A Designof Stand-alone Hybrid Wind/PV Desalination Systemin Lingshan Island China

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***Abstract*--In this paper, an integral design is proposed for constructing a hybrid wind/PV power system to supply electricity to a sea water desalination system. Considering the practical weather condition at Linshang Island, the better working condition for batteries and the economy, the circuit diagram is drawn and an optimal sizing scheme is designed. Some results were calculated by using the parameters given by the manufacturers.At last, the power system is simulated and the investment budget is estimated.**

Keywords—wind; PV; desalination system; load & output forecast, optimal sizing, investment budget.

I. INTRODUCTION

With the global environmental pollution and the primary energy resource shortage, clean and renewable energy has been considered to generate electricity. Meanwhile, fresh water, as another extraordinary shortage resource in the world, is taken as human's treasure. Although over 72% of the earth is covered by water, however, only 0.007% of water can be used directly by our human.

However, people have notice this issue and start to try some ways to produce fresh water. From the west coast of America to the islands of Japan, from Middle East to Mediterranean, lots of water desalination plants are built. These water desalination plants did generate a huge amount of fresh water, but it also consumed a large quantity of energy.China is one of the most water-scarce countries. In this paper, a method that processing water desalination which supplied by renewable energy is introduced on Lingshang Island, China. Lingshan Island is located in the southeast sea area of Qingdao, China. The island is 20 nautical miles far from the main land, the total area is 7.28 km^2 and the elevation is 513m. There are 13 villages and the population is 3454 people on the island. In the past, there were 39 wells and one small reservoir on the island. The normal drinking water supplement is feasible only in high flow years, once it gets into drought years, the drinking water cannot be supplied regularly. Since the continuous drought years in 70's, the whole water storage project and wells were exhausted. After 1981, the water supplements of Lingshan Island can only depend on shipping fresh water from main land by the army. However, when the storms or foggy days come, shipping fresh water by ship is infeasible.Fig 1 shows the full view of LingshanIsland .

Fig 1. Full View of Lingshan Island

Lingshan Island gets electricity via submarine cables from the main land, and the capacity is only match the residential load of the island. Assuming to use sea water desalination system on the island to produce fresh water is decided, then, there are two feasible ways to deliver electricity to the desalination system. First, build another new submarine cable between the island and the main land. Second, build a stand-alone power system on the island and directly supply electricity to the desalination system.For building a new submarine cable, compare with the stand-alone system, it is cheap. However, it is difficult and expensive to maintain and sustainable development. For building a stand-alone power system, it is expensive than to build a submarine cable. But, the stand-alone power system is sustainable and easy to maintain. Under the local weather condition, Lingshan Island is full of solar energy and wind energy. So, a hybrid wind/PV power system is selected to generate electricity and deliver electricity to the sea water desalination system. It is not only the cheap way to generate electricity, but also the way to generate electricity without any pollution.

II. INTEGRATE SYSTEMFORLINGSHAN ISLAND

Fig2 shows the integrate system for Lingshan Island. The hybrid wind/PV power system will be used for energy collection and electricity generation, and reverse osmosis process is introduced for water desalination.In the power system, based on the local weather, a type of 10kW wind turbine and a kind of 300W PV panel are selected as the distributed generators.[1][2]In the desalination system, a machine which produces 20T of fresh water per hour is selected.

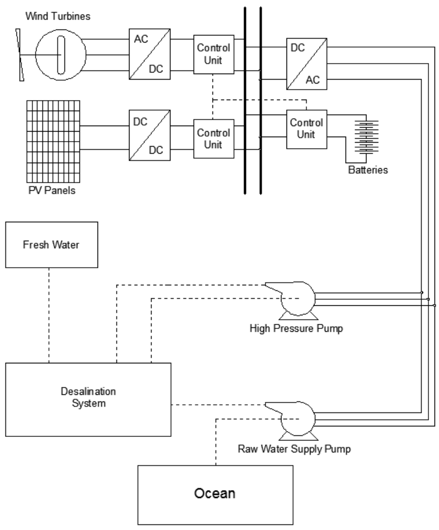

Fig2. Hybrid Wind/PV Desalination System for Lingshan Island

III. LOADAND POWER OUTPUT FORECAST

A. *Desalination System*

According to the per capita water consumption in Shandong Provence, China, the minimum volume is 0.14m^3/d per person in Qingdao area. The population in Lingshan Island is about 3400, it indicates that the sea water desalination system should, at least, produce 476m^3/d to satisfy the needs. For current market, manufacturers have already constructed the system as a machine which includes the high-pressure pump and controllers, etc.

