Liu Liqun, Liu Chunxia

Taiyuan University of Science & Technology

Feasibility analyses of hybrid wind-PV-battery power system in Dongwangsha, Shanghai

***Abstract**. This paper gives the feasibility analysis of a wind-PV-battery system for an off-grid power station specially located in remote village of Dongwangsha, Shanghai. The simulation and optimization results indicated the feasibility analyses of the proposed hybrid wind-PV system with storage battery backup. Moreover, the GHG emissions, project costs and savings/income summary, financial viability, and risk analysis are discussed. The proposed hybrid system is more environmental friendly as compared with the diesel only system.*

Streszczenie.** W artykule przedstawiono analizę wykonalności budowy systemu baterii dla farmy wiatrowo-fotowoltaicznej wyłączonej z sieci energetycznej w oddalonej wiosce Dongwangsha, w okolicy Szanghaju. Przeprowadzono kompleksowe badania obejmujące parametry takie jak: emisja GHG, koszty i wpływy projektu, analizę ryzyka. (**Analiza wykonalności systemu baterii dla hybrydowej farmy wiatrowo-fotowoltaicznej w Dongwangsha, w okolicy Szanghaju).

Keywords: enewable energy; Feasibility analysis; Hybrid power supply system.
Słowa kluczowe:energia odnawialna, analiza wykonalności, hybrydowy system zasilania.

Introduction

The State Grid in China can not supply the total end consumers with enough power due to the large territory and there are so many remote districts, and there is millions of off-grid consumers have to use the stand-along diesel generating system in order to supply the power demand. The diesel only power system consumes a lot of diesel and a mass of greenhouse gases emissions. And with the ever-increasing price of fossil resource, the hybrid generating system is proposed to offer steady and reliable and cheap power supply for the off-grid user as compared with the diesel only generating system.

Many literatures have analyzed the renewable resource generating system by using HOMER or Hybrid2 or RETscreen [1-8]. RETscreen is clean energy project analysis software to analyze the technical and financial viability of possible clean energy projects, which takes advantage of renewable power generating technology to improve conventional electricity grid in the method of replacing sectional or entire traditional electricity grid by renewable energy power generation. This paper presents the feasibility analyses of hybrid wind-PV-battery power system to arouse the regard of the designer and engineers in China. In this context, the present study carries out a feasibility analysis by using RETscreen software of Natural Resources Canada and the data of National Aeronautics and Space Administration (NASA) to analyze a hybrid wind-PV system with storage battery backup for a remote village located in Dongwangsha, Chongming islands, Shanghai, China [9-11].

Site and Electrical load and Meteorological data

Dongwangsha located in Chongming island of Shanghai where apart from the national electrical grid. The diesel only system cannot ensure the continuous electricity supply during breakdown and scheduled shutdown of diesel units. With the change of environmental and social factors, especially the decreases of non-renewable energy resource, the power generated by conventional electrical grid do not meet the demand any more. As a result, a kind of hybrid wind-PV-battery system generating system is compared with the conventional fossil resource generating system, and the proposed system has many advantages superior to others. To be more specific, on one hand, local abundant renewable resource like wind and solar energy is able to supply enough resource for the renewable energy power generation. On the other hand, the use of clean energy reduces the greenhouse gas emissions and environmental damage greatly while generating electrical energy, which can save cost at the same time. The power load of Dongwangsha is shown in Fig.1 [12].

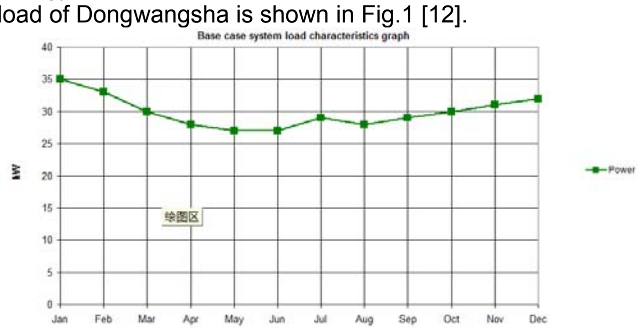


Fig.1. Base case system load characteristics graph.

