

Hybrid Solar-Wind System for Future Power Supply in Hong Kong and Guangdong Coastline Area

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Abstract: Solar energy and wind energy are the two most viable renewable energy resources in the world. This paper reports the potential of solar and wind energy applications in Chinese's Guangdong coastline area. Good complementary characteristics are found between the solar and the wind energy resources. One optimization sizing model for hybrid solar-wind energy systems is presented based on the Loss of Power Supply Probability (LPSP) technique and the Levelised Cost of Energy (LCE) concept. Two pilot hybrid solar-wind power projects have been developed for China Mobile's communication stations. The monitoring results of one of the projects are reported.

Keywords: solar energy, wind energy, hybrid system, complementary characteristics, LPSP, LCE

1. INTRODUCTION

The Hong Kong SAR Government and local private companies are working hard towards renewable energy applications, especially solar photovoltaics and wind power in recent years. A lot of work has been done for investigating the wind and solar power potentials under Hong Kong weather conditions [1-4], but no detailed report about hybrid solar-wind energy resources has been found from literature review. In order to promote solar energy and wind energy application in this region, it is necessary to study this technology for combining solar energy and wind energy for power generation in Guangdong coastline area where power supply shortage is very serious due to its high-density manufacturing industry.

This paper is to assess the solar and wind energy application potentials in Hong Kong and Guangdong coastline area, and to present the monitoring results from one pilot hybrid power generation project which are designed by the developed optimization sizing model using the Loss of Power Supply Probability (LPSP) technique and the Levelised Cost of Energy (LCE) concept to achieve the lowest investment with

a reasonable and full use of the PV system, wind system and battery bank [5-8].

2. WIND ENERGY

2.1 Weibull Distribution Function

The wind speed distribution predominantly determines the performance of wind power systems. Once the wind speed distribution is known, the wind power potential and, hence, the economic viability could be easily obtained. The Weibull distribution function, expressed by Eq. (1), is one of the normally used functions to illustrate the wind speed distributions of a given location over a certain period of time, typically monthly or annually [7-8].

$$f(v) = \frac{k}{c} \left(\frac{v}{c} \right)^{k-1} \exp \left[- \left(\frac{v}{c} \right)^k \right] \quad (1)$$

where c is scale parameter; k is shape parameter; and v is wind speed, m/s.

With the Weibull density function and its parameters, the average power in the wind can be expressed as:

$$\bar{P}_w = \frac{\rho A \bar{v}^3 \Gamma(1+3/k)}{2[\Gamma(1+1/k)]^3} \quad (2)$$

2.2 Average Wind Speed Density Analysis

Hong Kong and Guangdong area is characterized by a long coastline and numerous islands. Due to the strong winds on the islands, wind power is one of the potential renewable energy resources.

The wind data of four islands along the south-east coast of Asiatic continent are chosen to analyze the wind power potentials in this region shown in Fig. 1.

In the present study, the annual Weibull function and its two parameters are derived from the available data and are shown in Fig. 2 and Table 1. The result shows that Waglan Island is the most 'windy' place with the largest scale parameter c , and its most possible wind speed is 5.2 m/s; Cheung Chau Island has the most 'peaked' Weibull wind distribution with



Fig.1 Locations of the four islands in the area

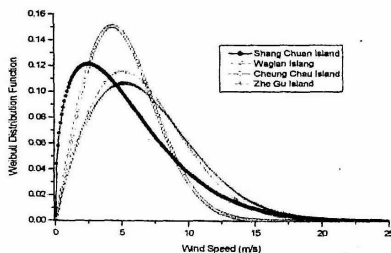


Fig.2 Annual wind speed Weibull distribution

Table 1: Weibull function parameters of the islands

Places	Parameter K	Parameter C
Shang Chuan Island	1.40	6.06
Waglan Island	1.88	7.75
Cheung Chau Island	2.09	5.86
Zhe Gu Island	1.97	7.35

the greatest shape parameter k , and its wind speed tends to be very close to 4.3 m/s (the most possible wind speed); the highest-frequency wind speed of Shang Chuan Island is 2.5 m/s, but it has more opportunities of experiencing wind speeds of above 9.2 m/s than Cheung Chau Island. Zhe Gu Island has similar wind conditions to Waglan Island except that it has more frequency of lower wind speeds and less frequency of higher wind speeds. From the above analysis, an obvious conclusion is that the Weibull distribution function and its two parameters are quite different for different places, so it's very important to choose a suitable site with good wind field for wind power generation.

2.3 Average Wind Power Density Analysis

The wind power resource is rich in the Hong Kong and Guangdong coastline area. The annual mean wind speed of 5.7, 6.9, 5.2 and 6.4 m/s are derived from the hourly measured time-series wind speed data for Shang Chuan Island, Waglan Island, Cheung Chau Island and Zhe Gu Island respectively. Their average wind power densities are 320, 417, 160 and 328 W/m² respectively. If the cut-in and cut-out speeds of 3.0 and 25 m/s are used, their operating possibilities amount to 85%, 69%, 78% and 84% respectively. These statistic figures illustrate the wind power potentials in this region.