The selected machine can generate 20 tons fresh water per hour. Assuming the density of fresh water equals 1000 kg/m^3, then the volume of produced fresh water per hour and total in one day are 20 m^3 and 480 m^3 respectively.

Another load comes from the raw water supply pump which is using for pumping sea water from the ocean to the desalination system. The capacity of the row water supply pump can deliver 20 m^3 of water per hour, which match the volume of water input from the sea water desalination machine.

In conclusion, the total load of the desalination system is the sum of the power of the desalination system and the raw water supply pump. Since the desalination system is always running expect the time for maintaince, and the maintaince duration is comparatively short. So, the load curve will be basically a straight line. Meanwhile, soft start is used to the desalination machine to decrease the impact current.

B. *Power Output Forecast in PV System*

Lingshan Island is located in Shandong Provence, which belongs to the solar available area. According to the information, the solar data in Lingshan Island is list below in table 1.The peak sun hoursare calculated by month.

TABLEITHE SOLAR DATA IN SHANDONG PROVINCE[3]

Month	Peak sun hours (h/d)
January	4.00
February	4.76
March	4.81
April	5.08
May	5.08
June	4.84
July	4.27
August	4.29
September	4.60
October	4.22
November	3.66
December	3.55
Average	4.43

Based on the solar data above, the PV panel was selected.There are a lot of factors that effects on the output of the PV panel, such as the environmental temperature, solar irradiance, shade, crystalline structure and the impedance of the load.

Equation 1 is introduced to calculate the average daily output.

$$Q = \eta_1\eta_2\eta_3\eta_4\eta_5 W_P t_P \qquad (1)$$ [4]

Where: Q is the average daily output (kWh);
$W_P$is the maximum output (kW);
$t_P$is the peak sun hour in a particular day(h);
$\eta_1$is the series-parallel factor (0.9);
$\eta_2$is the temperature loss factor (0.95);
η_3 is the dust covered loss (0.93);
η_4 is the charge and discharge loss (0.9~0.97);
$\eta_5$is the transmission anddistribution losses (0.98).

After calculation by using equation 1, the output of one PV panel in every month can be gained.

C. *Power Output Forecast in Wind System*

Lingshan Island is 513m height above the sea, the wind energy is extraordinary abundant. According to the data collected by Qingdao Huawei Wind Power Plant, the average wind speed in every particular hour in every month is obtained. The Qingdao Huawei Wind Power Plant is located in Jiaodong Bay, Qingdao, where the elevation equals zero. It means Qingdao area is the base point of elevation in China.

Equation 2 is introduced here to gain the velocity in a particular height.

$$\frac{V_h}{V_0} = \left(\frac{h}{h_0}\right)^{\alpha} \qquad (2)$$ [5]

Where, V_h is the velocity in a particular height;
$V_0$is the measured velocity;

$h$is the particular height;
$h_0$is the reference height;
αequals 0.1 if it for a calm sea.

Thus, the wind speed on Lingshan Island can be calculated by equation 2. Since the height of turbine tower is 12m, and the elevation of Liangshan Island is 513m, so the total height is 525m.

TABLEII AVERAGE WIND SPEED AT 525M

Month	Average Wind Speed at 525m
January	8.1 m/s
February	6.5 m/s
March	8.7 m/s
April	8.5 m/s
May	7.6 m/s
June	7.5 m/s
July	7.0 m/s
August	5.6 m/s
September	5.2 m/s
October	6.2 m/s
November	7.3 m/s
December	8.5 m/s

Table 2 shows the average wind speed in each months at 525m height.