According to the load characteristics, the maximum monthly power of the load is 35KW. The summer and winter are the periods of peak load. On the basis of the project location and local meteorological data, the scaled annual average value of wind speed is 4.5m/s and the highest values of wind speed are observed during the months of January to February with a maximum of 4.91m/s. The scaled annual average value of monthly average daily total global solar radiation (GSR) is $3.48\,\mathrm{KWh}/m^2/d$, the highest values of GSR are gained during the months of May to August with a maximum of $4.84\mathrm{KWh}/m^2/d$ as can be seen from Fig.2. Compared to the price of PV power system, the wind power system is relatively cheap. Thus, the wind power becomes the technology of base load power system while the PV generator which has more rated power constitute the intermediate load power system in the renewable power generation system. The peak load power system consists of traditional grid electricity. To be mentioned, the peak load power system can not be designed in the renewable system if it was not required so that we can save the cost of diesel and reduce the greenhouse gas (GHG) emissions.

As shown in Fig.3, the base case of power system, which is an off-grid system, its power generation relies on the fuel generator. The fuel rate is 1.5$/L， and the total electricity cost is 194191$. In general, it’s not easy for the typical clients to afford to these high fees. They would like to invest in those economical projects. Further more, in the case of the electricity generation efficiency is 31% and the transportation and the distribution losses are 8%, the annual greenhouse gas emissions are 226.2t, which bring much air pollution to the environment.

	Unit	Climate data location	Project location
Latitude	°N	31.4	31.4
Longitude	°E	121.5	121.5
Elevation	m	4	4
Heating design temperature	°C	-0.6	
Cooling design temperature	°C	33.6	
Earth temperature amplitude	°C	14.8	

Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
		°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January		4.9	72.2%	2.04	102.5	3.0	5.3	406	0
February		6.4	71.3%	2.63	102.4	3.1	6.3	325	0
March		9.9	73.1%	3.12	102.0	3.3	9.5	251	0
April		15.5	72.7%	4.02	101.5	3.2	14.4	75	165
May		20.4	74.5%	4.44	101.0	3.3	18.9	0	322
June		24.3	79.4%	4.24	100.5	3.1	23.0	0	429
July		28.4	78.4%	4.84	100.4	3.3	26.6	0	570
August		28.0	79.2%	4.47	100.5	3.6	26.6	0	558
September		24.6	75.5%	3.96	101.1	3.4	23.1	0	438
October		19.5	72.3%	3.34	101.8	2.9	18.3	0	295
November		13.8	72.0%	2.51	102.3	2.9	13.2	126	114
December		7.7	70.7%	2.05	102.6	3.0	7.8	319	0
Annual		17.0	74.3%	3.48	101.5	3.2	16.1	1,502	2,891
Measured at	m					40.0	0.0		

Fig.2. Meteorological data of project site.

Power project	Unit		
Base case power system			
Grid type		Off-grid	
Technology		Grid electricity	
Fuel type		Diesel (#2 oil) - L	
Fuel rate	$/L	1.500	
Capacity	kW	35	
Heat rate	kJ/kWh	11,613	
Annual O&M cost	$	67,798	
Electricity rate - base case	$/kWh	0.738	
Total electricity cost		$	194,191

Fig.3. Base case power system.

Hybrid power system and results and discussion

Compared to base case power system, the proposed power system adds wind turbine （the power capacity per wind turbine with 3KW, as shown in Fig.4）and photovoltaic generator with 25KW and the considered number is 24 and 10, respectively.

If the project uses 20 wind turbines, as shown in Fig.5 to Fig.7, the IRR is only 53.5% while the net annual GHG emission reduction is 198.2t. The amount of electricity delivered to load is just 68.4% [13].