3. SOLAR ENERGY

The first step in evaluating the efficiency of a PV system requires an accurate estimation of the amount of solar irradiance falling on the PV panel. The mean daily global solar radiation is found as 14.46 MJ/m² in Hong Kong from the recorded solar data between 1961 and 1990 by the Hong Kong Observatory [9], and the monthly solar radiation distributions are shown in Fig.3. Compared with other countries or areas [10], where the mean daily global solar radiation is 9 MJ/m² in London, 13.2 MJ/m² (4 sites) in Hawaii, 16.9 MJ/m² in Sydney, 13.9 MJ/m² in China (21 sites), 9.8 MJ/m² in Germany (11 sites), and 13.1 MJ/m² in Japan (79 sites), the Guangdong coastline area is a favorite region of solar energy resource.

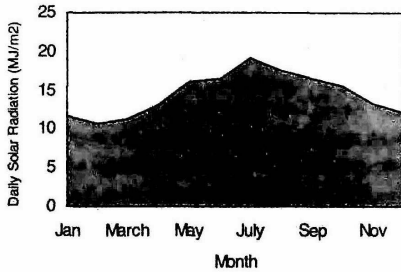


Fig.3 Solar radiation in Hong Kong (1961-1990)

In Hong Kong, the worst season is spring with the lowest daily solar radiation value of 10 MJ/m², while the solar radiation is very ample and rich in other seasons, especially in summer with the highest value of nearly 20 MJ/m².

4. COMPLEMENTARY ANALYSIS

The climate data for 1989 are taken as the typical weather year, as shown in Ref. [11], to analyze the complementary characteristics between the solar energy and the wind energy. It is seen from Fig. 4 that solar and wind sources are complementary over that year. The summer provides good solar irradiance but poor wind conditions, whilst a relatively good wind source but poor solar radiation occurs in winter. For the daily distribution the results are shown in Fig.5. On most days with high solar radiation, the wind energy is poor. Such periods usually last for 3-5 days so that the complementary characteristics make the hybrid application more reliable. The above shows that the combination of the two energy sources can provide a better utilization factor for the available energy.

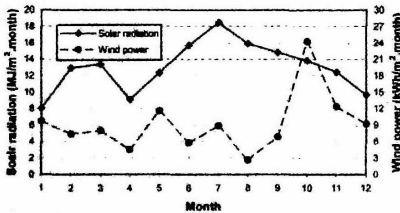


Fig.4 Monthly accumulated solar radiation and wind power distribution in 1989

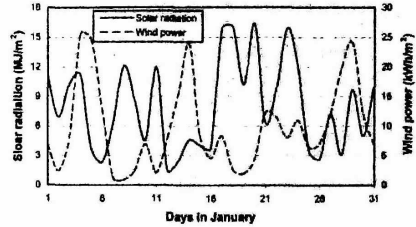


Fig.5 Daily accumulated solar radiation and wind power distribution in January

5. OPTIMIZATION SIZING MODEL

Besides the climatic conditions (solar irradiance, wind speed, temperature, and so forth), an optimum match design method is also needed in order to efficiently and economically utilize the renewable energy resources. Here in this paper, an optimization sizing model, which is developed based on the Loss of Power Supply Probability (LPSP) concept and the Levelised Cost of Energy (LCE) concept is used to size a hybrid solar-wind system.

5.1 The Technical Model

The loss of power supply probability (LPSP) which is the probability that an insufficient power supply results when the hybrid system (PV array, wind power and energy storage) is unable to satisfy the load demand. The LPSP technique is considered to be the technical implemented criteria for sizing and evaluating a hybrid PV-wind system employing a battery bank. The objective function of the LPSP from time 0 to T can be described by:

$$LPSP = \frac{\sum_{t=0}^T \text{Time}(P_{\text{supplied}}(t) < P_{\text{needed}}(t))}{N} \quad (3)$$

where N is the number of hours in this study with an hourly weather data input. Accordingly, the power needed by the load side can be expressed as:

$$P_{\text{needed}}(t) = \frac{P_{\text{LOAD}}(t)}{\eta_{\text{INVERTER}}(t)} \quad (4)$$

and the power supplied from the hybrid system can be expressed by:

$$P_{supplied}(t) = P_{PV}(t, \gamma, \beta) + P_{WIND}(t, h) + C \cdot V_{bat}(t) \cdot MIN \left[\frac{0.2C_{bat}}{\Delta t}, \frac{C_{bat} \cdot (SOC(t) \cdot \sigma - SOC_{min})}{\Delta t} \right] \quad (5)$$

where C is a constant, 0 for battery charging process and 1 for battery discharging process.

Using the above developed objective function according to the LPSP technique, the system configuration can be optimized for one certain load profile according to the desired reliability of the system. For a given LPSP value for one year, one set of configurations can guarantee the required reliability of power supply technically.

