four technologies, the traditional desalination technologies include electrodialysis (ED), freezing, hydrate, solvent extraction, ion exchange and humidification and dehumidification. Due to their different characteristics, these methods have not been widely used in commercial desalination, It is more widely used in the pretreatment and post-treatment process of desalination, the occasion with less demand for fresh water resources or other industrial occasions.

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2.2 Desalination technology based on renewable energy

In order to avoid the difficulties brought by the exhaustion of traditional energy, all countries are actively developing new renewable energy, such as solar energy, wind energy, marine energy, etc., some renewable energy utilization technologies have made technological breakthroughs, and formed a certain scale of renewable energy industry around the world, in addition to the continuous development and maturity of desalination technology. It is possible to combine desalination with renewable energy utilization, which can ensure sustainable desalination production in an environmentally friendly way. At present, more and more new energy combined with desalination technology, which is developing rapidly, are researched and applied, mainly including solar energy, wind energy, marine energy, etc. Most common renewable options are shown in Table 2.

Table 2 Possible combinations of renewable energy and desalination technologies

Thermal Technologies	Membrane Technologies				
	MSF	MED	VC	RO	ED
Renewable Technologies	●	●	●	●	●
Solar thermal			●	●	●
Solar PV			●	●	●
Wind	●	●	●	●	●
Geothermal	●	●	●	●	●

2.2.1 Solar desalination technology

After several centuries of development, solar desalination has occupied 1/4 of the market in the field of desalination. There are many researches on solar desalination at home and abroad. The solar energy utilization efficiency has developed from less than 10% at the beginning to nearly 50% at present, and the water production efficiency has also been greatly improved. At present, solar desalination technology can be divided into thermal solar desalination technology, membrane solar desalination technology and photovoltaic desalination technology [5].

Thermal desalination solar energy (TD-SE) is a kind of desalination technology that uses solar energy to generate heat driven phase change process of seawater. At present, the research of solar thermal desalination system at home and abroad focuses on the improvement of solar collector and the corresponding desalination device. In 2002, Peking University and huaruineng Technology Co., Ltd. jointly developed a solar desalination prototype, which also made a beneficial exploration on the operation of solar desalination. The College of logistics engineering and Beijing University of science and technology put forward "horizontal tube falling film evaporation multi effect regenerative solar desalination system" and "multi-stage enhanced condensation solar desalination device", trial produced a series of principle prototypes, carried out experimental test and theoretical research on the prototypes, and established the actual operation system in the Island and coastal areas.

The membrane solar desalination technology (RO-SE) mainly refers to the reverse osmosis (RO) desalination technology combined with solar energy technology. Because of its low energy consumption per unit area, it is paid more and more attention. It is another direction of the

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development of solar desalination. Seawater is sent into RO system under high pressure, and desalination is carried out by selective permeability of membrane.

Photovoltaic (PV) technology (ETSAP E11) can be connected directly to RO or ED desalination processes, which are based on electricity as the input energy (Figure 5). Many small PV-based desalination systems have been demonstrated throughout the world, especially in remote areas and islands, including Gran Canaria, Canary Islands (PV-RO, seawater, 1-5 m^3/d), Riyadh, Saudi Arabia (PV-RO, brackish water, 5 m^3/d), and Ohshima Island, Japan (PV-ED, seawater, 10 m^3/d) (Kalogirou, 2005). The main issue of PV desalination is the (still) high cost of PV cells and batteries for electricity storage. Careful maintenance and operation of battery systems are also necessary. Further technology advances in electricity storage (ETSAP E18) associated to PV could lead to wider use of PV desalination.

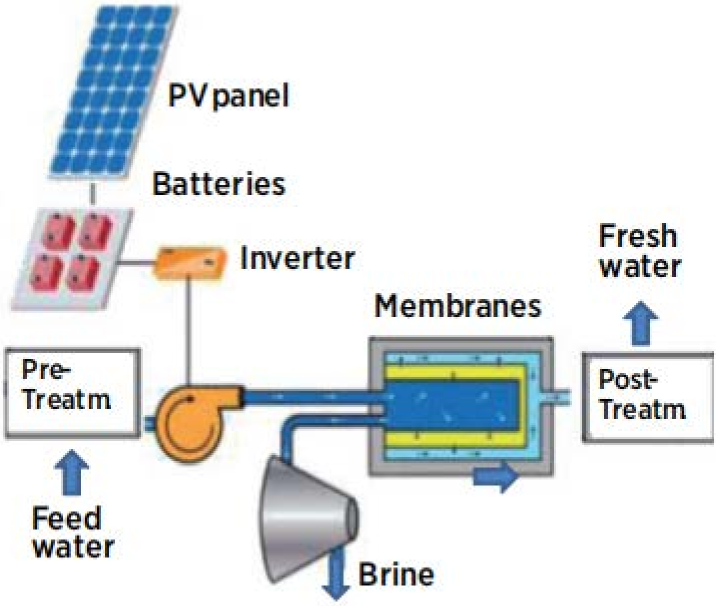

Figure 5 Coupled PV and RO desalination plants

2.2.2 Wind energy desalination technology

As a kind of renewable and clean energy, wind energy is favored by all countries in the world, and it is recognized as one of the main new energy sources to replace the traditional fossil fuel in the future. Wind energy is mainly used to drive windmills to generate electricity. The application of wind energy in desalination engineering has achieved substantial research results. With the continuous progress of wind energy utilization technology and desalination technology, wind power desalination industry is booming. There are two main ways to use wind energy for thermal desalination: (1) coupling type: directly using the mechanical energy from wind turbine for desalination. (2) Separate type: use wind turbine to convert wind energy into electric energy first, and then use electric energy to desalinate sea water. The coupling method avoids the conversion process of "mechanical energy electric energy mechanical energy", improves the efficiency of energy utilization, and simplifies the system structure, but there are still problems such as wind fluctuation affecting the stability of the compressor, so it is rarely used. In most cases, the separation method is used for desalination.

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At present, the technical bottleneck of the development of wind energy desalination is the influence of wind energy fluctuation and intermittence on desalination. How to realize the direct drive of wind energy desalination device is the main research direction of researchers at home and abroad. China's coastal areas are rich in wind energy resources, and there are many planned and under construction projects of beach wind power generation and offshore wind power generation. If we can break through the technical bottleneck of intermittent and fluctuating wind power on desalination, its market development prospect is huge.

2.2.3 Solar wind coupling desalination technology

There are two main ways of coupling wind and solar energy for desalination: (1) wind and solar power supply power. Its main characteristics are: to make up for the shortcomings of independent wind power generation and solar photovoltaic power generation system, to provide more stable power to the grid; to make full use of space, to achieve the reasonable use of the ground and the high altitude.(2) Wind power is used for power generation, and solar collector system is used for heat source. On the one hand, it directly uses the solar energy to collect heat, which saves the conversion process of "solar energy electric energy thermal energy" and improves the efficiency of energy utilization; on the other hand, it transforms the wind energy into the stable storage of electric energy, reducing the impact of wind fluctuation on the system dynamics.

2.2.4 Ocean energy desalination technology

The application of ocean energy in seawater desalination has a very broad application prospect. The theoretical reserves of all kinds of ocean energy (natural inherent power) in the world are the largest in terms of temperature difference energy and salt difference energy, which are 10 billion kilowatts. Wave energy and tide energy are in the middle, which are 1 billion kilowatts, and current energy is the smallest, which is 100 million kilowatts. The main ocean energy used in sea water purification technology is wave energy and hydrostatic pressure.

Wave energy desalination refers to the kinetic energy and potential energy of ocean surface waves. Wave energy desalination system has three parts: energy absorption device, energy conversion device and desalination device. Up to now, the wave energy conversion devices that can be used in wave energy desalination mainly include oscillating float type, nodding duck type, oscillating water column type, water wave pump type and water hammer pump type.

In the research of wave energy desalination, there are many researches on the coupling performance of wave energy conversion device and desalination, but few further detailed researches. In addition, there are few researches on the theoretical basis and numerical simulation of wave energy desalination. Up to now, there is no wave energy desalination device with good operation effect and low water production cost, which is one of the reasons why wave energy desalination cannot be commercialized. No matter from the total energy or energy density of wave energy, wave energy desalination is worth studying and popularizing. Wave energy desalination is still a hot spot in the future.

Hydrostatic pressure is a relatively new marine energy. Hydrostatic pressure is mainly used in reverse osmosis desalination. The energy consumption of water production in this way of reverse osmosis desalination is lower than that in common reverse osmosis desalination, and renewable energy is used, which has a good research and application prospect. Because of the high water pressure requirement of RO desalination. Therefore, in order to achieve the required pressure of RO, it is usually 5.5-8.0Mpa, and the water depth used for hydrostatic desalination shall be more than

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500m. At present, the main hydrostatic reverse osmosis desalination methods include artificial well type, deep sea type and high mountain type.

Compared with conventional reverse osmosis desalination, hydrostatic desalination does not need high-pressure pump. For conventional reverse osmosis desalination, the operating cost of high-pressure pump accounts for 35% of the total operating cost of the system, which is one of the main factors affecting the product water cost. Therefore, the energy consumption of water desalination by hydrostatic reverse osmosis is lower than that by conventional reverse osmosis. In addition, most of the energy used by high-pressure pumps at present comes from fossil fuels, so hydrostatic desalination can also reduce carbon emissions. The only disadvantage of hydrostatic desalination is that it is more difficult to construct and maintain it than conventional RO desalination.

2.2.5 Geothermal Desalination

As geothermal energy can produce electricity and heat, it can be combined with both thermal and membrane desalination technologies. Low-temperature geothermal energy, typically in the range of 70–90°C, is ideal for MED desalination. A project on Milos Island, Greece, has proposed a geothermal desalination system to produce 1,920 m^3/d of water. The plant consists of a dual system with hot water from geothermal wells being employed to run either an organic Rankine cycle (ORC) with a 470-kWe turbine for electricity generation or a MED desalination unit. The system can benefi t the local community by producing desalinated water at a very low cost, i.e. USD 2/m^3(Constantine, 2004). However, the exploitation of geothermal energy very much depends on the specific local conditions, with upfront investment costs that are usually high.

Desalination with renewable energy is one of the main research and application directions of new energy and new water sources, and also one of the fundamental measures to solve the shortage of water resources in the 21st century. With the development of renewable energy technologies such as solar energy, wind energy and tidal energy, the utilization of renewable energy can be combined with almost all desalination systems. At present, the utilization of renewable energy in desalination is mainly limited by natural conditions, can not operate all day, and the initial investment is large. The research on efficient and practical desalination system using renewable energy has been a hot topic at home and abroad. In view of the development and demand of desalination technology and renewable energy utilization technology, it is necessary to carry out in-depth research on the basic theory of solar desalination, new materials and technologies for desalination, medium and high temperature solar energy heat collection and storage technology, renewable energy power generation technology, etc.

3 The present status

3.1 Desalination status

China's desalination began in the late 1950s, coastal cities and island areas actively carried out desalination projects. According to the *2018 national Seawater Utilization Report* [6] issued by the State Oceanic Administration, 142 desalination projects had been completed in China by the end of 2018. In recent years, the annual growth rate of desalination in China is more than 8%. The growth of capacity scale mainly comes from large-scale projects with a capacity of over 10000 tons. There are 36 large-scale desalination projects in China, with a project scale of 1059600 t/d, accounting for 89.11% of the total scale of desalination in China. China's desalination projects are mostly carried out in coastal provinces and cities, such as Liaoning, Tianjin, Hebei, Shandong, Jiangsu, Zhejiang,

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Fujian, Guangdong and Hainan, and the desalinated seawater is mainly used for Industry and life. Among them, most of the northern cities use desalinated water for industrial purposes, concentrated in high water consumption industries such as iron and steel, power, chemical industry, etc; while for the southern coastal cities and islands with serious water shortage, desalinated water is mainly used as a supplement for domestic water, with the water production scale mainly of 100 tons and 1000 tons, currently mainly distributed in Zhejiang, Guangdong and other places. At the end of 2017, 33.11% of China's desalinated water was used as drinking water, an increase of nearly 4% compared with 2013, and the proportion increased year by year. 66.56% of desalinated water was used in industry, and a small part of it was used for greening and other water. Seawater desalination projects in Tianjin, Zhoushan and Qingdao have entered the municipal pipe network to provide domestic water for residents after "point-to-point" water supply or mixing with conventional water sources in proportion.

In terms of the application of desalination technology, there are 121 projects nationwide applying reverse osmosis (RO) technology, with a project scale of 825641 t/d, accounting for 68.70% of the total project scale; there are 16 projects applying low temperature multi effect (MED) technology, with a project scale of 369150 t/d, accounting for 30.72% of the total project scale; there is one project applying multi-stage flash evaporation (MSF) technology, with a project scale of 6000 t/d, accounting for the total project scale 0.50% of the total; 1 project with forward osmosis (FO) technology, with a project scale of 500 t/d, accounting for 0.04% of the total project scale; 3 projects with electrodialysis (ED) technology, with a project scale of 450 t/d, accounting for 0.04% of the total project scale.

In general, from the perspective of desalination process, large-scale desalination projects are mainly based on reverse osmosis desalination technology; from the perspective of regional distribution, they are mainly distributed in Tianjin, Zhejiang, Shandong and other coastal areas; from the perspective of use, they are mainly divided into industrial water and municipal water.

As an open source incremental technology of water resources, seawater desalination has the characteristics of "no inundation, no migration, no competition for water, no climate impact". Its water supply assurance rate and water quality are not affected by geographical location, environmental status, climate conditions and social factors. It has become an important way to solve the problem of water shortage in coastal water shortage areas and islands [7]. Therefore, China vigorously develops the desalination industry, and the seawater utilization industry is developing towards the direction of large-scale engineering, environment-friendly, low energy consumption and low cost [8].

