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Economic Analysis of PV-Wind Hybrid System at 25 Locations in Taiwan

臺灣25個地區太陽光電-風力混合發電系統之經濟分析

凌拯民 黎方長
Jeeng-Min Ling Phuong-Truong Le
南台科技大學 電機工程系
Department of Electrical Engineering,
Southern Taiwan University, Tainan, TAIWAN
jmling@mail.stut.edu.tw le_truong1982@yahoo.com.vn

Abstract – The aim of this study is to analyze the economic allocation problem for a photovoltaic-wind hybrid system at 25 locations in Taiwan. The HOMER software developed by the National Energy Renewable Laboratory (NERL) is applied to simulate the economic capacity problem, the comparisons of total Net Present Cost (NPC) at these 25 locations with different Hub Height and capacity shortage are conducted. Another simulation result is focus on the comparison with the combination of Photovoltaic-battery versus wind-photovoltaic-battery hybrid system in different type of wind turbine. 25 different weather station recorded data in year 2007 are used to characterize the different type of optimal capacity allocation in these areas.

Keywords: Economic analysis, Hybrid PV-wind system

摘要:
本研究主要探討於台灣25個中央氣象局觀測站所在位置架設混合式再生能源發電系統時，如何決定其最佳容量配置之經濟分析問題。利用美國再生能源研究室所發展之分散式電力之最佳化分析軟體(HOMER)進行測試，分別分析比較了25個不同觀測站所在位置，於不同風力發電機組之塔架高度及系統不同缺電率時的最佳容量配置解，另外亦比較了太陽光電-風力-蓄電池及太陽光電-蓄電池兩種不同獨立式再生能源混合系統之容量配置解。測試模擬之天候資料為中央氣象局2007年之實測氣象數據。
關鍵字：經濟分析、混合式再生能源發電系統。

1. Introduction

Nowadays, the problems caused by polluted environment have been increasing severely. That is why renewable energy has become an urgent task that is needed to be done and improved all over the world. Many hybrid renewable systems have been studied recently, such as photovoltaic (PV)-wind, PV-hydro system. Sizing of a micro-hydro-PV-hybrid system has been conducted for rural electrification in developing countries [1], the combination of PV and diesel/battery was proposed. It highlighted the use of an optimal model to size a hybrid renewable system at a village in the Cameroon. The PV-wind hybrid system in the Swedish location was presented [2]. They studied a Wind-PV hybrid system for stand-alone application and compared total net present cost (NPC) at 11 locations of the Sweden. Some interesting results about total NPC with different load primary and capacity shortage were demonstrated. Another wind-PV-battery hybrid power system at Sitakunda in the Bangladesh was presented by Nandi and Gosh [3]. They studied the optimization of a wind-photovoltaic-battery hybrid system and its performance for a typical community load. The optimal sizing comparisons for wind-photovoltaic-battery system and Photovoltaic-battery system in terms of different load primary/hub height/capacity shortage are often characterized [1-4]. The influenced factor, different types of wind turbine, will be integrated in this paper.

Two different types of hybrid renewable system, PV-wind-battery and PV-battery, are compared with the optimal NPC at 25 different weather station locations of Taiwan in terms of different hub height of wind turbine and different capacity shortage of system. The Optimization Model for Distribution Power (HOMER) developed by the National Renewable Energy Laboratory (NREL) is used to simulate and compare the NPC results [5]. HOMER models a power system's physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life span. It allows the system planner to compare many different design options based on their technical and economic merits. The sensitivity analysis characterizes the effects of uncertainty or changes in the system.

2. The Simulation Model

The simulation has been performed by the simulation software Homer. The net present cost (NPC) in the objective function during optimal simulation process can be considered as the main comparison index for optimal capacity allocation. The total NPC is defined by the following equation:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i,Rproj)} \qquad (1)$$

Where $C_{ann,tot}$ is total annualized cost[\$yr], *CRF()* is the capital recovery factor , *i* is the interest rate [%], R_{proj} is the project life time. The total annualized cost is the sum of the annualized costs of each system component, plus the other annualized cost.