			Shanghai
Wind speed - annual	m/s	4.4	3.2
Measured at	m	10.0	40.0
Wind shear exponent		0.14	
Air temperature - annual	°C	15.3	17.0
Atmospheric pressure - annual	kPa	1,015.0	101.5
Wind turbine			
Power capacity per turbine	kW	3.0	
Manufacturer		Guangdong Shangneng wind power epuipment ltd.	
Model		SN-3000WL	
Number of turbines		24	
Power capacity	kW	72.0	0.0%
Hub height	m	15.0	4.7 m/s
Rotor diameter per turbine	m	3	
Swept area per turbine	m²	7	
Energy curve data		Standard	
Shape factor		2.0	

Fig.4. Data of wind turbine of proposed system.

Technology		Wind turbine	
		Method 1	
		Method 2	
Analysis type		Method 3	
Wind turbine #1			
Power capacity	kW	60.0	174.9%
Manufacturer		Guangdong Shangneng wind power epuipment ltd.	
Model		SN-10000WL	1 unit(s)
Capacity factor	%	30.0%	
Electricity delivered to load	MWh	158	68.4%
Electricity exported to grid	MWh	0	

Fig.5. Proposed case power system 1.

GHG emission reduction summary	Base case GHG emission	Proposed case GHG emission	Gross annual GHG emission reduction	GHG credits transaction fee	Net annual GHG emission reduction
	tCO2	tCO2	tCO2	%	tCO2
Power project	226.2	17.6	208.6	5%	198.2

Fig.6. GHG emission reduction summary 1.

Financial viability		
Pre-tax IRR - equity	%	53.5%
Pre-tax IRR - assets	%	53.5%
After-tax IRR - equity	%	53.5%
After-tax IRR - assets	%	53.5%
Simple payback	yr	2.0
Equity payback	yr	1.9
Net Present Value (NPV)	$	1,260,163
Annual life cycle savings	$/yr	148,018
Benefit-Cost (B-C) ratio		5.02
GHG reduction cost	$/tCO2	(747)

Fig.7. Financial viability 1.

Wind turbine #1			
Power capacity	kW	90.0	262.4%
Manufacturer		Guangdong Shangneng wind power epuipment ltd.	
Model		SN-10000WL	1 unit(s)
Capacity factor	%	30.0%	
Electricity delivered to load	MWh	225	97.5%
Electricity exported to grid	MWh	12	

Fig.8. Proposed case power system 2.

GHG emission reduction summary	Base case GHG emission	Proposed case GHG emission	Gross annual GHG emission reduction	GHG credits transaction fee	Net annual GHG emission reduction
	tCO2	tCO2	tCO2	%	tCO2
Power project	226.2	0.1	226.1	5%	214.8

Net annual GHG emission reduction 215 tCO2 is equivalent to 39.4 Cars & light trucks not used

Fig.9. GHG emission reduction summary 2.

Financial viability		
Pre-tax IRR - equity	%	52.9%
Pre-tax IRR - assets	%	52.9%
After-tax IRR - equity	%	52.9%
After-tax IRR - assets	%	52.9%
Simple payback	yr	2.0
Equity payback	yr	1.9
Net Present Value (NPV)	$	1,478,794
Annual life cycle savings	$/yr	173,699
Benefit-Cost (B-C) ratio		4.96
GHG reduction cost	$/tCO2	(809)

Fig.10. Financial viability 2.

If the project uses 30 wind turbines, as shown in Fig.8 to Fig.10, although the amount of electricity delivered to load increases to 97.5%, the net annual GHG emission reduction rises to 214.8t simultaneously. Due to investing much fund in project for the equipments, the IRR drops to only 52.9%.

It can be seen clearly from the table that the IRR (56.7%) of the system which using 24 wind turbines is higher than that (52.9%) of the system using 30 wind turbines as a result of the lower cost of the former system. Further more, the percentage of electricity delivered to load is 82.1%, while the net annual GHG emission reduction rises to 211.6t. In terms of the project economic, the proposed power system comprised by 24 wind turbines tend to be the most economical one. More specifically, in this energy model, the percentage of electricity generated by wind turbines and PV generators are 82.1% and 16.2%, respectively. The remaining electricity supplied by fuel generators accounts for 1.6% of the total. The back-up power system made up with batteries is designed in case of emergency. All in all, the energy structure of this power generating system not only make full use of the local wind energy and solar energy, but also improve local conventional power generating system with low efficiency and high cost as well as meeting the demands eventually. The system design graph is shown in Fig.11 and Fig.12.

