HOMER ANALYSIS OF WIND ENERGY FOR CHINA

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ABSTRACT

As an excellent replacement of conventional energy, the alternative energy has gained much popularity around the world. Research has been undertaken by many countries due to its benefits. However, it is still far away from the widespread application because of its high construction cost. Therefore, the simulation for the performance of alternative energy system before the commencement of the construction is significant. As a huge country on land and population, it is more significant for China to explore the availability of alternative energy. In this Project, the HOMER software has been used to perform the simulation work for the wind energy system under different wind speed levels and real interest rates. Based on the simulation, the higher wind speed level may reduce the cost of the wind turbine system and the high real interest rate may make the whole project less expensive. Also, the larger number of wind turbine and battery make the whole system more reliable on the renewable energy and have less negative impact on the environment.

ABSTRAK

Tenaga alternatif telah mendapat populariti di seluruh dunia, sebagai pengganti yang baik untuk tenaga konvensional. Penyelidikan telah dijalankan di banyak negara disebabken oleh faedah-fadedahnya. Walau bagaimanapun, tenaga alternatif masih jauh daripada penggunaan yang meluas disebabkan oleh kos pembinaan yang tinggi. Oleh itu, simulasi bagi pelaksanaan sistem tenaga alternatif sebelum bermulanya pembinaan adalah penting. Sebagai sebuah negara yang besar denpan ramai penduduk, ia adalah lebih penting bagi negara China untuk meneroka tenaga alternatif. Dalam projek ini, perisian HOMER telah digunakan untuk melaksanakan kerja simulasi untuk sistem tenaga angin bagi menilai kesan tahap kelajuan angin dan kadar faedah sebenar yang berbeza. Berdasarkan simulasi, tahap kelajuan angin yang lebih tinggi boleh mengurangkan kos sistem turbin angin dan kadar faedah sebenar yang tinggi boleh mengurangkan kos keseluruhan projek. Selain itu, bilangan turbin angin dan bateri yang lebih banyak menghasilkan kesuluruhan sistem turbin angin yang lebih boleh dipercayai dan mengurangkan kesan negatif ke atas alam sekitar.

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LIST OF ABBREVIATIONS

SOC - State of Charge
DOD - Depth of Discharge
NASA - National Aeronautics and Space Agency
NPC - Net Present Cost

CHAPTER 1

INTRODUCTION

1.1 Background

In the 21st century, a great deal of research on alternative energy system is being undertaken by many countries. The concerns about energy security has risen as the conventional energy will run out in the near future. Because the alternative energy is clean, eco-friendly and sustainable, it is very important to put them into practice as soon as possible. There are many types of alternative energy, such as solar energy, biomass energy, thermal energy, hydrogen energy and ocean energy. As one of the most popular alternative energy, wind energy became popular in the late of 20th as the energy crisis broke out.

1.2 Overview of Wind Turbine

The wind can be used as a kind of alternative energy because it contains huge amount of kinetic energy. In order to convert the kinetic energy into electricity, the wind turbine must be used. The mechanism of the wind turbine is shown in Figure 1.1

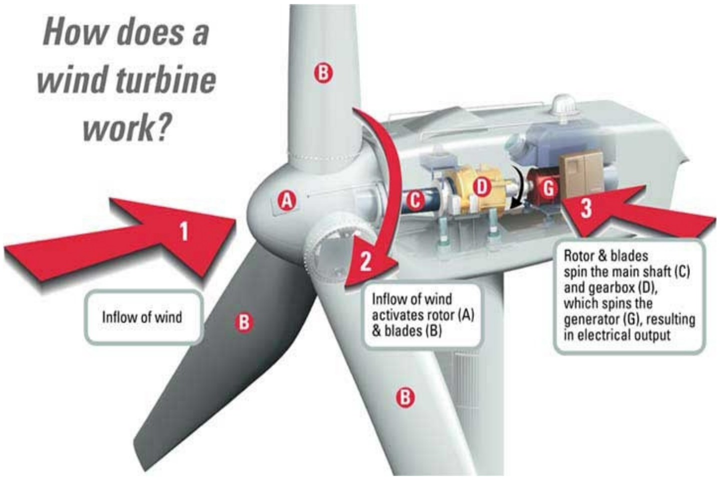

Fig 1.1 The Mechanism of Wind Turbine

When the air flow gets through the wind turbine, it will start to rotate. The rotation of the wind turbine will spin the main shaft and gearbox that spin the generator, contributing to the electricity output. During this process, the wind energy is converted into mechanical energy first, then the mechanical energy is transformed into electricity.