At present, the desalination project mainly solves the problem of large energy consumption through the joint production of hydropower and thermal film. Hydropower cogeneration is the combination of desalination project and power project, and the construction of power plant and desalination project together. In the process of power generation, the power plant generates a large number of electric power and latent heat rich steam, which can be used as the heat and power source of the desalination project, so as to properly solve the waste heat utilization problem and the cost problem of the desalination project of the thermal power plant, and realize the efficient utilization of resources and the maximization of economy. So the current large-scale desalination projects are all hydropower co production mode. Combined heat and membrane production is a mode of combined heat and membrane production for desalination, such as reverse osmosis, multi effect evaporation, reverse osmosis multi-stage flash evaporation. The purpose is to combine the advantages of different

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methods, improve the problem of high cost, reduce investment, and meet different water demand at the same time. Most importantly, the technology of combining desalination with solar energy, wind energy, tidal energy and other new energy is the most environmentally friendly development direction.

3.2 Current situation of typical desalination projects

3.2.1 Seawater desalination project of Shougang

The desalination project of Shougang Jingtang company is designed, manufactured, constructed and operated by the company on its own relying on its own advantages [9]. The design scale of phase I is 50000 m^3/d, including 4 sets of 12500 t/d main units, adopting low temperature multi effect (LT-MED) desalination process. Since its completion, the project has been in a state of full load and stable operation. The actual water production is 50000 m^3/d, which can produce about 18 million m^3 of fresh water every year, accounting for about 50% of the total use of fresh water in Jingtang Iron and steel plant. Shougang Jingtang company [10] delivers the concentrated salt water produced by desalination to the chemical enterprise, decalcifies and demerges the concentrated salt water, carries out chemical alkali production, and constructs a comprehensive utilization mode of concentrated salt water combining desalination and salt chemical industry, which not only solves the discharge problem of concentrated salt water, but also brings a certain economic benefit, effectively reduces the comprehensive cost of seawater desalination, and achieves a larger society benefit and environmental benefit, playing a leading role in large-scale development and application of desalination in coastal steel, petrochemical, electric power and other industries.

3.2.2 Tianjin Xinquan desalination project

Tianjin Xinquan desalination project [11] is located in the marine Petrochemical Park, Dagang District, Tianjin. The investor of the project is Tianjin Dagang Xinquan desalination limited company under Singapore Kaifa group, which is responsible for the design, construction, ownership and operation of the desalination plant. The total construction scale of the project is 150000 m^3/d, mainly to meet the needs of large petrochemical enterprises settled in Dagang and enterprises in Dagang marine park, and to alleviate the regional water shortage. Among them, the construction scale of the first phase is 100000 m^3/d, and the reverse osmosis desalination technology is adopted. The first phase of the project was put into operation on June 2009. It is mainly used for supporting water supply for the million ton ethylene refining and chemical integration project of Sinopec Tianjin Branch. Now, it is in good operation, with daily water supply of 70000-80000 m^3 and production capacity of 70%-80%.

3.2.3 Zhejiang Liuheng desalination project

Liuheng Island desalination project is the largest desalination project in Zhoushan City. It is jointly invested and constructed by East China Survey and Design Institute and local government, and operated by Liuheng water group. The total investment is 740 million yuan, the design scale is 100000 m^3/d, and the reverse osmosis desalination process is adopted. The completed scale is now 52500 m^3/d. The production desalinated water directly enters the municipal pipe network and is mixed with the reservoir water for local residents to drink. The project is operated on demand and seasonally, and the desalination water supply is adjusted at any time according to the change of water consumption. The operation of the desalination project is good at present. There are two main reasons. One is that the electricity for desalination in Zhejiang Province has been transferred from industrial power to agricultural power, which reduces the cost of desalination; the other is that the financial department

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of Zhejiang Province subsidizes the operational loss of desalination project according to the actual amount every year to ensure the cash flow of operation.

3.2.4 Qingdao Baifa desalination project

Qingdao Baifa desalination project [12] is the largest municipal desalination project in China. It is jointly invested by Spanish baifeisa company, Qingdao Soda Industry limited company and Qingdao Hairun Water Group limited company and operated by Qingdao Hairun Water Group limited company with a total investment of 109 million euros (about US $151 million), a design scale of 100000 t/d and a double membrane method Desalination technology. The production desalination water is planned to be fully connected to Qingdao municipal pipe network and incorporated into the domestic water for residents. By mixing the raw water of tap water, Baifa desalination project was put into full load operation for the first time on July 2017. Under the adverse condition that 5% of raw water supply in Qingdao depends on passenger water, the shortage of water supply in Qingdao was relieved. The project is also the first 10000 ton desalination project in China to achieve full load operation.

3.2.5 Tianjin North Xinjiang desalination project

Beijiang power plant project [13] is one of the first batch of pilot projects of circular economy in China, which adopts the circular economy mode of "power generation, desalination, salt production by concentrated seawater, land conservation and consolidation, waste recycling". The seawater desalination project of Tianjin Guotou Beijiang power plant is built with the first phase of its power generation project, with a total investment of about 2 billion yuan. The water production scale of the first phase of seawater desalination is 200000 m^3/d, which was put into operation on October 2010, adopting the low-temperature multi effect desalination process. As a key link in the power generation process system of Beijiang power plant, desalination plays a connecting role. Using the power of the power plant, a large number of low-pressure steam and seawater intake and drainage facilities are produced to produce fresh water. 10% of the desalinated water is planned to be used by the power plant for its own use, 40% is supplied to Hangu water plant, mixed with the tap water in a proportion of 1:3, and then enters into the municipal pipe network of Hangu to supply urban water, and the rest 50% is directly supplied to industrial users. At present, the desalination project is in a loss state. Although it has been incorporated into the municipal pipe network, the water supply is only 20% of the expected amount, and a large number of production capacity is idle.

3.3 development status of desalination technology

In recent years, in order to overcome and improve the shortcomings and shortcomings of traditional desalination technology, and further reduce the energy consumption of desalination, many methods have been proposed to optimize the performance of traditional methods of desalination, and different new desalination technologies have been developed. Generally speaking, the current development of desalination technology mainly starts from the following four aspects [2]: (1) improve the key technologies or equipment in the current desalination methods; (2) develop the mixed desalination methods combining different desalination technologies; (3) develop desalination methods using renewable energy or new energy; (4) develop new desalination technologies based on previously unused physical phenomena.

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4 strength and weaknesses of the studied scenarios

4.1 strength and weaknesses of typical traditional desalination technology

The most widely used technologies in desalination engineering are multi effect distillation, multi-stage flash, vapor compression, reverse osmosis and electrodialysis.

The advantages of multi effect distillation technology are: (1) the tendency of scaling is small. Because the seawater is heated in the condenser without phase change, and the flash process occurs on the surface of the brine pool at the bottom of each flash chamber, the heating and evaporation processes are carried out separately; (2) the pretreatment is simple. Generally, only adding acid and scale inhibitor to treat seawater is needed to prevent scale formation; (3) high quality product water. TDS is usually lower than 20mg/L; (4) the operation is safe and reliable, especially suitable for large-scale desalination industrial production. Disadvantages: (1) the flexibility of system operation is small. The operating range is 80%-110% of the rated water yield; (2) the operating temperature is high, so the corrosion tendency of structural materials is large, and when corrosion perforation occurs, the seawater in the condenser tube leaks out, resulting in the pollution of product water; (3) a large amount of seawater is required to circulate in the system, and the power consumption of the pump is large.

The advantages of multi-stage flash technology are: (1) the lower TBT in LT-MED system can slow down the formation of corrosion and scale. Because the lower the temperature of seawater, the lighter the corrosiveness to metal materials, and the higher the solubility of inorganic salt; (2) the pretreatment process of seawater is simple. It only needs simple screening and adding scale inhibitor; (3) the system is flexible in operation and can operate in the range of 40%-110% of the designed water production rating; (4) the power consumption required for sea water transportation is small. Unlike multi-stage flash evaporation, Med does not need a lot of seawater to circulate in the system; (5) there is phase change heat transfer on both sides of the heat exchange tube, with high heat transfer coefficient; (6) the operation of MED system is safe and reliable. Because the steam pressure in the heat exchange tube is greater than the pressure outside the tube, when the heat exchange tube is corroded and perforated, only a small amount of steam leakage to the tube will be caused without affecting the quality of product water; (7) the quality of product water is high. TDS is usually lower than 20 mg/L, and it can be lower than 5 mg/L in special applications. Disadvantages: (1) as the phase change heat transfer coefficient increases with the increase of temperature, the lower TBT can slow down the corrosion and scaling, but it also limits the improvement of thermal efficiency; (2) because the seawater evaporates on the outer wall of the heat exchange tube, Therefore, even if the scaling is slowed down, there are still calcium inorganic salts precipitated on the outer wall of the tube, which leads to the formation of scale. It is necessary to clean the outer wall of the heat exchange tube regularly to remove the scale, so as to maintain the efficient and stable operation of the system.

The advantages of vapor compression technology are: (1) Compared with MED and MSF, VC system only needs to provide power source, no need to provide additional external steam heat source, and no need to provide cooling water; (2) sea water pretreatment process is simple, insensitive to sea water pollution; (3) simple and compact structure, easy to modular structure, can be designed as shipboard, vehicle and other portable devices; (4) high energy utilization rate, good economy. Because the whole system constitutes a closed cycle, the latent heat of steam is recycled in the system; (5) the fresh water quality of the product is high, and the TDS is lower than 10 mg/L.The

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disadvantages are the pipe wall is easy to corrode and scale is easy to produce. Because the generated seawater evaporates on the outer wall of the heat exchange tube bundle.

The advantages of RO technology are: (1) there is no phase change in the process of brine separation, so the energy consumption is low; (2) the process flow is simple and the structure is compact. Disadvantages: (1) strict pretreatment of seawater is needed. Because the semi permeable membrane in RO system is very sensitive to the pH value of seawater, oxidants, organics, algae, bacteria, particles and other pollutants contained in seawater; (2) scale and dirt are easily generated on the semi permeable membrane, resulting in the desalination rate degradation and unstable water quality, so it needs to be cleaned and replaced regularly.

The advantages of electrodialysis technology are: (1) no phase change in the process of brine separation; (2) compared with the semi permeable membrane in RO, the ion exchange membrane has higher chemical and mechanical stability, and can also operate in a wider temperature range. The pretreatment process is simple and has better flexibility for different water quality; (3) high water recovery rate; (4) simple and compact structure. Disadvantages: (1) the power consumption is directly proportional to the concentration of seawater, which is generally suitable for desalination of brackish water from the perspective of energy economy; (2) only the charged ions in seawater can be removed, and the neutral organic matters, bacteria and non-ionic components cannot be treated, and the residual turbidity cannot be changed, so additional treatment is required to meet the drinking water standard; (3) ion It will gather on the surface of electrode and ion exchange membrane, which will lead to the formation of dirt over time, so it needs to be cleaned regularly.

From the above summary, it can be concluded that the raw water pretreatment process of thermal distillation based on the principle of evaporation phase change is simple, and the fresh water produced has higher quality, but the energy consumption is relatively large; while the membrane methods such as RO and ED have higher requirements for the pretreatment of raw water, and the quality of fresh water produced is lower than that of thermal distillation, but the energy consumption of RO is smaller than that of thermal distillation.

4.2 strength and weaknesses of desalination based on renewable energy

With the shortage of fresh water resources, the reduction of traditional fossil energy and the increase of cost, the desalination technology driven by renewable energy has attracted more and more attention. Especially for remote areas or small communities with insufficient water and electricity supply, renewable energy, as an environmentally friendly clean energy, has attracted more and more attention in recent years.

At present, the renewable energy used in desalination mainly includes solar energy, wind energy, geothermal energy, marine energy, etc. In addition to renewable energy, nuclear energy as a sustainable energy application in desalination is also considered to have the potential to supply a large amount of fresh water safely, economically and sustainably.

Solar desalination can be divided into direct method and indirect method. The direct system cost is relatively low and is only used for construction (i.e. solar still), but it requires a large area of land and low fresh water production. Indirect system (MED, MSF) can produce more fresh water, but has higher capital cost [14].

Advantages of wind energy: wind desalination is very suitable for areas with rich wind energy resources, such as islands; wind turbines can be connected to the grid system that provides power for

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the desalination system, or a single wind turbine can be directly connected to the desalination system. Disadvantages: due to the discontinuity and instability of wind energy, the generating power of wind turbine is not constant. These power changes will reduce the performance of desalination equipment, and may reduce the life cycle of specific components. Therefore, it is necessary to install backup power supply systems such as battery, diesel generator or flywheel, so as to use them without wind.

Advantages of geothermal energy: geothermal energy is the energy that has been produced and stored on the earth; geothermal energy is the third largest renewable resource currently used; geothermal energy can be directly used as thermal energy or converted into electric energy, which is applicable to most desalination processes (MED, MSF, RO, EDR); geothermal energy production is much more stable than other renewable energy sources such as solar energy and wind energy; geothermal energy can be directly used for steam power generation in thermal desalination plants. Disadvantages: the application of geothermal energy in desalination is still in the development stage.

Advantages of wave energy: energy can be obtained in the ocean through underwater current, wave and tide. Disadvantages: wave power generation technology is still in the research and development stage.

5 Case Study

Sansha City is located on Yongxing Island in the China South Sea. In the era when there was no seawater desalination device, the military and civilians mainly depended on groundwater and rainwater to obtain domestic water. The quality and quantity of water could not be guaranteed. With the convenience of transportation, the government transports fresh water for the people stationed on the island through ships. As shipping is greatly affected by weather and other objective factors, the government of Sansha decided to build a sea water desalination plant. The project was put into use in October 2016 [15].

5.1 Basic Information

Raw water is seawater from the China South Sea, conductivity: 45000-46000 μS/cm, water temperature: 20-35℃, pH value: 7.5-8.5, OPR: -200～-10 mV, other indexes are shown in Table1. The seawater desalination plant has a processing capacity of 1000 m^3/d. After the pretreatment of inclined tube sedimentation tank and ultrafiltration system, the raw seawater enters two-stage reverse osmosis for desalination. The first-level produced water is used for washing and bathing, and the second-level produced water is used for drinking and cooking. All produced water is supplied to the military and civilians on the island.