The influence factor of the output for a wind turbine is mainly the average wind speed. Different wind turbines have the different output curves. Based on the average wind speed in 12 months, a turbine can be selected for the power generation system. Since the most influential factor for the power output of a wind turbine is the wind speed, and the wind speed is a random process; therefore, it should be stated in a statistical method. In recent years, Weibull distribution is used in describing the random number of the wind speed. The probability density function is given by equation 3.

$$\mathrm{f}(v_i) = \frac{k}{c} \cdot (\frac{v_i}{c})^{k-1} \cdot exp\left[-(\frac{v_i}{c})^k\right] \qquad (3)$$ [5]

Where: c is the scale factor;
$k$is the shape factor;
$v_i$is the wind speed.

Considering the local wind speed in each hour, the shape factor k and the scale factor c can be calculated with a maximum likelihood method. [9] The equations are given below.

$$\mathrm{k} = (\frac{\sum_{i=1}^{n} {v_i}^k \ln(v_i)}{\sum_{i=1}^{k} {v_i}^k} - \frac{\sum_{i=1}^{n} \ln(v_i)}{n})^{-1} \qquad (4)$$

$$\mathrm{c} = (\frac{1}{n} \sum_{i=1}^{n} {v_i}^k)^{\frac{1}{k}} \qquad (5)$$

Where,v_i is the wind speed in time step i and n is the number of nonzero wind speed data points. Equation4need to be solved by using an iterative procedure (k=2 is a suitable initial guess), and then, equation5 can be solved explicitly. Equation4is only apply to the nonzero wind speed data points.[6]

By using equation 4 and equation 5, the shape factor and the scale factor can be calculated respectively in each month.

The output for a turbine in a certain wind speed can be expressed by equation 6.

$$P_{wt} = \begin{cases} 0 & v_i < V_{ci} \ or \ v_i > V_{co} \\ P_{wt\_r} \frac{v_i - V_{ci}}{v_r - V_{ci}} & V_{ci} \le v_i \le V_r \\ P_{wt\_r} & V_r \le v_i \le V_{co} \end{cases} \qquad (6)$$ [7]

Where: P_{wt} is the output in the certain wind speed;
$P_{wt_r}$is the rated output;
$v_i$is a certain speed;
$V_{ci}$is the cut-in speed;
$V_{co}$is the cut out speed;
$v_r$is the rated speed.

In order to gain the average power output in a certain period, equation 7 is introduced here.

$$P_{w,avg} = \int_0^{\infty} P_{wt} \cdot f(v_i) \cdot dv \qquad (7)$$ [6]

Where: $f(v_i)$ is the probability density function given by equation 3.

By using the equation 7, the power output for one wind turbine in each month can be calculated.

IV. OPTIMAL SIZING

Optimal sizing is using for minimizing the cost of the system. In general case, no matter the load or the power output from the distributed generator, they are not always constant. With the shift of the season and the temperature, the PV panels and wind turbines generate different quantity of power. By optimal sizing with the number of PV panels, wind turbines and batteries, the power output will be relatively complemented by each other. Thus, under the condition of system stable, the system cost reduces to the lowest.[8]

The battery bank is a backup power source to the power system. It usually discharges when the distributed generators cannot provide enough power to the load, such as the days without wind or sunlight or neither. It charges when the power output from the distributed generators exceed the load. Then, the rest part of energy was charged into the battery bank.

The longest day without neither wind nor sunlight on Lingshan Island is only 1 day; and the longest days without wind and the longest days without sunlight are 1 and 3 respectively.

Equation 8 is given to calculate the capacity of the battery bank when the wind and sunlight are not available.

$$\frac{V_L \cdot DOD \cdot \eta \cdot C_B}{P_L} = n_w \cdot 24 \qquad (8)$$ [4]

Where: V_L is the voltage of the load;
DOD is the depth of discharge, set to 80%;
η is the efficiency of invertor, set to 97%;
C_B is the total capacity of the battery bank;
P_L is the peak power of the load;
n_w is the longest days without wind and sunlight.

Since the load is only the desalination machine and a pump, so peak power equals to the sum of the desalination machine and the pump. By using equation 8, the capacity of the battery bank can be calculated.Based on the result of the total capacity, the model of batteries can be selected.