The capital recovery factor is a ratio used to calculate the present value of an annuity (a series of equal annual cash flows). The equation of capital recovery factor is shown by equation 2:

$$\mathrm{CRF}(i,n)=\frac{i(1+i)^N}{(1+i)^N-1} \qquad (2)$$

Where i is the interest rate, N is the number of year.

The hub height is very important factor during evaluating the wind energy. Different hub height converts different wind generation output. The conversion wind speed depends on the hub height and can be calculated by the equation below:

$$\frac{V(Z_{hub})}{V(Z_{anum})} = \left[\frac{Z_{hub}}{Z_{anem}}\right]^{\propto} \qquad (3)$$

Where Z_{hub} is the hub height of wind turbine (m), Z_{anem} is the anemometer height (m). $\propto$ is the law power exponent, $V(Z_{hub})$ is the wind speed at the hub height of the wind turbine (m/s), $V(Z_{anum})$ is wind speed at the hub height of the wind turbine (m/s) [6].

A capacity shortage of system is a shortfall that occurs between the required operating capacity and the actual amount of operating capacity the system can provide. HOMER keeps track of such shortages and calculates the total amount that occurs over the year [5]. With different capacity shortage, the net present cost will be changed. The NPC tend to increase with smaller capacity shortage

3. The Simulation Data for Homer

3.1. Load Profile

The primary load profile recorded in the building A of the Southern Taiwan University are used to tested the two different types of renewable system. The base data of average load profile was 1004 kw/hr/day, and the scale of average of load data was decreased to 50kw/hr/day to match the capacity of testing hybrid renewable system. Figure 1 and 2 shows the summary of month-based and yearly based load profile respectively.

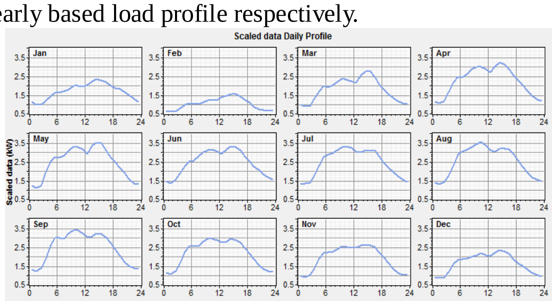

Figure 1. Monthly load profiles

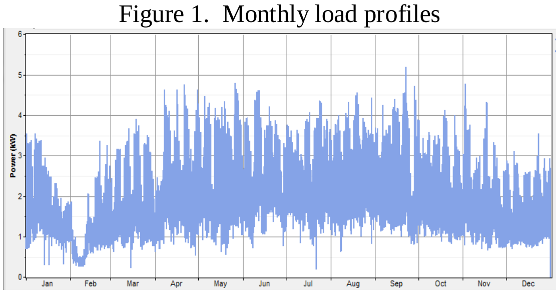

Figure2. Yearly load profile

3.2 The testing data of 25 different weather stations

The detailed geographical records of 25 different weather stations of the Central Weather Bureau are shown in the Table 1. The profile of average annual wind speed and global solar radiation at 25 locations are shown in the figure 3.

Table1. The detailed information for 25 locations of weather station in Taiwan[5]