Table 3 Seawater indicators $mg \cdot L^{-1}$

Component	value
Sodium	11000-12000
Fluoride	10-12
Chloride	20000-22000
Calcium	390-450
Sulfate	2800-3500
Magnesium	1200-1500
Potassium	400-450
Nitrogen Nitrate	4000-4300

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5.2 Process flow

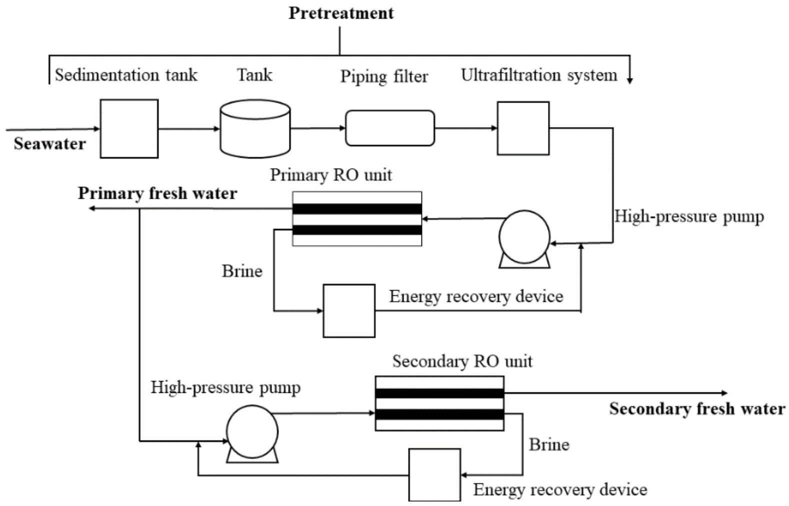

Figure 6 The process flow of seawater desalination

The process flow of seawater desalination is shown in Figure 1. The project diverts seawater from the offshore docks into the inclined tube sedimentation tank. The inclined tube sedimentation tank can reduce the turbidity of raw water. It is equipped with a flocculant and biocide dosing system. Flocculants can coagulate suspended substances such as colloids into large particles, which are removed by precipitation. The biocide can inactivate microorganisms and algae in raw water, which provides guarantee for the operation of the ultrafiltration system.

Water from the sedimentation tank enters the storage tank as a buffer before ultrafiltration. A pipeline filter is set before ultrafiltration to prevent larger mechanical particles from blocking the inlet channel of the ultrafiltration hollow fiber membrane. Otherwise it will lead to a decrease in water production and may damage the membrane element in severe cases.

Water from the pipeline filter enters the ultrafiltration system, which is used as a pretreatment process for the seawater desalination reverse osmosis system. It can remove colloids, viruses, bacteria, suspended solids and other substances in seawater, reduce the turbidity of raw water, and ensure the stability of the reverse osmosis system.

Water from the ultrafiltration system enters the two-stage reverse osmosis system, the produced water is then distributed to the water point through the transmission pipeline.

5.3 The operating effect of the project

The capacity of the seawater desalination reverse osmosis system is 3000 m^3/d, including pretreatment system, ultrafiltration membrane system, reverse osmosis desalination system. After deep treatment by membrane method, the desalination rate is >99%, the main ion removal rate is >98%.

The electricity consumption per ton of produced water is 3.7 kW·h; the electricity price of Yongxing island is \$0.2545/(kW·h); the cost of consumables such as chemical reagent and filter elements per ton is \$0.4525; the service life of reverse osmosis membrane is three years; the cost of replacing films per ton is \$ 0.07635/m^3; the labor cost is about \$0.4242/m^3; the total cost of fresh water is about \$1.8382/m^3.

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Through the application of the energy recovery device, the energy consumption of the system has been reduced by about 60% compared with the previous desalination project that does not use the device. The energy saving effect is outstanding; the cost of per ton fresh water has also been reduced by about 40%.

5.4 Improvement project

5.4.1 Solar and wind energy coupled reverse osmosis seawater desalination system

With the expansion of seawater desalination scale, the consumption of crude oil will increase year by year, which will aggravate the energy crisis. In addition, the burning of fossil energy will cause the emission of greenhouse gases and harmful substances. Therefore, seawater desalination technology driven by renewable energy has attracted more attention. At present, the main renewable energy sources used in seawater desalination are solar energy, wind energy, geothermal energy, and ocean energy, which are effective measures to solve the shortage of water resources and energy crisis [5].

Considering the location and climatic conditions of Sansha City, we decided to develop solar and wind energy coupled RO seawater desalination system. Using wind and solar energy to provide electricity for devices such as pumps, which is more friendly to environment and improves the economics of the project. In addition, it can also make full use of space and achieve reasonable use of the ground and altitude. So the solar and wind energy generation system is combined with the reverse osmosis seawater desalination.

The solar and wind energy is converted into electrical energy to drive the pumps of the seawater desalination. In order to maintain a stable electricity supply, it mostly uses accumulators to store electrical energy. Reverse osmosis seawater desalination equipments driven by photovoltaic panels has been used in many regions of the world; water production ranges from one to several hundred m^3/d; energy consumption of per ton water is 2. 4-17.9 kW h $/m^3$ [16].

The main job is to build a wind and solar power generation system based on the existing project. The system is mainly composed of the following parts:

(1) Wind power generation system:

It includes blade, motor rudder frame, tower, etc. Wind is used to drive the windmill blades to rotate, then it can drive the generator to generate electricity. Converting wind energy into electrical energy can effectively solve the defect that solar energy cannot work in rainy weather.

(2) Solar photovoltaic power generation system:

It includes photovoltaic brackets, photovoltaic panels, photovoltaic components, etc. Using the photovoltaic effect to directly convert solar energy into electrical energy, which effectively solves the instability of wind power.

(3) Power storage system:

The electricity generated by wind and solar energy charges the accumulator by the controller. Stable electrical energy is stored to meet the energy requirements of the seawater desalination.

(4) Power inverter system:

The stored electrical energy converts DC power into stable AC power through the inverter.

(5) Power supply system:

It is used to provide stable electricity supply to the desalination device through the power grid.

Finally, the solar and wind energy coupled reverse osmosis seawater desalination system is shown in Figure 7:

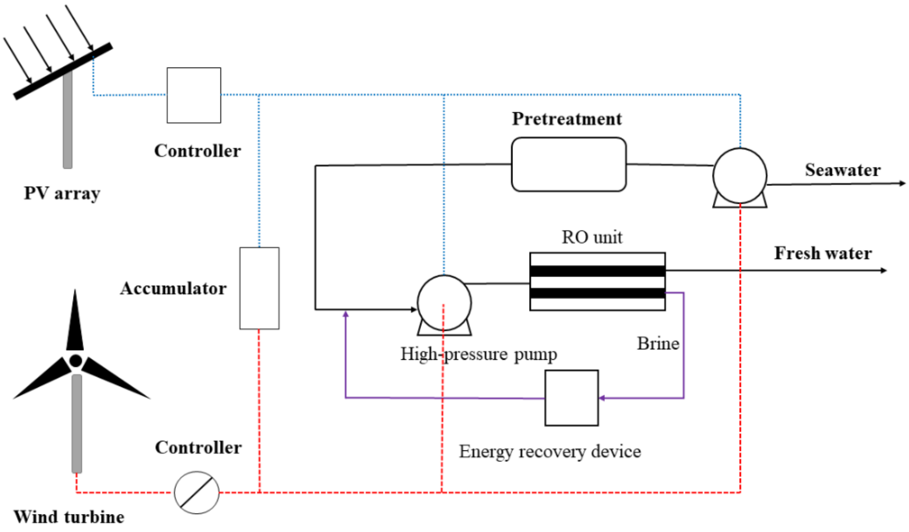

Figure 7 Solar and wind energy coupled reverse osmosis seawater desalination system

5.4.2Hybrid renewable energy system for water desalination

There are abundant marine energy resources along the coast of the island and nearby waters, such as tides, currents, waves, temperature difference and salt difference energy. At the same time, most islands are rich in wind and solar resources. Therefore, multiple renewable energy sources are developed and utilized at the same time, and their different intensity cycles are used to form complementary energy and achieve balanced power supply, thereby improving the island's energy supply and optimizing the island's energy structure[17].

In response to the natural environment and climate conditions in Sansha City, we designed a Hybrid renewable energy system for water desalination to Replace the current diesel power generation system.The system is mainly composed of the following parts:wave power desalination device, solar energy generation system, wind energy generation system and bio-energy generation system. The hybrid renewable energy system for RO water desalination is shown in the figure8.

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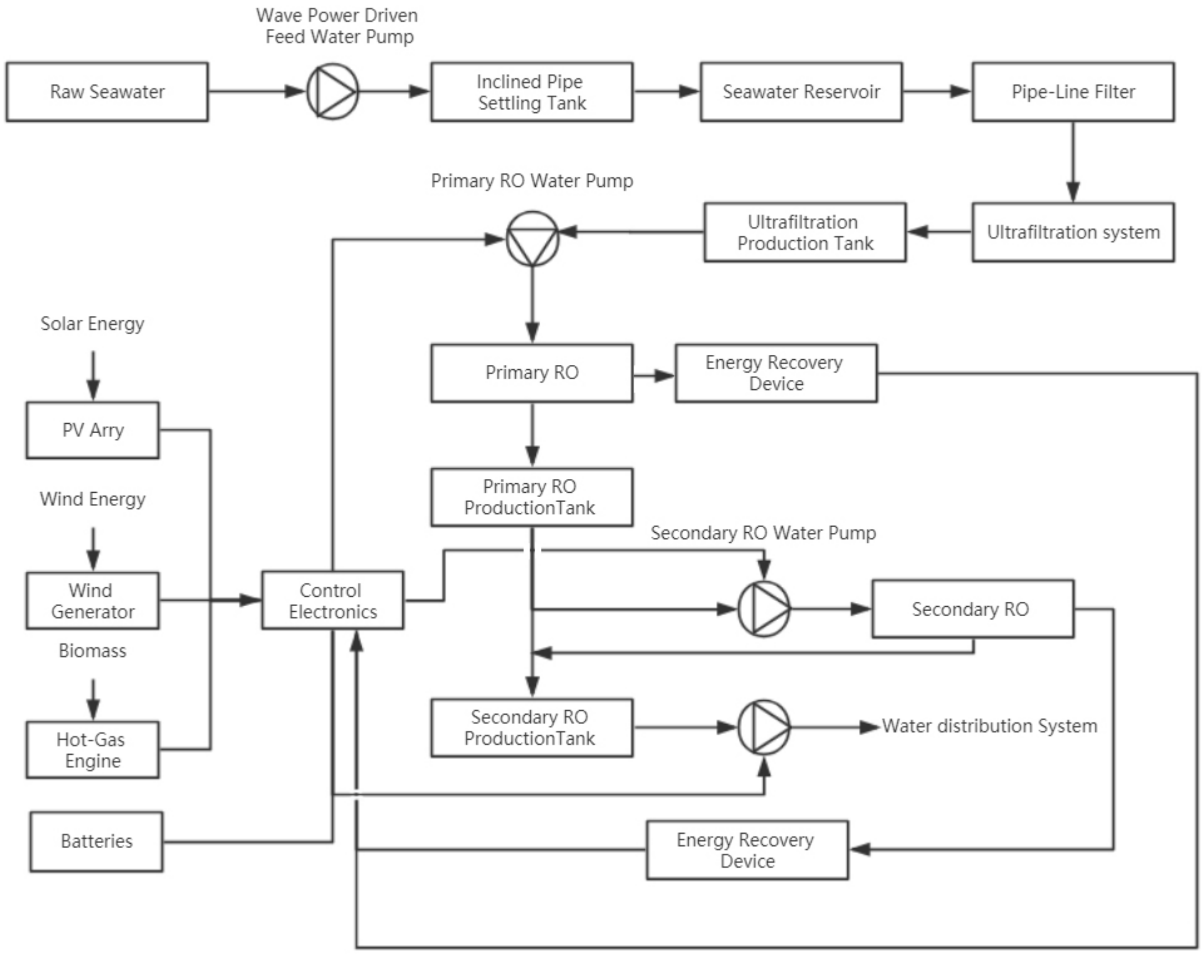

Figure 8 Hybrid renewable energy system for water desalination

(1) Wave power desalination device:

Under the same volume, compared with the sphere or vertical buoy, the horizontal buoy has a larger wave width and better effect of absorbing wave energy. The horizontal buoy is adopted in this device. In the same sea area, the installation location of the device can give priority to places with high wave height. As shown in Figure 9, X is the direction of wave travel. The pontoon swing plate 4 floats on the sea surface. The pontoon swing plate is set as far as possible against the waves. The upper part of the pontoon swing plate is connected to the foundation 1 through the link mechanism 2. A piston rod type seawater pump newly designed and developed by this research group is mounted on the connecting rod mechanism. When the wave rises, the wave impact force is transmitted to the piston rod type seawater pump 3 by the pontoon swing plate 4 and the connecting rod mechanism 2, the piston squeezes the seawater in the pump, the wave energy is converted into seawater pressure energy, and the high-pressure seawater is then sent to the Inclined pipe settling tank. The characteristic of the pontoon rocker type is that the horizontal thrust of the wave and the vertical upward force can play a role, and the wave energy conversion efficiency is higher. When the tide level is high, the device works at a high water level; when the tide level is low, the device works at a low water level. Compared with the oscillating float type, the pontoon swing plate construction process is less difficult, the civil engineering cost is not high, the wave energy is fully utilized and it can automatically adapt to the tide level [18].