5.2 The Economic Model

According to the studied hybrid solar-wind power generation system, the Levelised Cost of Energy is defined as the total cost of the whole hybrid system divided by the power supply from the hybrid system, and the economic model can be expressed by (three main parts are considered: PV array, wind generator, and battery bank):

$$C_e = \frac{\sum_{i=1}^n (C_i / y_i)}{E_a} = \frac{C_{PV} / Y_{PV} + C_{Wind} / Y_{Wind} + C_{Battery} / Y_{Battery}}{E_a(\gamma, \beta, h)} \quad (6)$$

where C_e is the Levelised Cost of Energy, \$/kWh; C_{PV} , C_{Wind} and $C_{Battery}$ are the sum of capital cost and replacement cost of the PV system, the wind system and the battery bank respectively; Y_{PV} , Y_{Wind} and $Y_{Battery}$ are the lifetime year of the PV system, the wind system and the battery bank; $E_a(\gamma, \beta, h)$ is the annual power supplied from the hybrid solar-wind system.

5.3 Optimizing Process

For a given load distribution and a desired LPSP value, the system configurations or combinations can be identified according to the simulation models and the weather data input.

For the desired LPSP value, the optimal configuration can be identified finally from the set of configurations by achieving the lowest Levelised

Cost of Energy. Thus, the hybrid system can be sized technically and economically according to the system reliability requirements.

6. A CASE STUDY

A case study is carried out by using the model for two field projects. These projects (Fig.6) are to supply power for telecommunication relay stations on remote islands (Zhegu Island and Dalajia Island) at Shanwei and Huizhou of Guangdong.

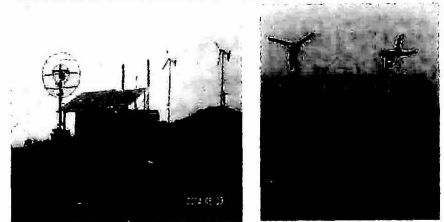


Fig.6 The two pilot hybrid system projects

The electric use of the station on Zhegu Island includes 700 W carrier wave (24 DC), 55 W microwave (24V DC). 1000 W is chosen as the demand load. For Dalajia Island, 13000 W GSM base station RBS2206 (24 AC), 200 W microwave (24V DC) are needed for the normal operation of the telecommunication station. 1500 W is chosen to be the load. The optimum design parameters in Table 2 are adopted for these two projects.

Table 2: Detailed design parameters of the projects

	Zhegu Island	Dalajia Island
Load	1000 W (+24V)	1500 W (+24V)
PV array	MBFP100 100W×60 = 6kW (29.5° inclination)	MBFP100 100W×77 = 7.7kW (29.5° inclination)
Wind turbine	WESTWIND 3kW 3kW×2 = 6kW	WT6000/024 6kW×2 = 12kW
Battery capacity	GFM-1000 (2V) 6000AH (24V)	GFM-1000 (2V) 5000AH (24V)

Because a long period of cloudy days occurred during this spring, in order to give a demonstration of the system performance under such unaccustomed weather conditions, the measured data from 26 Jan 2005 to 29 Mar 2005 are used to analyze the hybrid systems' energy performance for one project.

Fig. 7 illustrates the power supplies from the PV arrays and the wind turbines of Dalajia Island during the measuring period. The complementary character of the hybrid system can be clearly seen, especially during 7 Mar to 11 Mar, little power was generated by the wind turbines, but the solar irradiance is high and the power from the PV arrays was abundant. This has alleviated the power shortage during this period. Take the whole measuring period into consideration, the hourly average power generated by the wind turbines is 995 W, and the power generated by the PV arrays is 539 W.

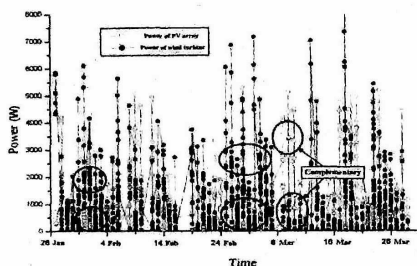


Fig.7 Power supplies of the Dalajia Island project

Fig. 8 shows the variation of the power supply, consumption and battery voltage. The hourly average power supply of the hybrid system is 1534 W, which is a little higher than the hourly average power consumption (1450 W). The hybrid system was found to be working quite well except several very short periods when the battery voltage was below the Load Disconnection Voltage (23.4 V in this project).

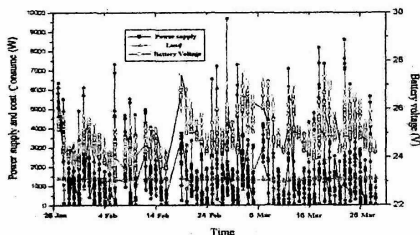


Fig.8 Power supply, consumption and battery voltage

7. CONCLUSIONS

The results show that solar power and wind power in Guangdong coastlines have

complementary characteristics and can provide a good utilization factor for renewable energy resources. The reliability and economic models can give an optimum design of a hybrid solar-wind power system. A case study shows its applications. The hybrid system performed very well throughout the year.

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