Then, the number of batteries both in parallel and in series can be gained by using equation 9 and equation 10.[4]

$$N_p = \frac{C_B}{C_b} \qquad (9)$$

$$N_s = \frac{V_L}{V_b} \qquad (10)$$

Where: N_p is the number of batteries in parallel;
N_s is the number of batteries in series;
C_B is the total capacity of the battery bank;
C_b is the capacity of one battery;
V_L is the voltage of the load;
V_b is the voltage of one battery.

When the days without wind or days without sunlight come, equation 11 and equation 12 give the relations between the numbers of PV panels, wind turbines and batteries.

$$n_b \cdot DOD \cdot \eta \cdot C_B + n_{pv} \cdot P_{pv} \geq 3 \cdot 24 \cdot P_L \qquad (11)$$

$$n_b \cdot DOD \cdot \eta \cdot C_B + n_{wt} \cdot P_{wt} \geq 24 \cdot P_L \qquad (12)$$

Where: n_b is the number of batteries;
n_{pv} is the number of PV panels;
n_{wt} is the number of wind turbines;
P_{pv} is the power output from one PV panel in one month;
P_{wt} is the power output from one wind turbine in one month;
P_L is the peak power of load.

Use MATLAB to calculate the minimum cost of the whole system and the numbers of every distributed generator.

$$\min f = 200 \cdot n_b + 9416 \cdot n_{wt} + 255 \cdot n_{pv}$$
$$\text{s.t} \quad -P_{wt} \cdot n_{wt} - P_{pv} \cdot n_{pv} \leq -P_L$$
$$-n_b \cdot DOD \cdot \eta \cdot C_B - n_{pv} \cdot P_{pv1} \leq -3 \cdot 24 \cdot P_L$$
$$-n_b \cdot DOD \cdot \eta \cdot C_B - n_{wt} \cdot P_{wt1} \leq -24 \cdot P_L$$

Where: P_{pv1} is the power output from one PV panel in one day;
P_{wt1} is the power output from one wind turbine in one day.

V. HYBRID WIND/PV POWER SYSTEM SIMULATION

Using MATLAB to construct a model and then, simulate the process of power generation. The wind speed, peak sun hours and load are using the data obtained, functions are using equation 1 and equations 3~7 for photovoltaic array and wind turbines respectively.

The result reflects the relation between the total power of the load and the power generation for each month in one year, in kW•h. Show in Fig 3.

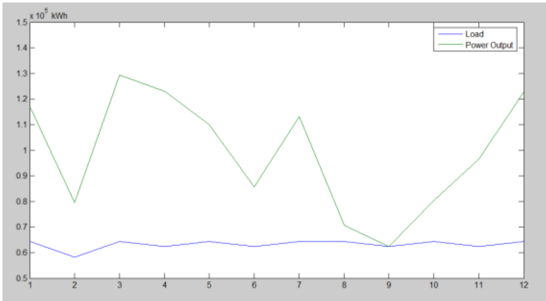

Fig3. Load and Power Output Curve

The result shows the power output is more than the load in the whole year.

Use the same model to simulate the relation between power output and load in one typical day. Fig 4 shows the relation between power output and load in a typical day in September.

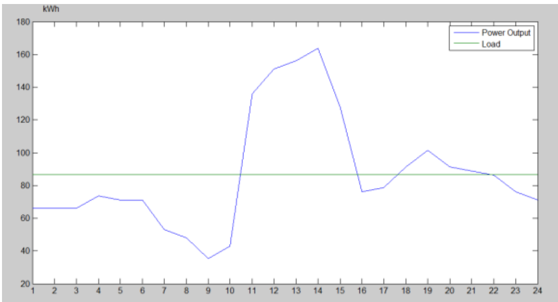

Fig4. Load and Power Output Curve in a Typical Day in September

VI. INVESTMENT BUDGET ESTIMATION

A. *The Investment Budget Estimation for the Hybrid Wind/PV Power System*

The investment budget estimation of the hybrid wind/PV power system is the sum of the devices' prices. Table 3 shows all the prices for each device.