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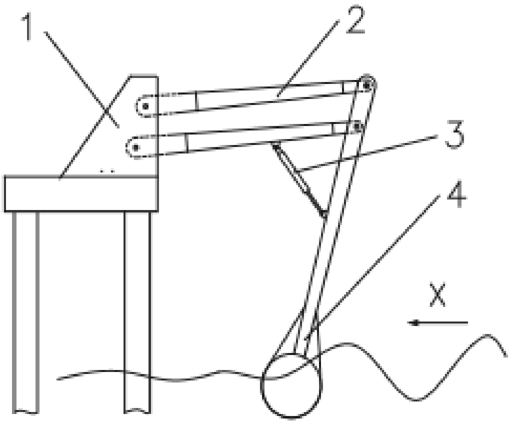

Figure 9 Wave power desalination device

1. Pile platform 2. Connecting rod mechanism 3. Piston rod type seawater pump 4. Floating plate of pontoon

(2) Solar energy generation system:

In hybrid renewable energy system for water desalination, photovoltaic arrays are the components that convert solar energy into electrical energy. The photovoltaic array uses the photovoltaic effect of the solar panel to convert light energy into electrical energy, then charges the battery, and converts the DC power into AC power through the inverter to power the load

(3) Wind energy generation system：

A wind turbine is a device that realizes the absorption and conversion of wind energy in a multi-energy coupled power supply system. From the perspective of energy conversion, a wind turbine is composed of a wind turbine and a generator. The wind turbine converts wind energy into mechanical energy, and the generator converts mechanical energy into electrical energy, thereby realizing the conversion of wind energy into electrical energy. The system uses magnetic levitation wind generator. This kind of wind turbine has the advantages of lower starting wind speed, high power generation efficiency, lighter weight, less fatigue to the bracket, and stronger safety[19].

(4) Bioenergy generation system:

The power generation system intends to use a gas-fired gas engine to form a biomass power generation system. Its working principle is shown in Figure 10. A biological anaerobic treatment device is built on the island, the collected domestic organic waste is fermented and treated, and the biogas generated is stored, and then the biogas is desulfurized, filtered, The treatment of dehumidification, pressurization and voltage stabilization finally enters the gas-fired gas generator for power generation. The hot water generated by the heat generator during the power generation process can be used not only for the life of the island residents, but also for the heating and insulation of the anaerobic process.

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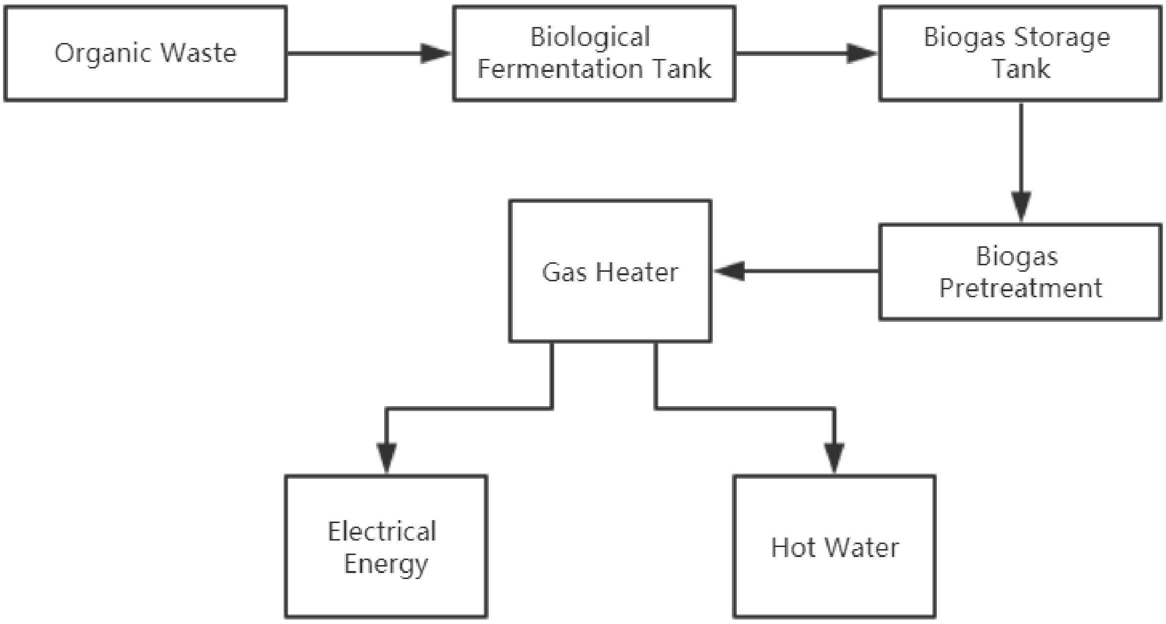

Figure 10 Bio-energy generation system

(5) Electronic control system:

The whole system is composed of three parts: energy generation, energy storage and energy consumption. Energy generation links: The AC-DC-AC method is used when wind energy, wave energy and biomass energy generation systems merge and convert energy. The storage of energy is borne by the storage battery. The main purpose of the introduction of the storage battery is to try to eliminate the imbalance of energy supply and demand due to weather and other factors, and play the role of energy regulation and load balancing in the entire system. The energy consumption link is a variety of electrical loads, which can be divided into two types: DC loads and AC loads. Inverters are required when AC loads are connected to human circuits.

Sansha Island is rich in renewable energy and is suitable for the construction of a multi-energy complementary power generation system. The hybrid power generation system can supply power to the seawater desalination device. While reducing the island's dependence on the mainland's input energy, it also reduces the cost of seawater desalination. At the same time, it also plays a important role in improving the energy use in island, and promoting the sustainable development and environmental protection.

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Master Program on Bio-Based Circular Economy

Course of Renewable Energy Technologies

Renewable energy driven desalination in China

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Università degli Studi Firenze · Universität Rostock, Traditio et Innovatio · Mälardalen University Sweden · Tongji University · East China University of Science and Technology · Sichuan University · cesie, the world is only one creature

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Content

1.Background

Table 1 Statistical tables of total water resources and per capita water resources

Time	Total water resources (Unit:100 million cubic meters)	Per capita share of water resources (Unit:100 million cubic meters)
2013	27860	
2014	28370	
2015	28306	
2016	30150	2354.9
2017	28761.2	2074.5

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1.Background

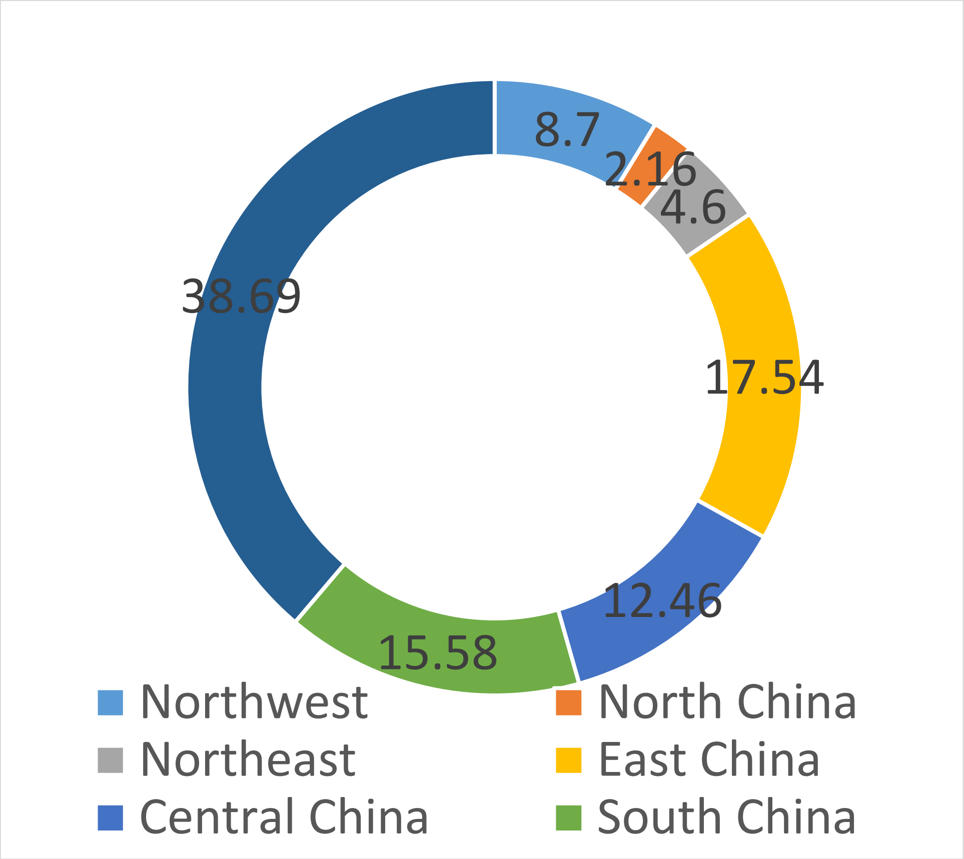

Figure 1. Distribution pattern of water resources in China in 2017

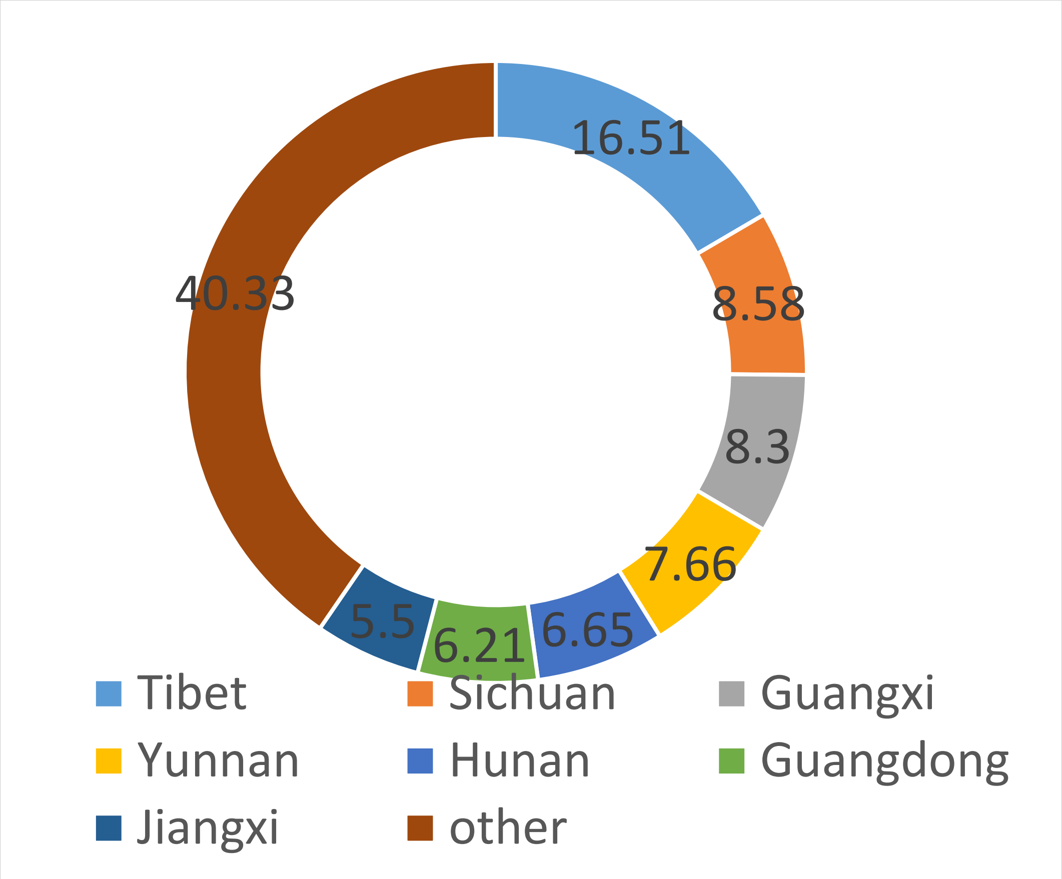

Figure 2. Analysis on the concentration of water resources in China's provinces and cities in 2017

2.Desalination technology

Traditional desalination technology include：
1.Multi-effect distillation
2. Multi-stage flash
3.Reverse osmosis
4.Vapor compression
5.Other methods include： electrodialysis (ED), freezing, hydrate, solvent extraction, ion exchange and humidification and dehumidification.

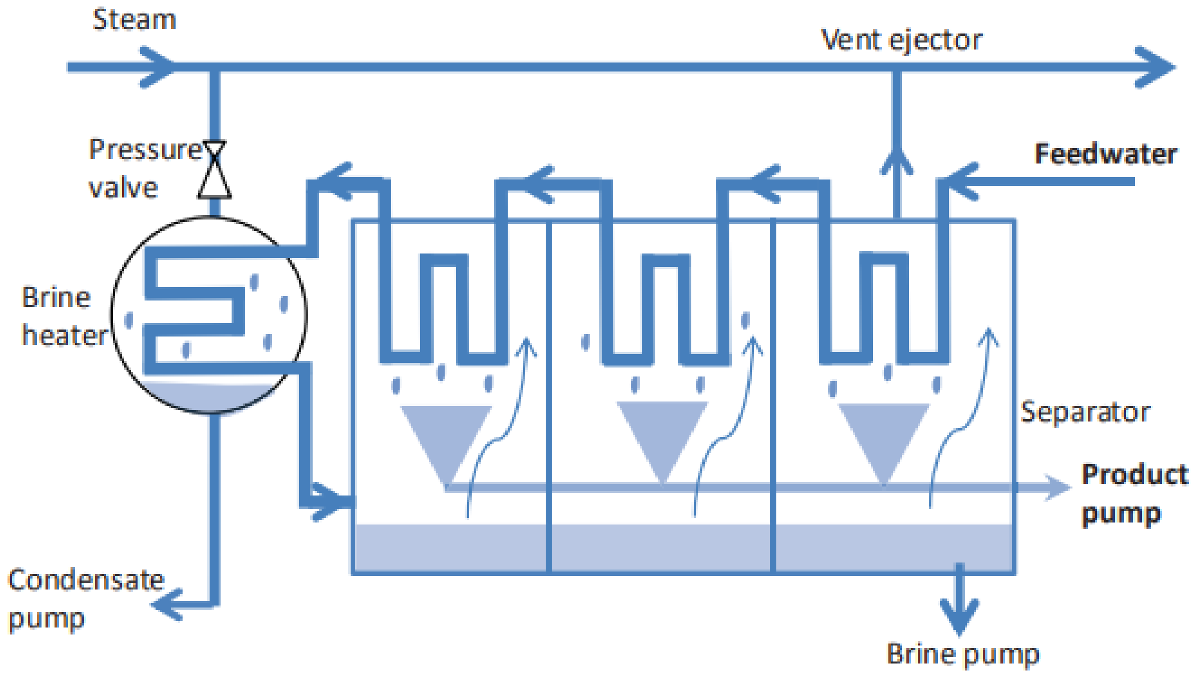

Figure 3. MSF technical process flow chart

2.Desalination technology

Table 2 Possible combinations of renewable energy and desalination technologies

Thermal Technologies	Membrane Technologies				
	MSF	MED	VC	RO	ED
Renewable Technologies	●	●	●	●	●
Solar thermal			●	●	●
Solar PV			●	●	●
Wind	●	●	●	●	●
Geothermal	●	●	●	●	●