Proposed case system characteristics	Unit	Estimate	%
Power			
Base load power system			
Technology		Wind turbine	
Operating strategy		Full power capacity output	
Capacity	kW	72	209.9%
Electricity delivered to load	MWh	189	82.1%
Electricity exported to grid	MWh	0	
Intermediate load power system			
Technology		Photovoltaic	
Operating strategy		Full power capacity output	
Capacity	kW	25	72.9%
Electricity delivered to load	MWh	37	16.2%
Electricity exported to grid	MWh	17	
Peak load power system			
Technology		Grid electricity	
Suggested capacity	kW	34.3	
Capacity	kW	35	102.0%
Electricity delivered to load	MWh	4	1.6%
Back-up power system (optional)			
Technology		battery	
Capacity	kW	60	

Fig.11. proposed case system characteristics.

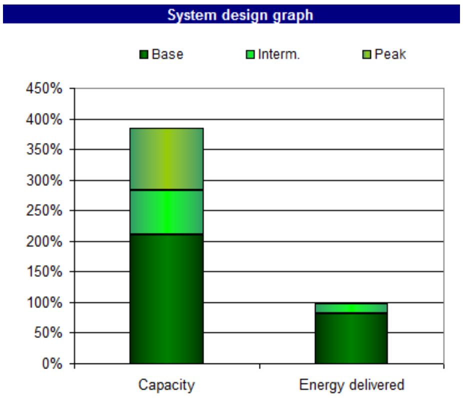


Fig.12. System design graph.

GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2			Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Power project	226.2	3.5			222.7	5%	211.6
Net annual GHG emission reduction	212	tCO2	is equivalent to	38.8	Cars & light trucks not used		

Fig.13. GHG emission reduction summary.

In terms of GHG emissions, the proposed case power system declines the emissions because of the use of clean energy. If calculated as the emissions of 25t carbon dioxide equal to 1t methane and the emissions of 298t carbon dioxide equal to 1t nitrous oxide, the electricity generation efficiency is 31% and the transportation and the distribution losses are 8%, the amount of GHG emissions of generating 1MKWh electricity declines from 226.2t to 3.5t. At the same time, the gross annual GHG emission reduction is 222.7t. What's more, the net annual GHG emission reduction is 211.6t and the total emission is 4232t when the GHG credits transaction fee is 5% and the project life is 20 years, as shown in Fig.13.

Project costs and savings/income summary			
Initial costs			
Feasibility study	1.5%	$	5,000
Power system	86.7%	$	292,600
Balance of system & misc.	11.8%	$	40,000
Total initial costs	**100.0%**	**$**	**337,600**
Annual costs and debt payments			
O&M		$	7,492
Fuel cost - proposed case		$	5,611
Total annual costs		**$**	**13,104**
Periodic costs (credits)			
User-defined - 20 yrs		$	22
Annual savings and income			
Fuel cost - base case		$	194,191
Total annual savings and income		**$**	**194,191**

Fig.14. Project costs and savings/income summary.

In terms of financial analysis, the total cost of renewable energy is lower than that of non-renewable energy considerably. Even though the renewable system invests much in the construction and equipments, the management and operation cost less relatively. It is assumed that fuel cost escalation rate is 2%, inflation rate is 2%, discount rate is10% and project life is 20 years , the annual savings and income is 194191$, the net present value (NPV) is 1461288$, the annual life cycle savings is 171642$ and the IRR is 56.7%. At the same time, the benefit-cost ratio is

5.33 and the simple payback is 1.9 yr. In a word, as compared to other systems, its project payback peaks to the maximum, as shown in Fig.14. The financial viability and the cumulative cash flows graph are shown in Fig.15 and Fig.16.