N0	Location	latitude	Longitude	Z1	Z2	α
1	Chenggon	120°21'E	23°05'N	33.5	12.8	0.144
2	Hengchun	120°44'E	22°00'N	21.9	14.3	0.194
3	Penghu	119°33'E	23°34'N	10.7	14.6	0.150
4	Wuci	120°30'E	24°15'N	7.2	33.2	0.130
5	Keelung	121°43'E	25°08'N	26.7	34.6	0.250
6	Alishan	120°48'E	23°30'N	2413.4	15.1	0.110
7	Anbu	121°31'E	25°11'N	837.6	7.31	0.110
8	Chiayi	120°25'E	23°29'N	26.9	14.5	0.617
9	Jhuzihhu	121°32'E	25°09'N	607.1	11.03	0.250
10	Hsinchu	120°58'E	24°48'N	26.9	15.6	0.194
11	Hualien	121°36'E	22°58'N	16.1	12	0.173
12	Ilan	121°44'E	24°45'N	7.2	26	0.150
13	Kaoshiung	120°18'E	22°34'N	2.3	14	0.105
14	Lanyu	121°33'E	22°02'N	324.0	12.50	0.110
15	Pengjiayu	122°04'E	25°37'N	101.7	12.5	0.110
16	Dongjidao	119°39'E	23°15'N	43.0	9.1	0.125
17	Suao	121°51'E	24°36'N	21.9	14.3	0.150
18	Sunmoonlake	120°53'E	23°52'N	1014.8	8	0.150
19	Taichung	120°40'E	24°08'N	84	17.2	0.250
20	Taitung	121°08'E	22°45'N	9	11.4	0.150
21	Taipei	121°30'E	25°02'N	5.3	34.90	0.150
22	Tanshui	121°26'E	25°09'N	19	12.2	0.250
23	Dawu	120°53'E	22°21'N	8.1	12.7	0.244
24	Tainan	120°11'E	22°59'N	8.1	37.6	0.218
25	Yushan	120°57'E	23°29'N	2844.8	9.20	0.150

Where Z_1 is elevation from MSL, Z_2 is the anemometer height

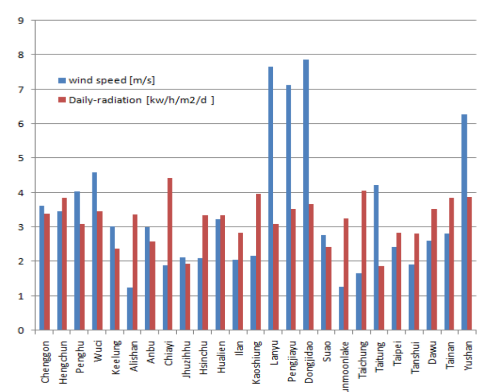

Figure 3. Average wind speed and daily global solar radiation at 25 locations in Taiwan on year 2007.

3.3. The cost data of the hybrid renewable system

The costs of different devices in the hybrid PV-Wind system are assumed by the Table 2. [6]

Table2. Price for simulation

Parameter	Capacity	Type	Prices (usd)
Wind turbine 1	10 kw	Generic	28900
Wind turbine 2	7.5 kw	BWC Excel-R	23030
Wind turbine 3	3 kw	Generic	5875
PV	1 kw		5059
Converter	1kw		750
Battery	200A 2.4kw/h	Vision 6FM200D	400

4. Simulation Results and Discussions

The Table 3 and 4 show the simulation result of the optimal total NPC at 25 locations in Taiwan with different capacity shortage and hub height (set to 20m). Because of limited space, only the simulation results of testing wind turbine, type of BWC ExcelR rated 7.5kw, are shown.

For PV-battery hybrid system, the optimal NPC among 25 locations occurs at Chiayi (239450USD), but the worst case appears at Keelung (622949USD) when the capacity shortage is set 3% and the hub height of wind turbine is set to 20 meter. The same place can be evaluated for the capacity shortage set to 5%. It is noted that the optimal total NPC is lower than capacity shortage is 3%. However, the place has the optimal NPC occurs at Hengchun (182302USD) and highest NPC appears at Keelung (483758USD) when the capacity shortage set to 10%.

For PV-Wind-battery hybrid system, the optimal NPC occurs at different places. It is demonstrated by a yellow space when the optimal and worst results occur. The optimal total NPC occurs at Pengjiayu (127973USD) and worst case appears at Ilan (494892USD). It is noted that that places are the same when capacity shortage is 5%. If capacity shortage equal 10%, the place has the optimal NPC is Pengjiayu (96924USD), and highest cost located at Keelung (362458USD).