1.3 The HOMER Software

To assess the performance of the alternative energy system based on the economics and environmental effect, the HOMER software are frequently used. The HOMER software is the hybrid optimization modeling software, developed by National Renewable Energy Laboratory. Its main function is to perform simulation, optimization and sensitivity analysis. First of all, the HOMER simulates the different configurations of alternative energy system. Secondly, it gets the optimal result on the basis of the NPC(Net Present Cost). At last, the sensitivity analysis will be conducted due to the instabilities of some key factors.

1.4 Problem Statement

The wind speed level is critical to the construction of the wind energy conversion system as it may significantly affect the system's performance. It is well known that China has a mass of land area, which leads to the diversity of geographical situation of China. Therefore, the wind speed levels distribution varies from region to region. The wind speed levels distribution in different regions of China is shown in Figure 1.2

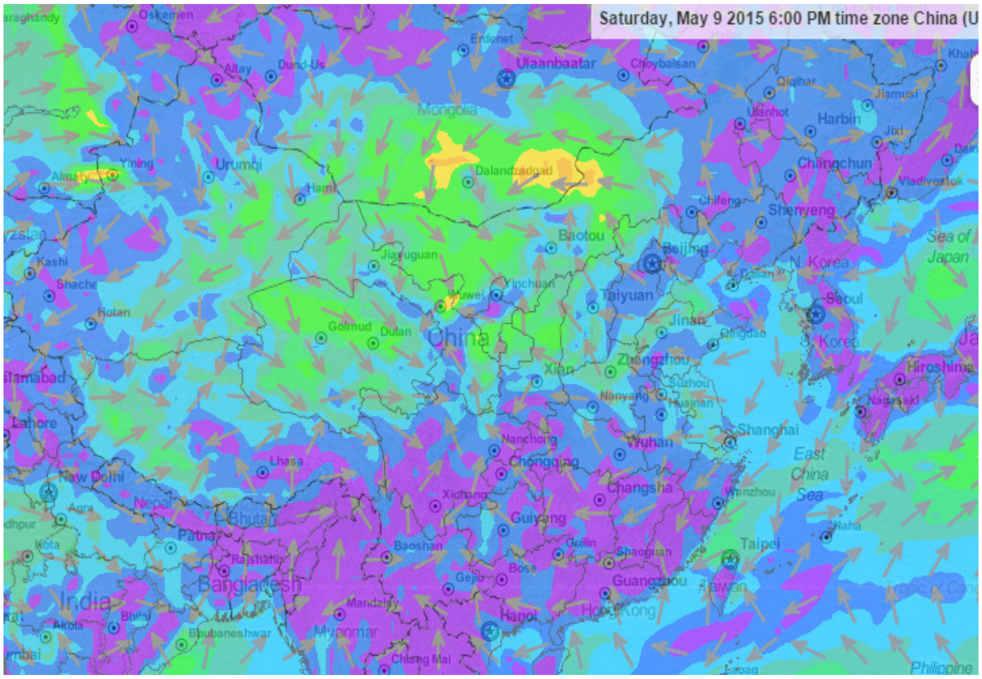

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Fig 1.2 The Wind Energy Distribution In China

From this picture, the different wind speed level has been indicated by using different colors. It can be seen that the northern part of China is in the possession of maximum wind speed of approximate 20m/s. Considering this situation, it is necessary to find out the effect of the wind speed level on the construction of wind energy conversion system in China.

1.5 Objectives

The Objectives of this project are: 1)to acquire the important geographical data . For example, the wind speed in the given height. 2)to design and simulate the wind energy system under different conditions(wind speed level, real interest rate)by using Homer software 3) to assess the performance of the wind energy system under different conditions.