2.Desalination technology

Desalination technology based on renewable energy：

1.Solar desalination technology

2.Wind energy desalination technology

3.Solar wind coupling desalination technology

4.Ocean energy desalination technology

5.Geothermal Desalination

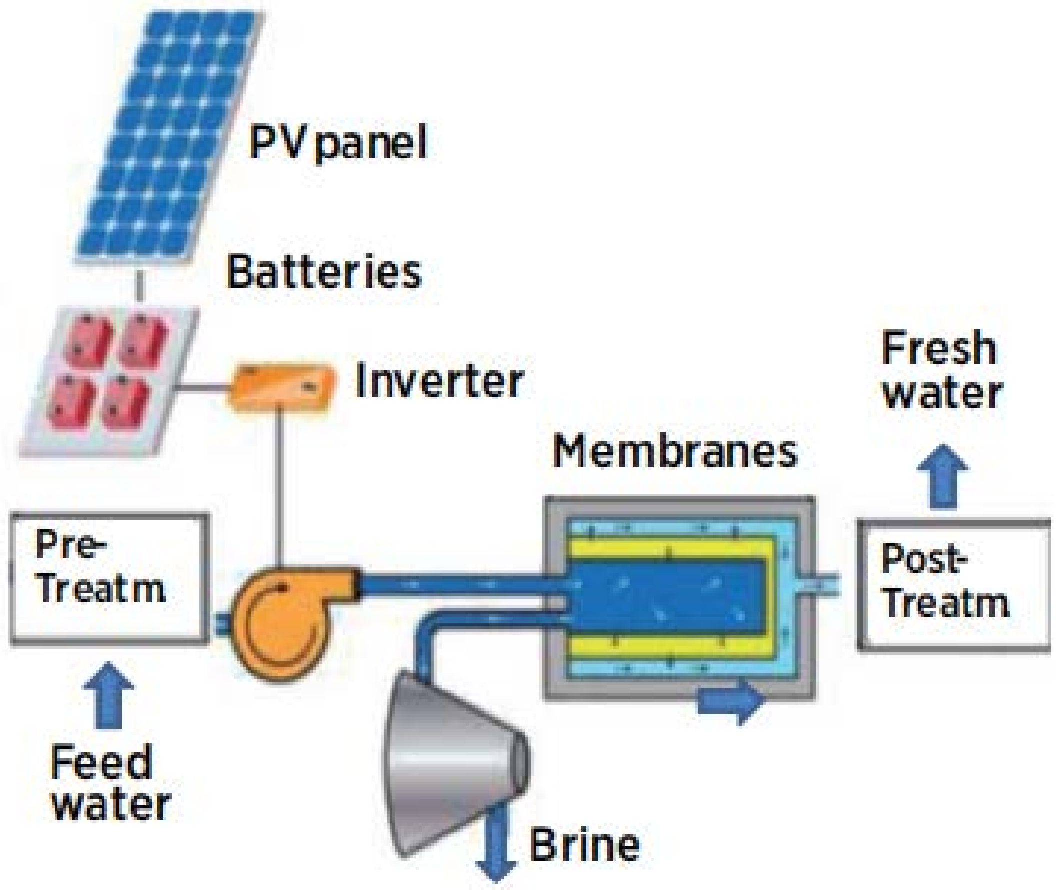

Figure 4 Coupled PV and RO desalination plants

3.The present status

Scale of desalination project:

142 desalination projects have been completed in China(36 projects of 10000 tons, 41 projects of more than 1000 tons, and less than 10000 tons, 65 projects of less than 1000 tons) with a project scale of 1201741 tons/day.

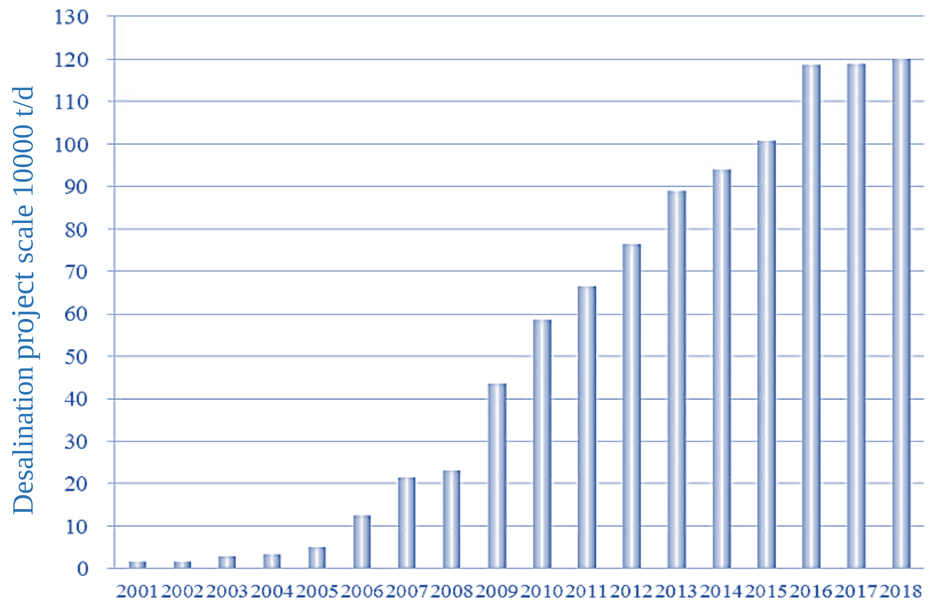

Figure 5 Scale growth of desalination projects in China

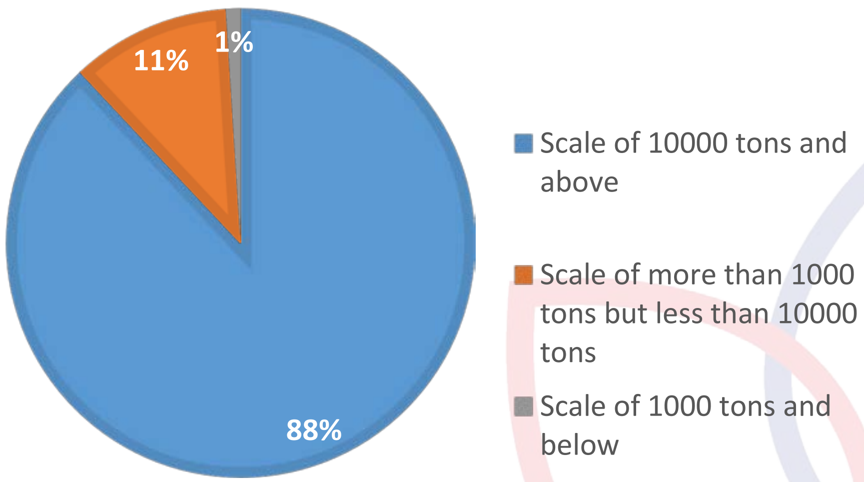

Figure 6 Scale distribution and proportion of completed desalination projects in China

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3.The present status

Regional distribution of desalination:

Tianjin, Shandong, Hebei are dominated by large-scale industrial desalination projects.

Zhejiang and Guangdong mainly focus on the desalination project of domestic water.

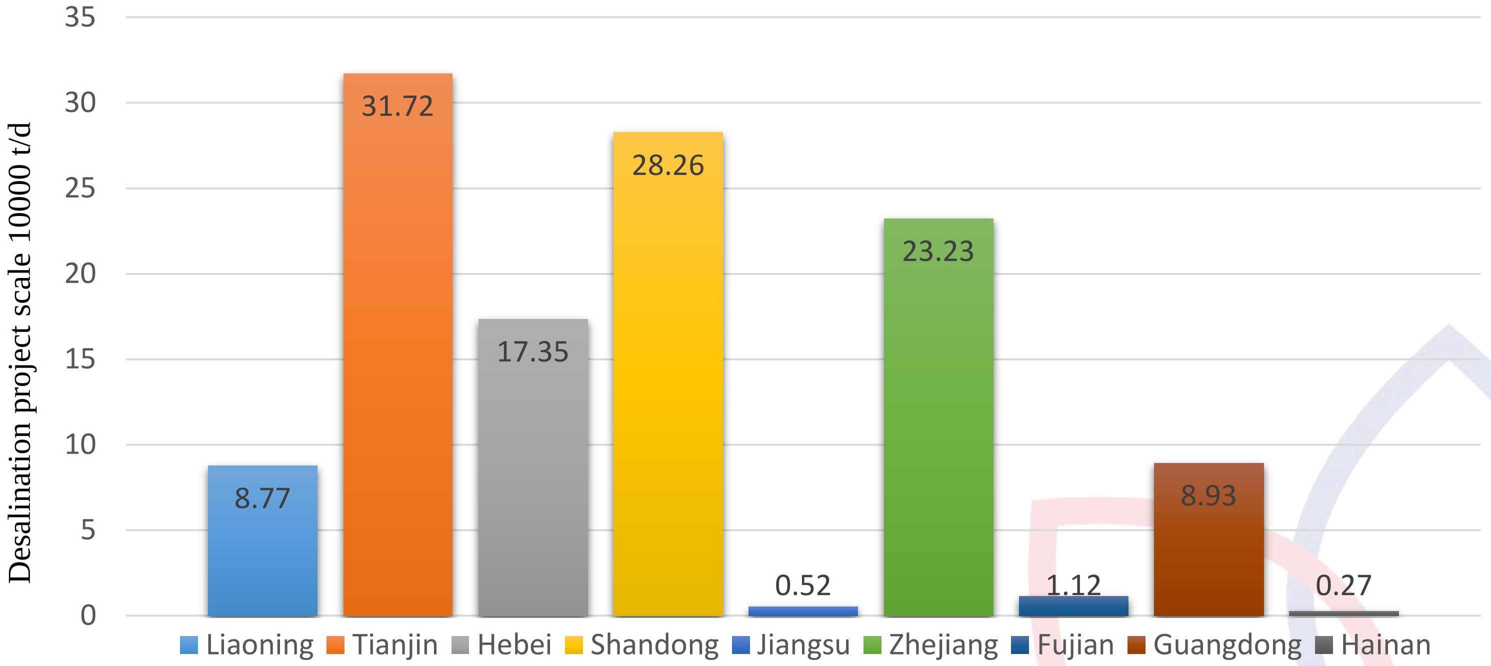

Figure 7 Distribution of desalination projects in coastal provinces and cities of China

3.The present status

Application of desalination technology:

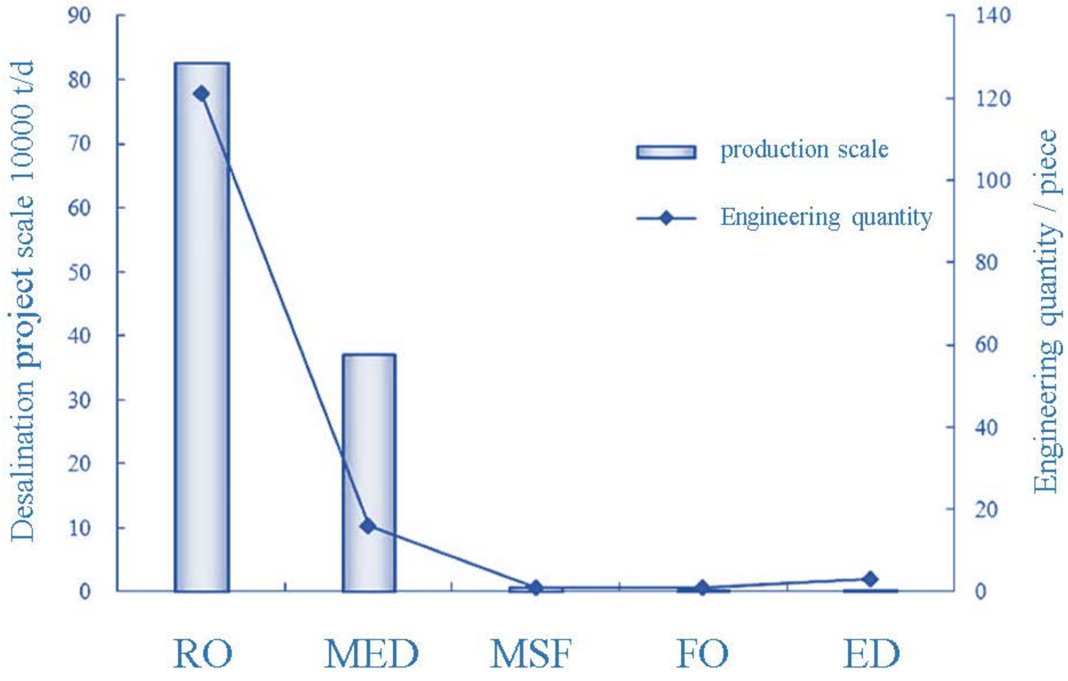

Figure 8 Distribution of the application of desalination engineering technology in China

121 projects applying RO technology, with a project scale of 825641 t/d, accounting for 68.70% of the total project scale

16 projects applying MED technology, with a project scale of 369150 t/d, accounting for 30.72% of the total project scale;

1project applying MSF technology, with a project scale of 6000 t/d, accounting for 0.50% of the total project scale;

1 project applying FO technology, with a project scale of 500t/d, accounting for 0.04% of the total project scale;