For PV-battery hybrid system, comparisons with different capacity shortage can be shown by the Figure 4. The optimal and worst results can be concluded more obvious than the Table 3 and 4. The worst NPC occurs at Keelung, other places with low solar radiation, such as Anbu, Ilan, Suao, Jhuzihhu, Taipei, Tanshui, also have high NPC. The results are invariability in spite of different capacity shortage. Similar results but with a Wind-PV-battery hybrid system can be concluded and demonstrated by the Figure 5.

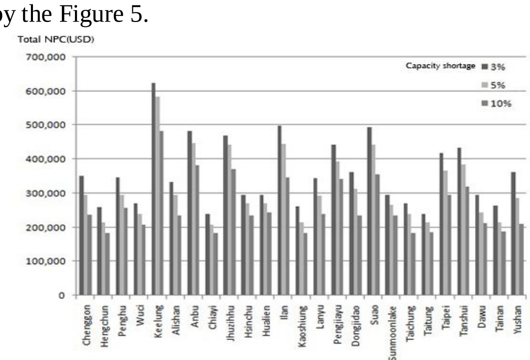

Figure 4. The optimal NPC with different capacity shortage using the PV- battery hybrid system

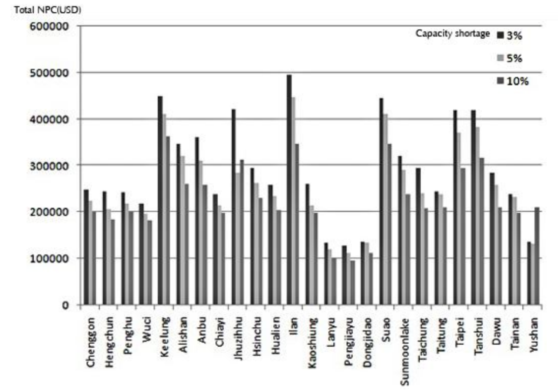

Figure 5. The optimal NPC with different capacity shortage using the Wind-PV- battery hybrid system.

With the wind turbine type BWC Excel-R, the comparisons of NPC in the wind-PV-battery & PV-battery hybrid system can be shown in the Figure 6. Results show that the NPC are lower in the Win-PV-battery hybrid system than in the PV-battery system in most of the locations in Taiwan, except at the locations of Alishan, Chiayi, Kaoshiung, Taichung, Taitung and Tainan. These results sourced from different weather features, such as higher solar resources (Alishan, Chiayi, Kaoshiung and Taichung) or lower wind resources (Taitung and Tainan).

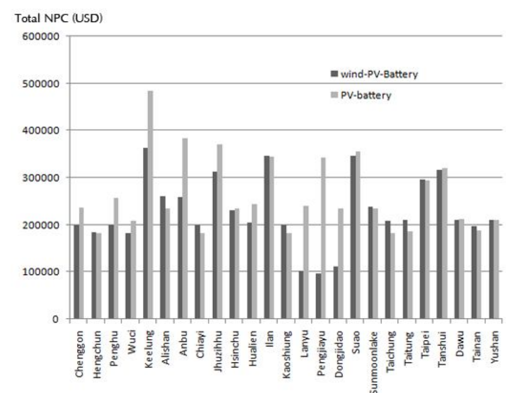

Figure 6. Comparisons with NPC in the PV-battery and wind-PV-battery system.
(hub height is 20m and capacity shortage is 10%)

The NPC is compared with four different hub heights of wind turbine and the results shown in Figure 7. The variations of hub height impact slightly on NPC in most of the locations. In general, wind speed tends to increase with increasing height above the ground. However, a small wind turbine installed below 50 meter, hub height is not the important factor affect the wind power. Only at Keelung the NPC changes from 311505USD to 398835USD.