1.6 Scopes

The Scopes of this project are as follow:

1. Design wind energy system

2. Simulate, optimize the wind energy system and conduct the economic and technological analysis

CHAPTER 2

LITERATURE REVIEW

2.1 The Wind Energy Conversion System(WECS)

The WECS, which is also known as wind energy harvester, is to convert the wind energy into electricity. In order to acquire the good quality of electrical power, it usually contains many electrical components such as diode, converter and battery. The control system is also implemented frequently.

2.1.1 The Configuration of WECS

The Figure 2.1 is a typical configuration of the WECS[1]. The HAWT (Horizontal-Axis Wind Turbine) converts the wind energy into mechanical power which activates the gearbox. Consequently, the rotor of the generator starts to rotate and lead to the generation of electricity.

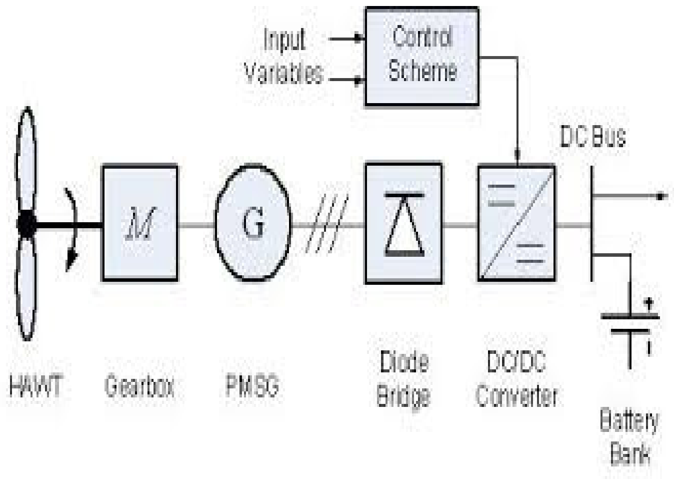


Fig 2.1 The Typical Configuration of WECS

However, the electricity generated by the wind turbine cannot be applied to the load directly. It must be either converted or regulated through a group of power electronic equipment regardless of its original form[2]. And because of the variability of the wind energy, a control system is formulated to affect the operation of wind turbine. More importantly, with the purpose of the increase of efficiency, the excess electrical power generated by the wind turbine has to be stored in the battery system. So it will be able to supply the load when there is a shortage of electrical power.

2.1.2 The Output Power of Wind Turbine

It is not that the faster wind speed will result in the more output power, the Figure 2.2 is wind speed power curve[3]. It demonstrates the relation between the output power and the wind speed. When the wind speed reaches 3.5 m/s, the wind turbine mechanical starts to be converted into electrical output power, this speed is defined as cut-in speed. The output power goes up with the increase of the wind speed till that reaches the maximum output power[4]. After this, the output power remains consistent. When the speed is 25 m/s, which is defined as the cut-off speed, the wind turbine stops generating more electrical power.

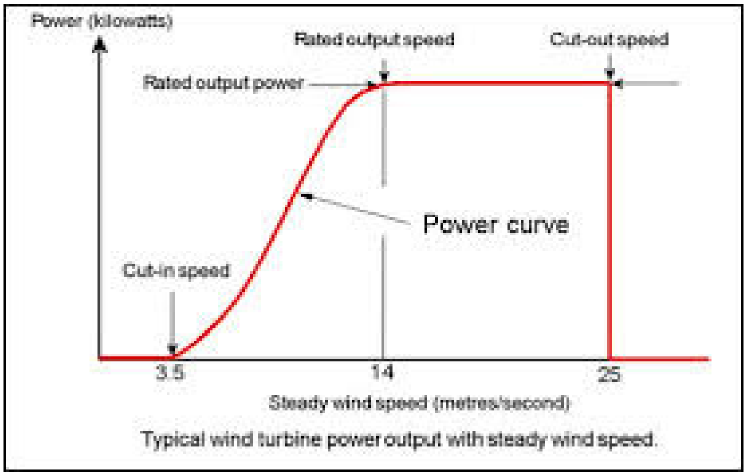


Fig 2.2 Wind Speed Power Curve

2.2 Energy Storage Technology

In order to avoid the waste of excess electrical power, the electrical power can be stored by means of converting it into other forms of energy, such as potential energy, Kinetic energy and Chemical energy. Currently, there are many storage technologies such as batteries, fuel cells and flywheels.