3 projects applying ED technology, with a project scale of 450t /d, accounting for 0.04% of the total project scale

3.The present status

Location	Raw water	Desalination Technology	Year	Energy Category	Scale/$m^3 \cdot d^{-1}$
Little Heishan Island	Brackish water	ED	1992	Wind	24
Dongfushan Island	Seawater	RO	2011	Solar,Wind,Diesel	50
Ledong County	Seawater	MED	2013	Solar	30
Dongshan County	Seawater	RO	2009	Wind	10
DaFeng	Seawater	RO	2014	Wind	10000
Nanpeng Island	Seawater			Solar,Wind	20
East Island	Seawater		2011	Solar	20

Table 4 Renewable energy seawater disalination project in China

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3.The present status

Dayushan Island PV driven Desalination demonstration project

Installed Capacity:6.0KW
Fresh Water Production: ： 5 $m^3 \cdot d^{-1}$
Energy Usage： 4.7KW·h/m^3
Water production cost reduced by €0.443/t
Desalination Unit: RO

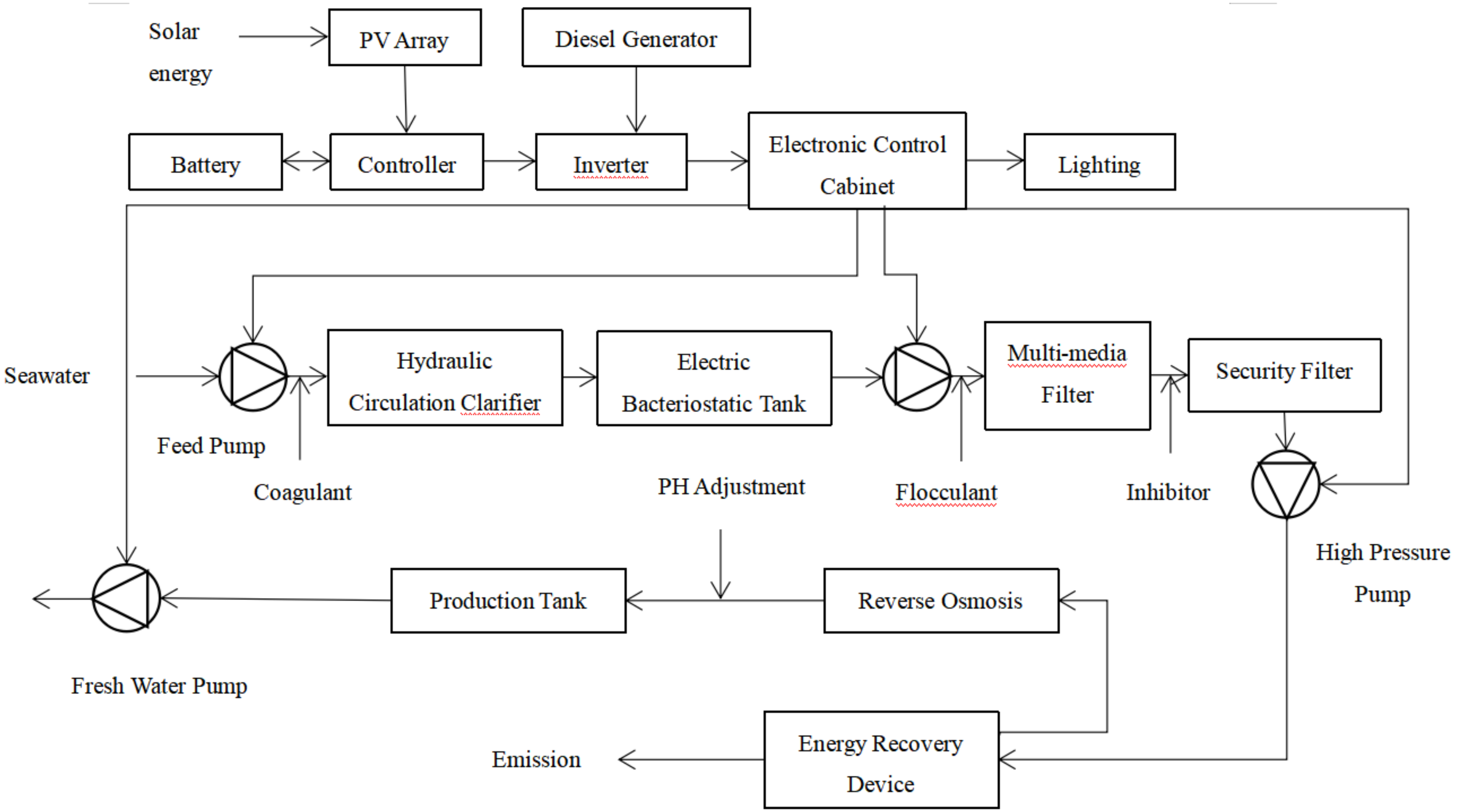

Figure 9 Dayushan Island PV driven Desalination demonstration project

3.The present status

Dongfushan island seawater desalination plant

Installed Capacity:510KW
Fresh Water Production： $50m^3 \cdot d^{-1}$
Energy Usage： $4.32KW \cdot h/m^3$
Water production cost: €0.6961/t
Desalination Unit: RO
Wind Turbine： 7 wind turbines with single unit capacity of 30KW
PV： 100KWp photovoltaic power generation system,
Diesel generator： 200KW

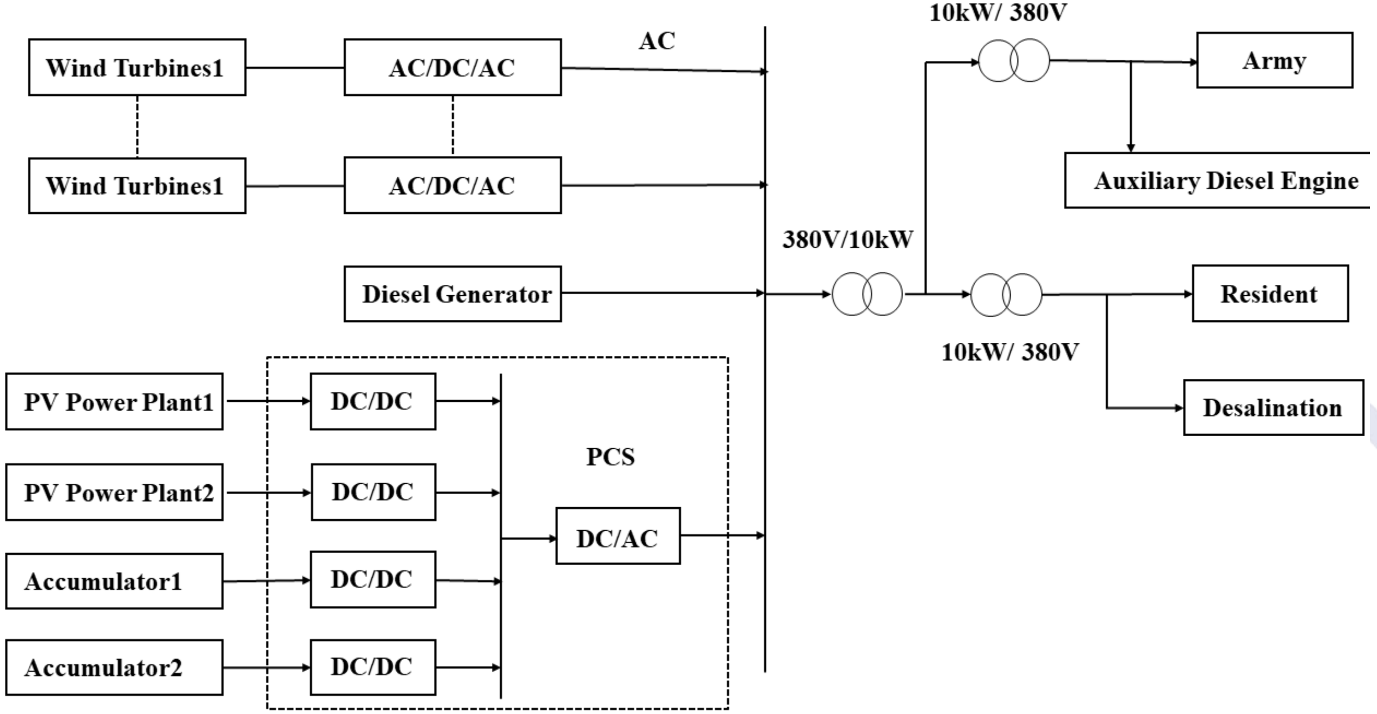

Figure 10 PV/Wind/Diesel Generator System in Dongfushan island seawater desalination plant

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4.Strength and weaknesses of the studied scenarios

desalination technology	Pretreatment requirements	TDS(mg/L)	Corrosion tendency	Incrustation tendency	Dirt tendency	energy consumption (Kw h/m3)
MED	low	<20	small	Relatively small	small	5.7-7.8
MSF	low	<20	Relatively small	small	small	12.7-15.0
MVC	low	<10	small	Relatively small	small	8.5
RO	high	<500	nil	large	large	2.5-4.0
ED	high	<500	nil	large	large	16-20

Table 3 Performance comparison of typical desalination technologies

4.Strength and weaknesses of the studied scenarios

Desalination technology based on renewable energy:

Solar energy:☺providing fresh water at both large and small scales
☺solar stills are a relatively well-established and low-efficiency technology
☹direct method has low cost but low output, indirect method has high output but high cost

Winder energy: ☺ a single wind turbine can be connected directly to the desalination system
☹with discontinuity and instability, necessary to install standby power supply system

Geothermal energy: ☺ has been produced and stored on the earth
☺ applicable to most desalination processes
☹ still in the research and development stage

Wave energy: ☺ can be obtained in the ocean through underwater current, wave and tide
☹ still in the research and development stage

5.Case Study

Sansha City Seawater Desalination Project

Location: Sansha City, China South Sea
Processing capacity: 1000 m^3/d.
Electricity consumption per ton: 3.7 kW·h;
The service life of RO membrane: 3 years;
The total cost of fresh water: about \$1.8382/m^3.

After the pretreatment of inclined tube sedimentation tank and ultrafiltration system, seawater enters two-stage reverse osmosis for desalination.
The first-level produced water is used for washing and bathing;
The second-level produced water is used for drinking and cooking.

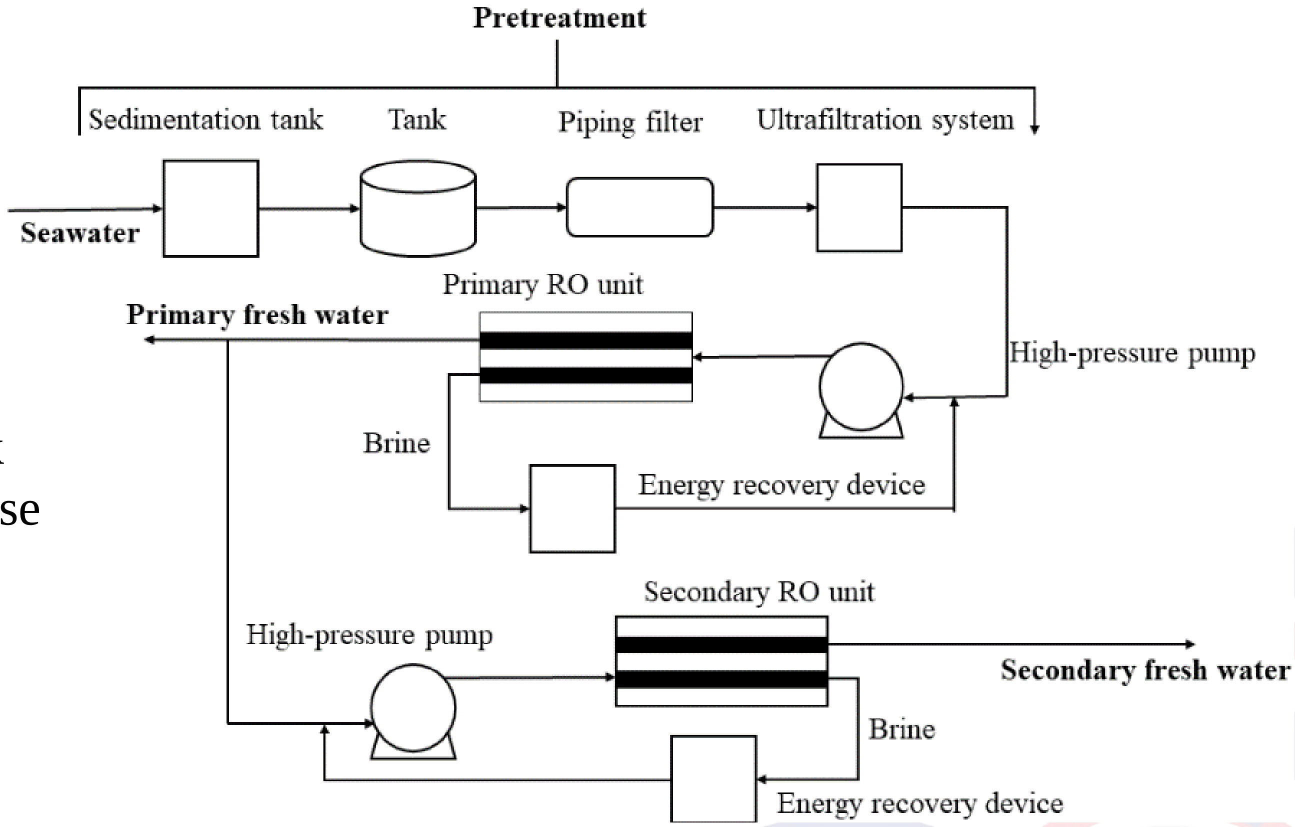

Figure 11 The process flow of desalination

5.1 Improvement Project:

Solar and wind energy coupled RO seawater desalination system

Considering the location and climatic conditions of Sansha City, we decided to develop solar and wind energy coupled RO seawater desalination system. Using wind and solar energy to provide electricity for devices such as pumps, which is more friendly to environment and improves the economics of the project.