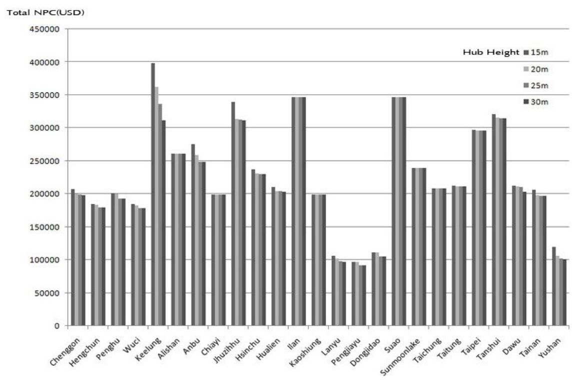

Figure 7. The comparisons of optimal total NPC with different hub height (capacity shortage is **10%**)

Finally, the impact of different wind turbines to NPC is discussed. In this study, the comparison of 3 types of wind turbine (Generic 10kw, BWC Excel-R 7,5kw, Generic 3 kw) is shown in the Figure 8. Expect Taichung, the Generic 10kw is the most expensive type of wind turbine in Taiwan. Compared to the factor of wind turbine type, the locations influence greatly on the total NPC.

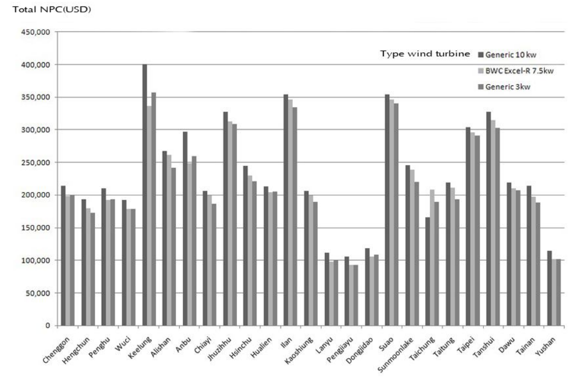

Figure 8. The comparisons of NPC with different types of wind turbine (hub height is 20m and capacity shortage is **10%**)

Table 3. Simulation result of the optimal total NPC at 25 locations in Taiwan with different capacity shortage and hub height set to 20m (Type wind turbine BWC ExcelR 7.5kw)

Capacity shortage		**3%**							**5%**						
No	Location	PV-Battery			Win-PV-Battery				PV-Battery			Win-PV-Battery			
		NPC	C.PV	N.B	NPC	C.PV	C.W	N.B	NPC	C.PV	N.B	NPC	C.PV	C.W	N.B
1	Chenggon	351,919	50	120	248886	20	2	100	295,295	40	100	224358	20	2	80
2	Hengchun	259,969	35	80	244,080	25	2	80	214,444	25	100	207651	20	1	100
3	Penghu	345571	45	150	243199	30	1	80	295985	35	150	217894	25	1	80
4	Wuci	269686	30	150	218785	20	2	80	240381	30	100	197131	20	1	80
5	Keelung	**622949**	55	450	449692	30	4	250	**584314**	55	400	412062	30	4	200
6	Alishan	333,616	35	200	347,467	40	1	150	294,981	35	150	321,167	35	1	150
7	Anbu	483,758	50	300	360,580	25	3	200	447,132	50	250	311,619	30	3	100
8	Chiayi	**239,450**	30	100	239,735	25	1	100	**208,975**	25	80	215,525	20	1	100
9	Jhuzihhu	469710	50	280	421723	40	1	250	443410	45	280	284093	40	1	200
10	Hsinchu	294981	35	150	295872	30	1	150	269686	30	150	263543	30	1	100
11	Hualien	294981	35	150	259631	25	2	100	269686	30	150	235038	20	2	100
12	Ilan	499815	50	320	**494892**	50	1	280	444415	45	280	**447018**	45	1	250
13	Kaoshiung	260796	35	80	260769	25	1	80	214265	25	100	214265	20	1	100
14	Lanyu	343742	50	100	134951	15	1	30	292722	40	100	119431	10	2	50
15	Pengjiayu	443410	45	280	**127973**	8	2	40	392820	35	280	**111904**	10	1	40
16	Dongjidao	363275	55	80	135781	15	1	30	312106	45	80	134776	15	1	30
17	Suao	495005	55	280	446198	35	2	280	443410	45	280	411284	40	2	200
18	Sunmoonlake	294981	35	150	321167	35	1	150	265613	35	100	291256	35	1	100
19	Taichung	269686	30	150	295872	30	2	150	238927	30	100	239869	25	1	100
20	Taitung	239840	30	80	244494	25	1	100	215600	25	80	238924	25	1	80
21	Taipei	418115	40	280	419007	35	1	280	367525	30	280	371133	30	1	250
22	Tanshui	433168	40	300	420011	35	1	280	384206	45	200	384206	40	1	200
23	Dawu	294981	35	150	284539	35	1	80	243939	30	100	258795	30	1	80
24	Tainan	264987	35	100	238423	25	1	100	215389	25	100	232140	20	2	80
25	Yushan	363354	55	100	137199	15	1	40	287187	40	100	131569	10	2	30