2.2.1 The Battery

The battery is a device that converts the electrical energy into chemical energy, with its mature technology, it has gained much popularity in the global market. There are a great many types of batteries, such as Lead-acid, Nickel cadmium, Nickel metal hydride and Lithium ion battery.

The Lead-acid battery has the most matured technology and it is widely used in distribution generation system[5]. The deep-cycle Lead-acid battery is the most suitable option for small-cycle alternative energy system given that it can be discharged repeatedly as much as 80% of its capacity. The disadvantage of this kind of battery is that it has limited cycle life and is vulnerable to the temperature.

Compared with the Lead-acid battery, the Nickel cadmium battery has much longer cycle life. It is considered as a excellent replacement for Lead-acid battery. The Nickel metal hydride battery is environmentally harmless with improved performance. It is predicted that it will become the most leading battery technology in the future.

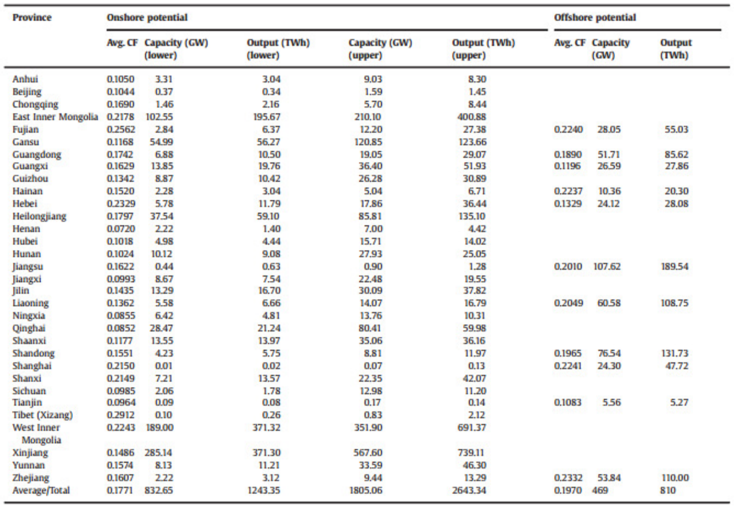
At present, the Lithium ion battery is mostly used in some small electronic gadgets, such as mobile phone, laptop and tablet. But it has a bright prospect in the application of alternative energy system. The efficiency of this kind of battery is amazingly closed to 100%. However, the biggest obstacles for this technology is the large initial investment. Fortunately, Many research has been carried out to reduce the cost.

2.2.2 The State of Charge (SOC)

The battery state of charge (SOC) is the cumulative summation of the daily charge and discharge transfers[6]. The Depth of Discharge(DOD) is determined by the period of discharge**,** it suggests the amount of energy that the storage system has taken out, the maximum SOC equals 1 while the minimum is determined by DOD.

2.3 Wind Energy Distribution in China

In this study, the wind energy distribution is acquired through the simulation with geographical information system. The wind speed, wind direction, temperature and air pressure at any given time are the significant inputs for this simulation[7]. The locations has been chosen according to some criteria in each province of China. The potential wind capacity and the capacity factor are two important values that need to be obtained through the simulation[8]. After this simulation, the potential wind capacity and capacity factor in different provinces of China is shown in Figure 2.3