Combined wind and solar power generation could make up for the deficiencies of independent power generation system and provide more stable electricity supply to the power grid.

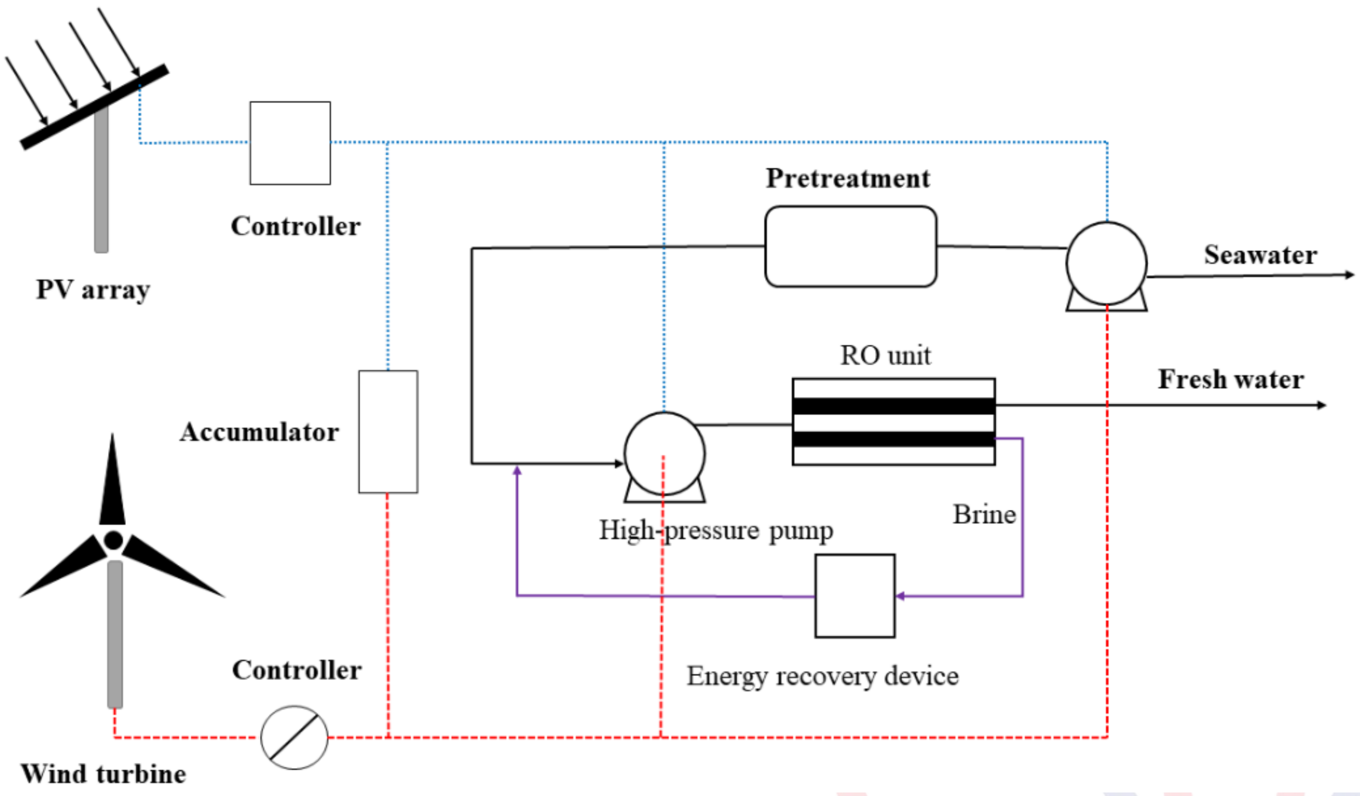

Figure 12 Solar and wind energy coupled RO seawater desalination system

5.1 Improvement Project：

Solar and wind energy coupled RO seawater desalination

The main job is to build a wind and solar power generation system based on the existing project. It mainly includes the following parts:

1. Wind power generation system
2. Solar photovoltaic power generation system
3. Power storage system

   Using accumulator to store electrical energy；
   The electricity generated by wind and solar energy charges the accumulator by the controller.
4. Power inverter

   Converting DC power into stable AC power
5. Power supply

   Stable electricity supply through the power grid.

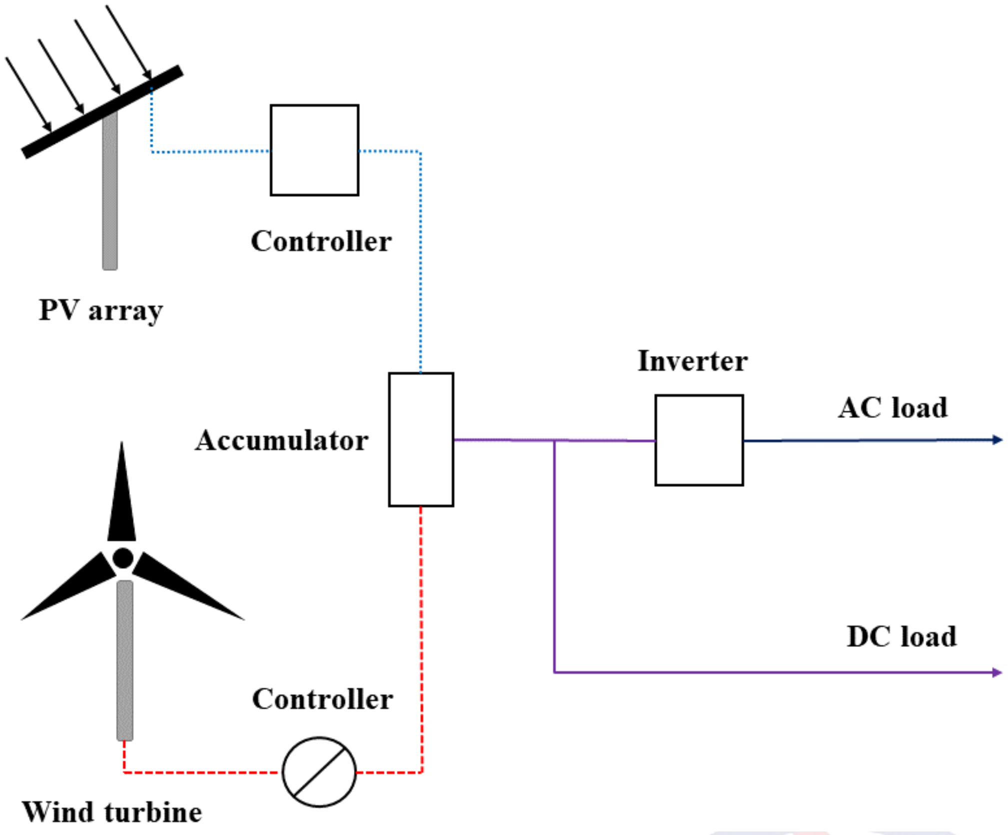

Figure 13 Wind and solar power generation system

5.1 Improvement Project：Hybrid renewable energy system for seawater desalination

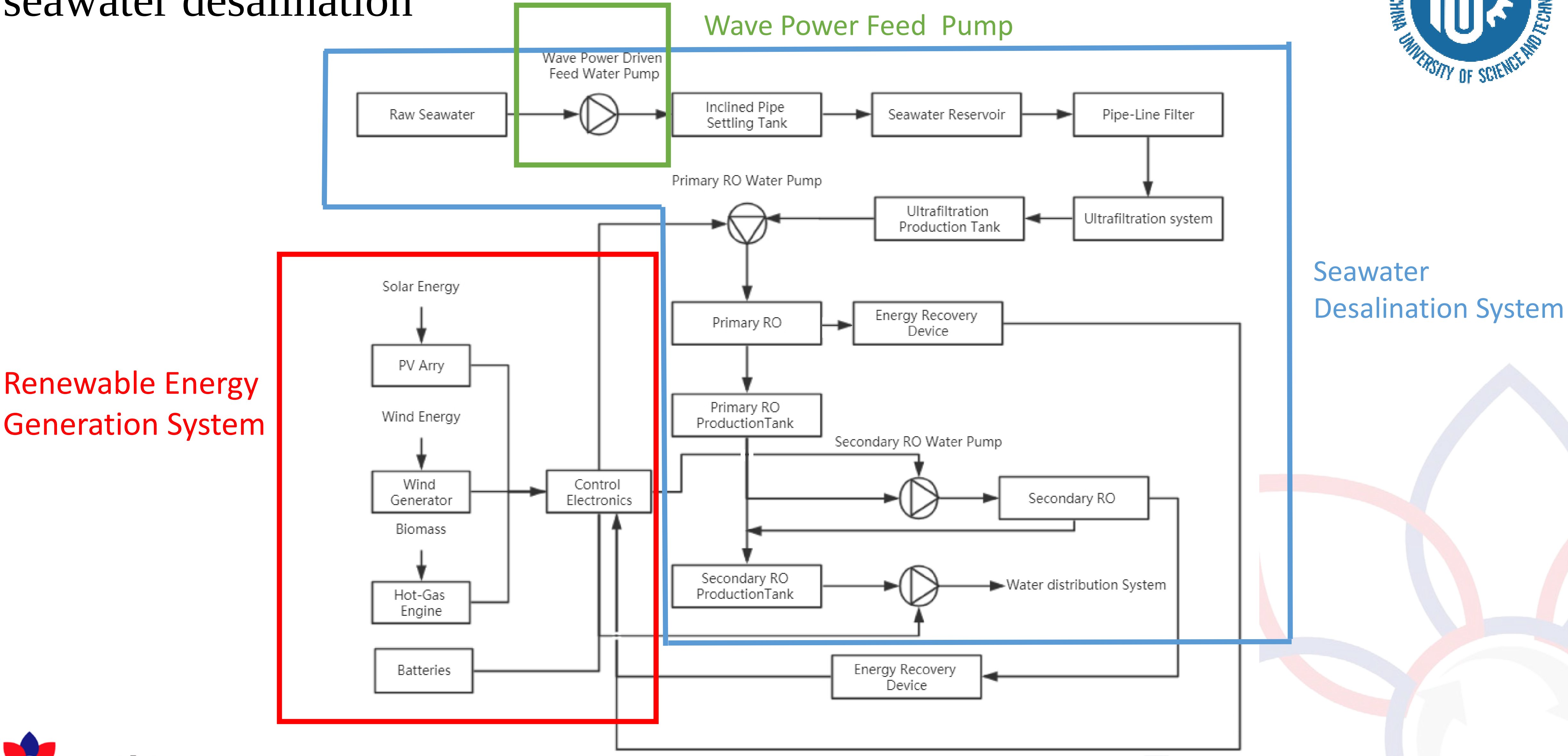

Figure 14 Sansha City seawater desalination plant based on RES

5.1 Improvement Project：Hybrid renewable energy system for seawater desalination

(1) Wave power desalination device

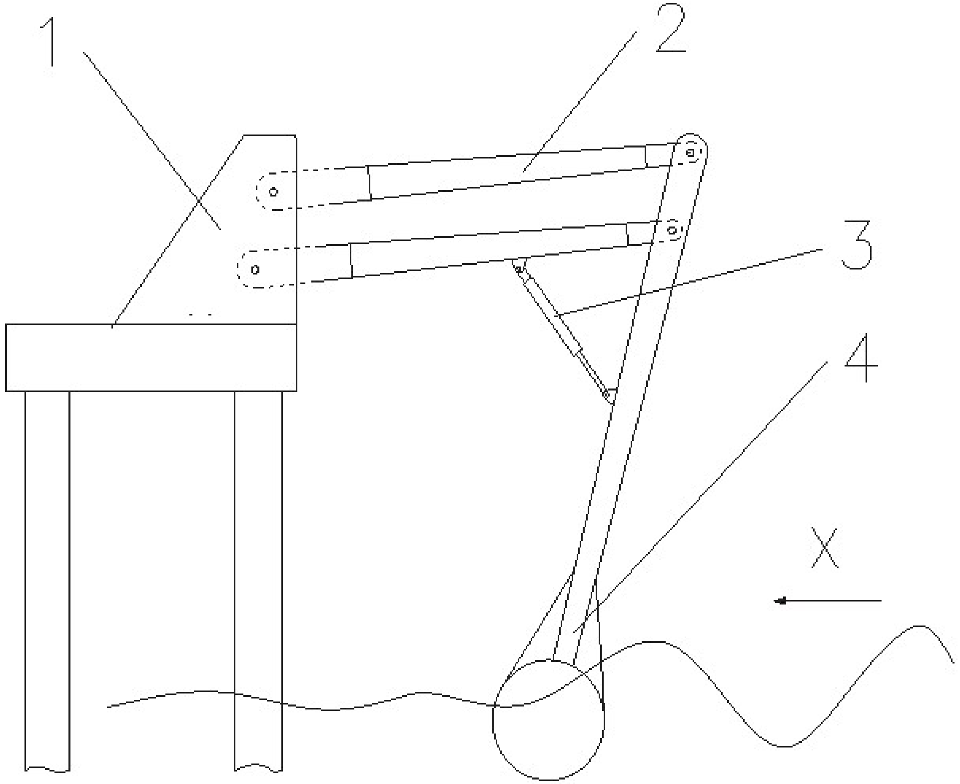

Figure 15 Wave power desalination device
1. Pile platform 2. Link mechanism 3. Piston rod pump 4. Swing plate with pontoon

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5.1 Improvement Project：Hybrid renewable energy system for seawater desalination