TABLEIIITHE INVESTMENT BUDGET ESTIMATION FOR THE HYBRID POWER SYSTEM

Equipment	Unite Price	Quantity	Total Price
PV Panels	$255	407	$103,785
Wind Turbines	$9416	19	$178,904
Batteries	$200	576	$115,200
Inverter	$2000	1	$2,000
Wind Power Controller	$1000	19	$19,000
Solar Power Controller	$500	18	$9,000
Total	$427,889		

By calculating the prices in Table 3, the total investment budget of the wind/PV hybrid power system equals $427,889.

B. *The Investment Budget Estimation for the Desalination System*

The investment budget estimation of the sea water desalination system mainly include the price of desalination machine, the price of the raw water supply pump and the price of steel pipes. Table 4 shows the details.

TABLE IVTHE INVESTMENT BUDGET ESTIMATION FOR THE DESALINATION SYSTEM

Equipment	**Unite Price**	**Quantity**	**Total Price**
Desalination Machine	$9,2300	1	$9,2300
Raw Water Supply Pump	$1,500	1	$1,500
Steel Pipes	$290	20	$5,800
Fresh Water Tank	$8,000	11	$88,000
Total	$187,600		

By calculating the prices in Table 3 and 4, the total investment budget of the wind/PV hybrid power system equals $615,499.

C. *The Installation Cost Estimation*

The installation fee for the system usually equals to 4.5% of the total cost. Equation 13 gives the basic rules to calculate the installation cost.

$$J = Y \times t_1 \times t_2 \times t_3 \qquad (13)$$

Where, J is the total installation cost;
Yis the basic cost;
$t_1$is the professional adjustment coefficient, set to 1.2;
$t_2$is the engineering complexity adjustment coefficient, set to 1.0;
$t_3$is the additional adjustment coefficient, set to 1.1.

D. *Payback Time of the Integrate System*

The total coast of the whole system is the sum of the prices of desalination system, wind-solar hybrid power system and the installation cost, which equals to $615,499. Currently, the fresh water for the Lingshan Island can be only delivered by ship. The cost of a 500 tons cargo ship is listed below, in table 5.

TABLEVTHE COST OF SEA TRANSPORTATION

Items	**Unite Price**
Fuel Fee	$50/h
Depreciation Cost	$80/h
Cost of Labor	$12/h
Other Cost	$20/h
Total	$162/h

Lingshan Island is 20 nature miles far from the mainland. The cargo ship's speed is 10 km/h, which equals to 5.4 nature miles per hour. So, one round trip for the ship at least needs 8 hours. Thus the total cost for one round trip is $1296. Since the cargo ship can carry 500 tons, so there will be only one round trip per day. By calculation, after 503 days, the total cost of sea transportation is $651,888. In another word, after almost 16 month, the whole system becomes free.

VII. CONCLUSIONAND RECOMMENDATION

In this paper, a basic design for a sea water desalination system and a matched wind-solar hybrid power system was introduced. The accomplished tasks mainly include:

- Introduction of a hybrid wind/solar desalination system and Lingshan Island.
- Equipment selection.
- Load and power output forecast.
- Optimal sizing.
- System simulation
- Investment budget estimation.

In the load and power output forecast part and the optimal sizing part, a large quantity of data was calculated for the theoretical design. For actual project design, some of the factors need to be modified.

Meanwhile, there were still some drawbacks in this paper and need to be solved:

- All of the weather data were collected from different sources; it would cause some error in the calculation.
- All of the equipment information was collected from www.alibaba.com, the prices may not be the latest.

In the optimal sizing part, the power output, in most months in the year, is exceeding the load capacity and that part of energy should be consumed reasonably.

As a recommendation, the local government could consider to build a saltworks. Since the desalination system is not only produce fresh water, but also remains a large quantity of high salinity water; and this part of high salinity water would let out back to the ocean. A saltworks would use this part of high salinity water to produce salt, and the rest part of the energy would also be consumed by the saltworks. So, by building a saltworks, the high salinity water would not be wasted and the exceed power would also be used reasonably.

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