Province	Onshore potential					Offshore potential		
	Avg. CF	Capacity (GW) (lower)	Output (TWh) (lower)	Capacity (GW) (upper)	Output (TWh) (upper)	Avg. CF	Capacity (GW)	Output (TWh)
Anhui	0.1050	3.31	3.04	9.03	8.30			
Beijing	0.1044	0.37	0.34	1.59	1.45			
Chongqing	0.1690	1.46	2.16	5.70	8.44			
East Inner Mongolia	0.2178	102.55	195.67	210.10	400.88			
Fujian	0.2562	2.84	6.37	12.20	27.38	0.2240	28.05	55.03
Gansu	0.1168	54.99	56.27	120.85	123.66			
Guangdong	0.1742	6.88	10.50	19.05	29.07	0.1890	51.71	85.62
Guangxi	0.1629	13.85	19.76	36.40	51.93	0.1196	26.59	27.86
Guizhou	0.1342	8.87	10.42	26.28	30.89			
Hainan	0.1520	2.28	3.04	5.04	6.71	0.2237	10.36	20.30
Hebei	0.2329	5.78	11.79	17.86	36.44	0.1329	24.12	28.08
Heilongjiang	0.1797	37.54	59.10	85.81	135.10			
Henan	0.0720	2.22	1.40	7.00	4.42			
Hubei	0.1018	4.98	4.44	15.71	14.02			
Hunan	0.1024	10.12	9.08	27.93	25.05			
Jiangsu	0.1622	0.44	0.63	0.90	1.28	0.2010	107.62	189.54
Jiangxi	0.0993	8.67	7.54	22.48	19.55			
Jilin	0.1435	13.29	16.70	30.09	37.82			
Liaoning	0.1362	5.58	6.66	14.07	16.79	0.2049	60.58	108.75
Ningxia	0.0855	6.42	4.81	13.76	10.31			
Qinghai	0.0852	28.47	21.24	80.41	59.98			
Shaanxi	0.1177	13.55	13.97	35.06	36.16			
Shandong	0.1551	4.23	5.75	8.81	11.97	0.1965	76.54	131.73
Shanghai	0.2150	0.01	0.02	0.07	0.13	0.2241	24.30	47.72
Shanxi	0.2149	7.21	13.57	22.35	42.07			
Sichuan	0.0985	2.06	1.78	12.98	11.20			
Tianjin	0.0964	0.09	0.08	0.17	0.14	0.1083	5.56	5.27
Tibet (Xizang)	0.2912	0.10	0.26	0.83	2.12			
West Inner Mongolia	0.2243	189.00	371.32	351.90	691.37			
Xinjiang	0.1486	285.14	371.30	567.60	739.11			
Yunnan	0.1574	8.13	11.21	33.59	46.30			
Zhejiang	0.1607	2.22	3.12	9.44	13.29	0.2332	53.84	110.00
Average/Total	0.1771	832.65	1243.35	1805.06	2643.34	0.1970	469	810

Fig 2.3 The Potential Wind Capacity and Capacity Factor In Different Regions of China

2.4 Hybrid Wind/PV/Battery Power System In China

2.4.1 The Selection of Wind Turbine

The wind speed level in the place where this hybrid system has been installed has the range from 3.32 m/s to 3.94 m/s, and the average wind speed level each year is 3.61 m/s. Based on this meteorological information, the WES 5 Tulipo wind turbine has been selected.

2.4.2 The Advantage of The Hybrid System

The Hybrid wind /PV/battery power system is more advantageous than the PV battery and wind battery power system[9]. The total net present cost has been decreased by 9% and 11% in comparison with the PV battery and wind battery power system respectively.

2.4.3 The Limit Of The Hybrid System

According to the sensitivity analysis, the solar energy is more efficient than the wind energy and the cost of PV module contributes to the majority of net present cost. Therefore, for those places where the solar energy is unavailable and also for the economical reason, the wind energy system should be taken into consideration separately.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The chapter explains the process of this project from the beginning to the end. The summary of the methodology of this project is shown is Figure 3.1.

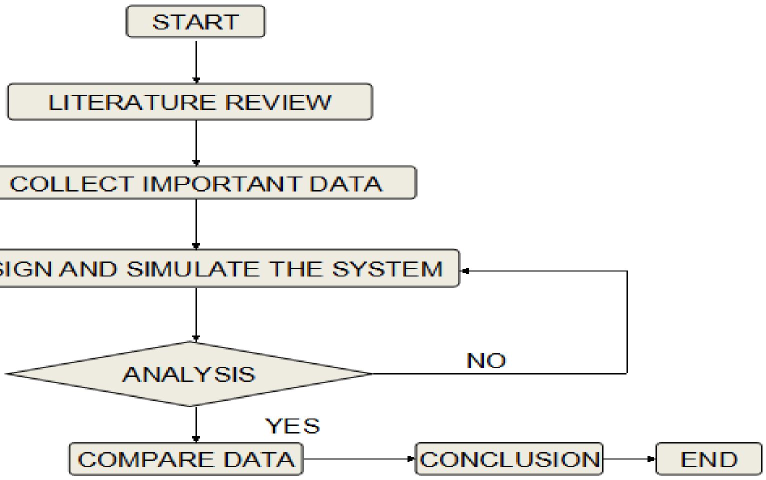


Fig 3.1 Flow Chart of The Methodology

3.2 Data Collection

The related data performs an significant role in this project. To make the design and simulation as accurate as possible, the date should be real and solid.