(2) Renewable Energy Generation System

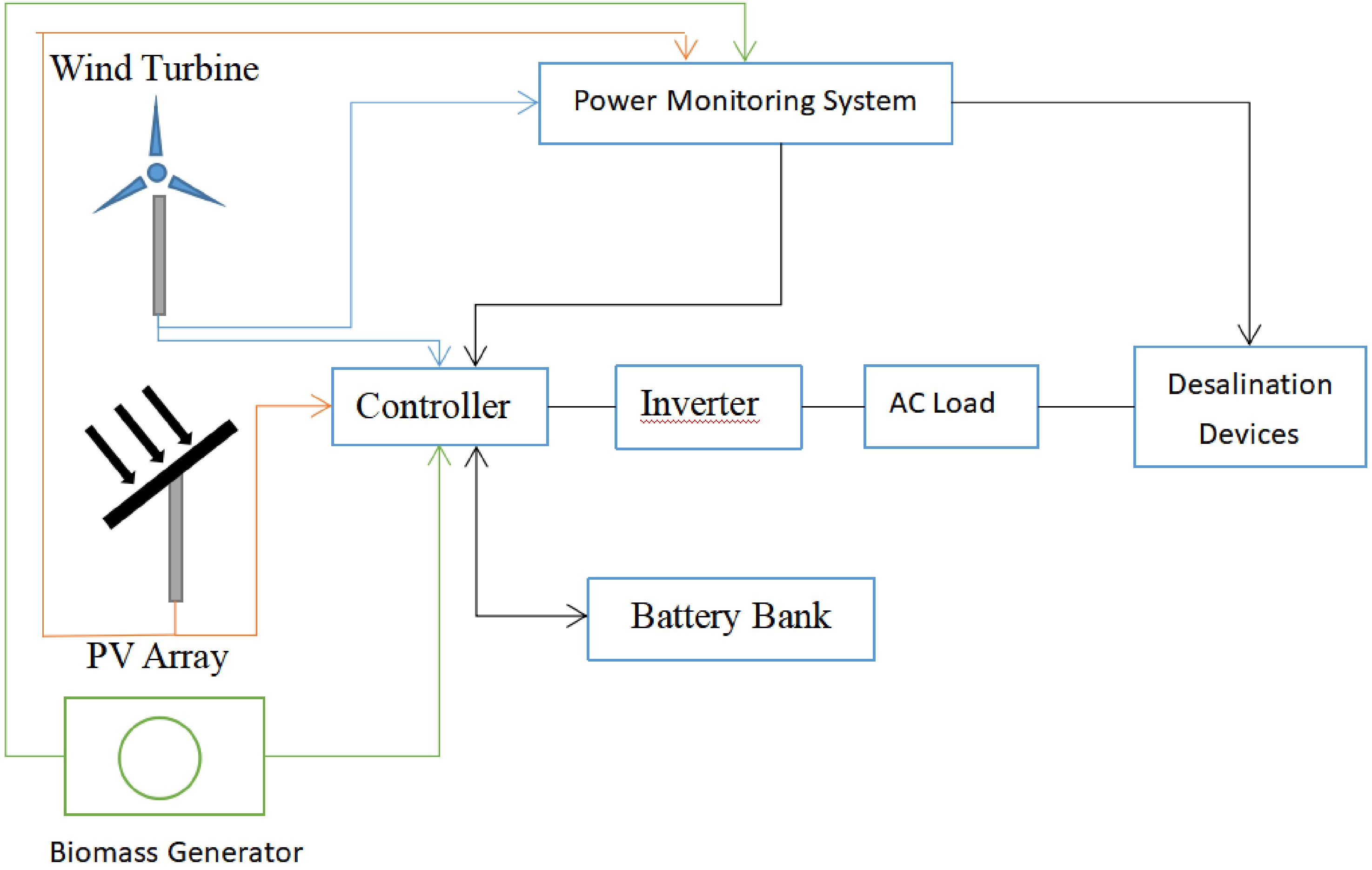


Figure 16 Renewable energy generation system

5.1 Improvement Project：Hybrid renewable energy system for seawater desalination

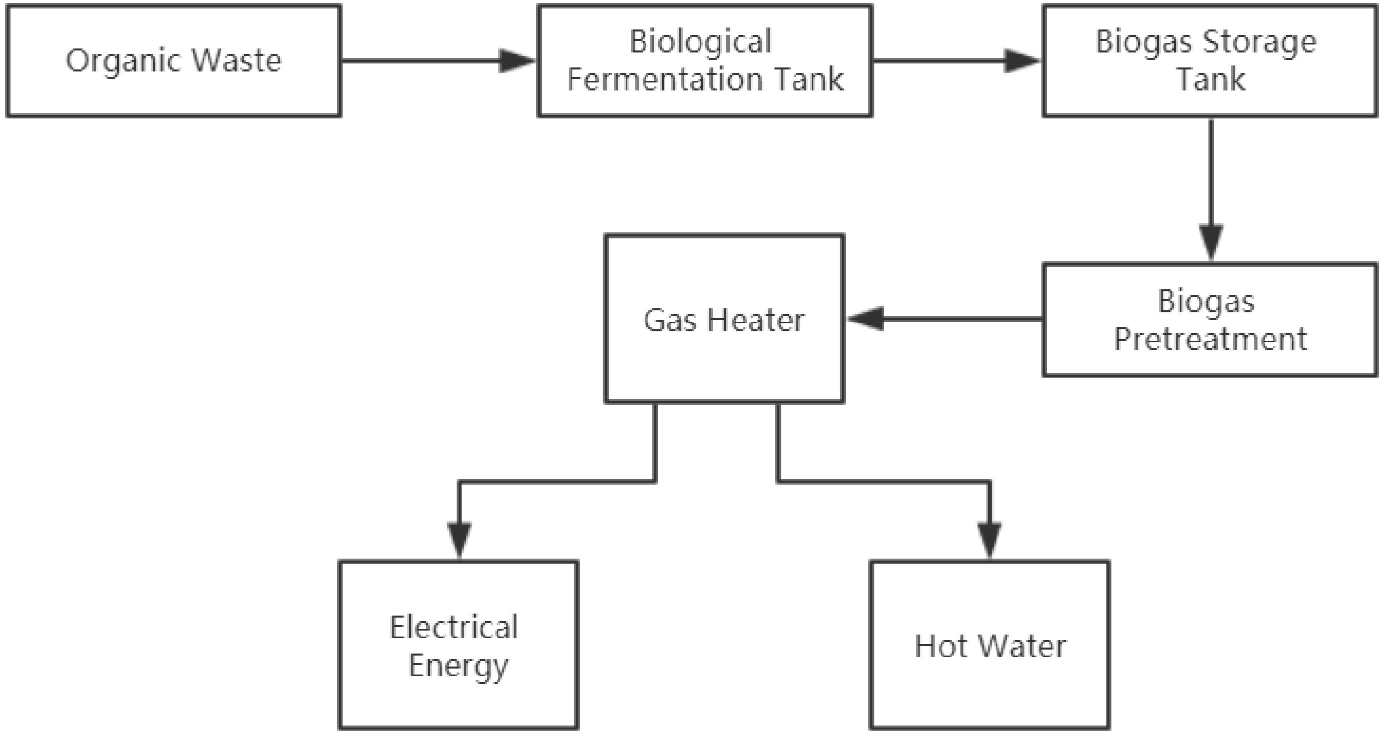


Figure 17 Bio-energy power generation system

5.1 Improvement Project：Hybrid renewable energy system for seawater desalination

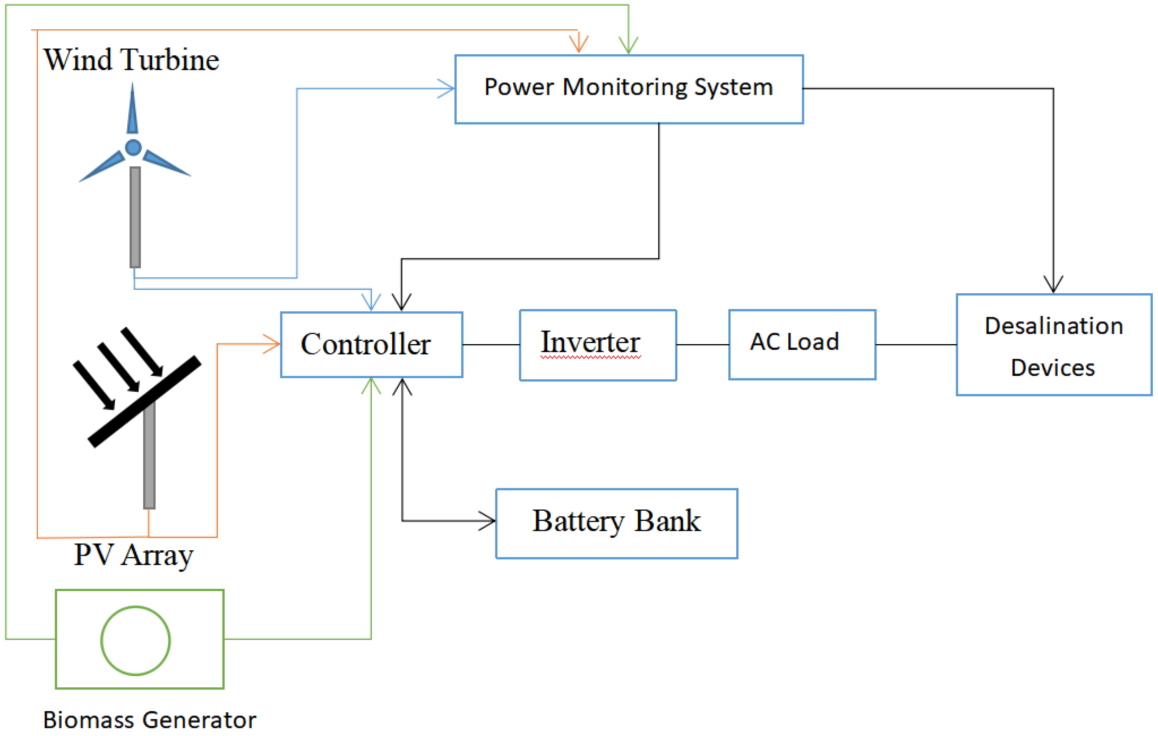
（3）Power control system:

The whole system is composed of three parts: energy generation, energy storage and energy consumption.

Energy generation link: The AC-DC-AC method is used when wind energy, wave energy and biomass energy generation systems is used to merge and convert energy.

The energy storage link is borne by the storage battery. The main purpose of setting the storage battery is to try to eliminate the imbalance of energy supply and demand due to weather and other factors, and plays the role of energy regulation and load balancing in the entire system.

The energy consumption link include the seawater desalination.Inverters are required when AC loads are connected to circuits.



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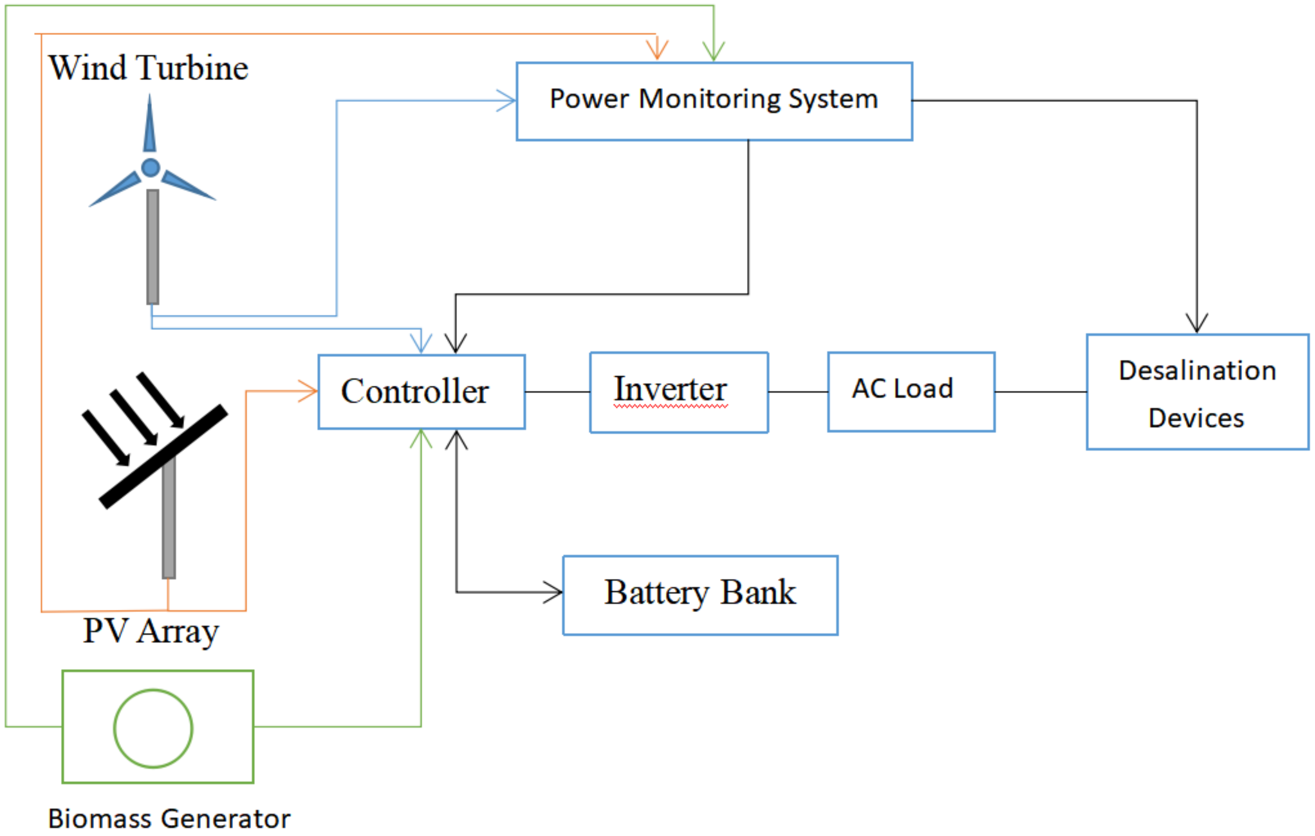
5.1 Improvement Project：Hybrid renewable energy system for seawater desalination

（4）Power Monitoring system:

The voltage, current, power, power generation and other data are measured by the power monitoring system, and the working status of each part of the power station is also measured. The status information of each part in real time is given for management personnel. In addition, the monitoring unit also has a regulation function to monitor the performance of the battery in real time, and make necessary protective actions according to the battery status;For example, when the battery is over-discharged or over-charged, it is necessary to cut off part of the load or suspend wind or solar power generation selectively.



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