Financial viability		
Pre-tax IRR - equity	%	56.7%
Pre-tax IRR - assets	%	56.7%
After-tax IRR - equity	%	56.7%
After-tax IRR - assets	%	56.7%
Simple payback	yr	1.9
Equity payback	yr	1.8
Net Present Value (NPV)	$	1,461,288
Annual life cycle savings	$/yr	171,642
Benefit-Cost (B-C) ratio		5.33
GHG reduction cost	$/tCO2	(811)

Fig.15. Financial viability.

In terms of risk analysis, the most critical factor is fuel cost. However, the reduction of fossil fuel and the cost of the system are able to lessen investment risk and sensitivity, as shown in Fig.17.

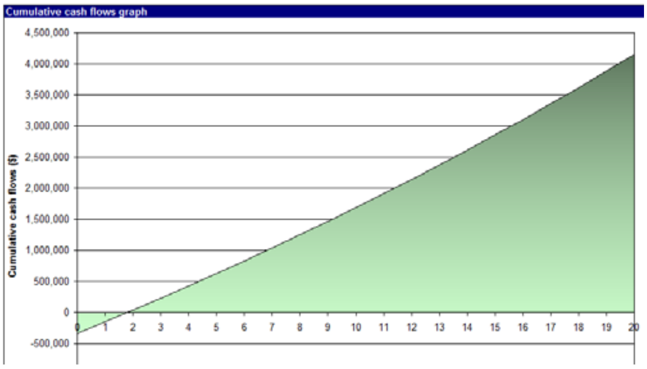
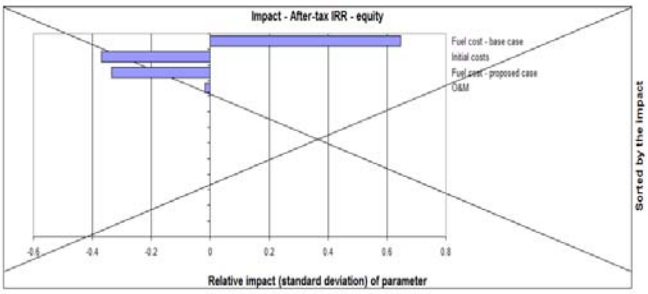
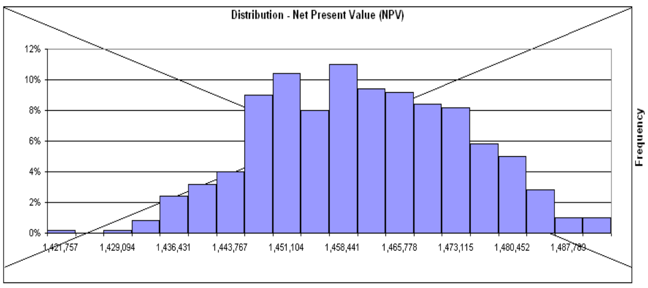


Fig.16. Cumulative cash flows graph.



(a)



(b)

Fig.17. Risk analysis.

Conclusion

In this paper, a hybrid wind-PV-battery power system is discussed to explore the possibility of utilizing power of the wind and solar to reduce the dependence on fossil fuel for power generating system to meet the electric requirement of remote village located in Dongwangsha, the seaside of the Chongming islands, Shanghai. In terms of the project economic, the proposed power system comprised by 24 wind turbines tend to be the most economical one. More specifically, in this energy model, the percentage of electricity generated by wind turbines and PV generators are 82.1% and 16.2%, respectively. The proposed system are more environmental friendly as compared with the conventional diesel only system and the greenhouse gases emission is less than the diesel only system. As a conclusion, the feasibility analyse is very important to select the appropriate hybrid renewable power system based on Local meteorological conditions.

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***Authors**: Assistant prof. L.Q. Liu, college of electronic and Information engineering, Taiyuan University of Science & Technology, Waliu road 66, Wanbolin district, Taiyuan, China, E-mail: llqd2004@163.com; Assistant prof. C.X. Liu, College of computer science & technology, Taiyuan University of Science & Technology, Waliu road 66, Wanbolin district, Taiyuan, China, E-mail: lcx456@163.com.*