3.2.1 Selected Wind Speed Levels

China is a geographically diverse country. In order to represent the geographic characteristics in different regions as much as possible, a wider range of wind speed levels have been selected,. In this study, the main focus is to investigate how the different wind speed levels influence the performance of the wind energy system , therefore , the detailed geographical information, such as longitude and latitude, hasn't been given. For the further research, this paper can be used as the reference for the case where the wind speed is similar to the ones in this paper.

3.2.2 Meteorological Data

The wind speed level is the most important meteorological data needed to obtain. In this study, as one of the most prestigious agencies in the world running the civilian space program as well as conducting aeronautics and aerospace research, National Aeronautics and Space Administration (NASA) has been chosen as the data source. In its website, it provides solid and latest all kinds of meteorological information more than wind speed level. What is more convincing and convenient, the wind speed level data has been collected based on the period of last 10 year and has been shown on the basis of month. So these data can be directly entered into HOMER software.

3.2.3 Real Interest Rate

The Real interest rate is one of the most important economic indicator which states the rate of interest an investor may receive after a certain period. For the wind energy system, it may significantly affect its economic performance. Before the investment for a wind energy system, real interest rate is a critical factor that has to be taken into account .

As an authoritative financial institution in the world. World Bank should be considered as a reliable source to provide all different types of economic data. The selection of the real interest rate for Homer simulation should be represent the history and the anticipation for the real interest rate of China.

3.2.4 The Electrical Load

The core part of this project is to compare the performance of the wind energy system under different economic and meteorological conditions. In order to make this comparison reasonable, the same load has been used for different conditions.

In this project, the model load are from a restaurant in Tianjin, China. The method of determining the daily load of every month of this restaurant is to note down the hourly consumption of electricity from the ampere-meter based on KWh. Each month, 24×30=720 values are recorded , then use the average value as the daily load for that month. After the collection of electric load data, it can be entered into the HOMER software for the simulation. It has been noted that there is a huge difference between the different seasons. For example, the electricity consumption in summer is much higher than that in other seasons due to the more frequent usage of the air-conditioning system.

3.3 The Design of Wind Energy System

The configuration of wind energy system in HOMER consists of wind turbine, inverter/converter, battery and generator. In order to get the feasible solutions via HOMER, it is very important to determine the size or numbers of these components.

3.3.1 Wind Turbine

The performance of wind turbine is deeply influenced by its power curve. The power curve is the relation between the wind speed level and the electrical output of the wind turbine. Hence, the wind turbine must be chosen according to the wind speed. Apart from that, the lifetime of the system also should be taken into consideration when selecting the type of wind turbine.

3.3.2 Battery

The battery is one of the most important components in wind energy system responsible for the storing the excess power. In order to determine the proper number of Battery, the simulation should be run until the Homer software doesn’t warn that the research space may be insufficient.

3.3.3 System Cost

In order to make the economics analysis as much accurate as possible, the market prices for different electrical equipment should be realistic. However, most of manufactures keep the real prices of their products confidential to maintain their competitiveness in the market.

Fortunately, Alibaba.com has built an extraordinary platform for the buyers and sellers for a wide variety of goods. Hence, the cost of different electrical equipment are able to be acquired through this website. Plus, Comparing the data obtained from this website with the one from other author's work make the it more reliable and realistic.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

The HOMER software can conduct the simulation, optimization and sensitivity analysis. These will give a comprehensive assessment for the alternative energy system and offer sensible advise to the project constructors. All needed to be done is to give the accurate parameters to HOMER software, then the HOMER will do the rest.

4.2 HOMER Simulation

The more possibilities of the parameters are given, the more time it will take to do the simulation. To get the most feasible result, the parameters should be given in a more detailed manner.