Table 4

Simulation result of the optimal total NPC at 25 locations in Taiwan with different capacity shortage and hub height set to 20m (Type wind turbine BWC ExcelR 7.5kw)

Capacity shortage		**10%**						
No	Location	PV-Battery			Win-PV-Battery			
		NPC	C.PV	N.B	NPC	C.PV	C.W	N.B
1	Chenggon	236,749	30	80	200093	20	1	80
2	Hengchun	**182,302**	20	80	184200	20	1	40
3	Penghu	257858	35	80	199831	20	2	40
4	Wuci	207773	25	80	182691	15	2	50
5	Keelung	**483758**	50	300	**362458**	35	4	100
6	Alishan	235,006	30	80	261,089	30	1	80
7	Anbu	383,201	45	200	259,133	25	2	100
8	Chiayi	182,413	20	80	199,531	20	1	50
9	Jhuzihhu	370866	50	150	313447	35	2	100
10	Hsinchu	234605	30	80	230895	25	1	80
11	Hualien	243536	30	100	204178	20	1	80
12	Ilan	345571	45	150	346462	40	1	150
13	Kaoshiung	182738	20	80	199395	20	1	50
14	Lanyu	240133	30	100	101786	8	2	40
15	Pengjiayu	342230	25	280	**96924**	8	1	30
16	Dongjidao	233920	30	80	111904	10	1	40
17	Suao	356194	35	230	346462	40	1	150
18	Sunmoonlake	233934	30	80	239248	25	1	100
19	Taichung	182552	20	80	208539	20	1	80
20	Taitung	186306	20	80	211220	20	1	80
21	Taipei	294981	35	150	295872	30	1	150
22	Tanshui	320276	40	150	316118	35	2	100
23	Dawu	211587	25	80	211154	20	1	100
24	Tainan	187959	20	100	198314	20	1	50
25	Yushan	210232	25	100	106239	10	1	30

PV-battery: photovoltaic-battery hybrid system,Wind-PV-battery: Wind-photooltaic-battery hybrid system
NPC : Net present cost,CPV : capacity of photovoltaic (kw), NB : number of battery,NW : number of unit wind turbine

5. Conclusion

This paper discusses about the comparisons of the optimal NPC at 25 weather station locations in Taiwan. The optimal result of NPC and the relevant capacity combinations in the hybrid renewable system are helpful for any renewable system planner. The optimal capacity allocation for Wind/PV/battery and PV/Battery hybrid system at 3 different system risk (capacity shortage 3%, 5%, 10%) are compared and discussed in different 25 locations. With the conclusions of the paper, the system planner can decide which components can be installed to attain an optimal total NPC in a stand alone hybrid renewable system.

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