4.2.1 The Configuration of The Wind Energy System

The designed wind energy system is shown in Figure 4.1. The wind turbine plays a role as the base-load and make sure that the power can be delivered to the load continuously[10]. In the first place, the wind turbine converts wind energy into a AC source, then it is used to supply the AC load. In the meantime, the excess AC power from the wind turbine will be rectified into DC power and stored into the battery .when there is a shortage of power supply from wind turbine, the battery will take charge. It inverts DC power into AC power through the inverter and supply the AC load. Given that the wind energy system has adopted the load flowing dispatch strategy, the generator would start to run only when the wind turbine and battery unsuccessfully generate sufficient power to fulfill the load demand. Due to the fact that the wind energy is not strong enough to generate enough electricity, the generator would run in most cases. The arrows in the schematic point out the direction of the power flow. In addition, the lifetime of this wind energy system has been designed as 25 year.

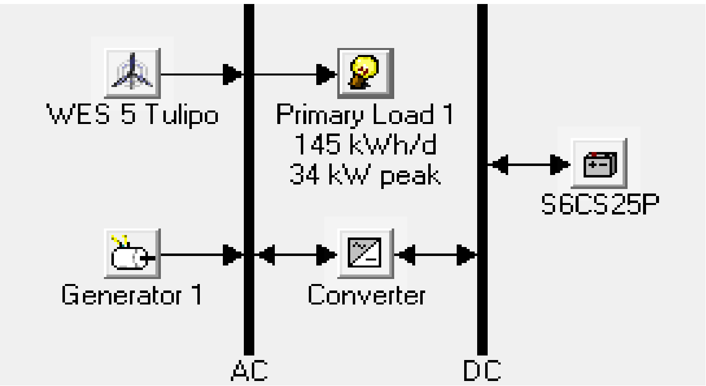


Fig 4.1 The Configuration of The Wind Energy System

4.2.2 Load Profile

In this project, a medium-sized restaurant has been used as a model, it is believed that the load profile of this restaurant can reasonably reflect the electrical demand for the most commercial and residential utility in China. A seasonal load profile is shown in Fig 4.2

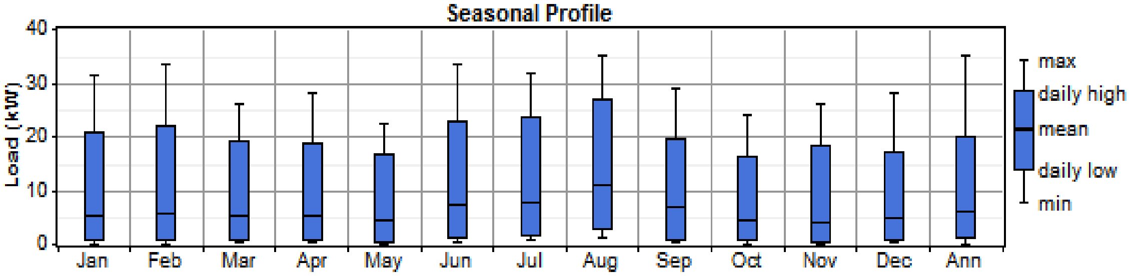


Fig 4.2 Seasonal Profile

It can be seen that the highest electrical load occurs in August, when it is in summer in China. It is because that people need to use more electricity to supply air-conditioning system in summer. The lowest electrical load occurs in May, when it is in spring in China. It is because that people are less likely to use any cooling or heating system in spring.

It also should be noted that the peak load for this system is 34 KW when the random variability, Day to Day and time-step-to-time-step were set 20%.

4.2.3 Wind Energy Data

Based on NASA website[11], three different wind speed levels have been chosen as the model and it is believed that this three wind speed levels can fully represent the general situation of wind energy in China. This three wind speed levels is shown in Fig 4.3, Fig4.4,and Fig4.5.

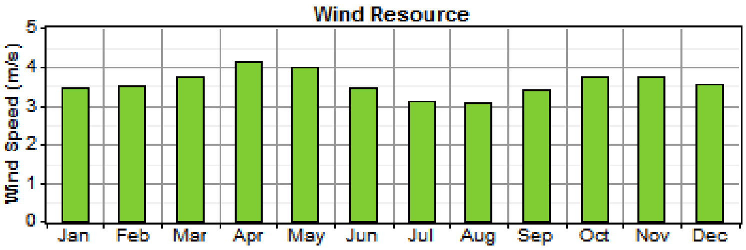


Fig 4.3 Average wind speed 3.56 m/s

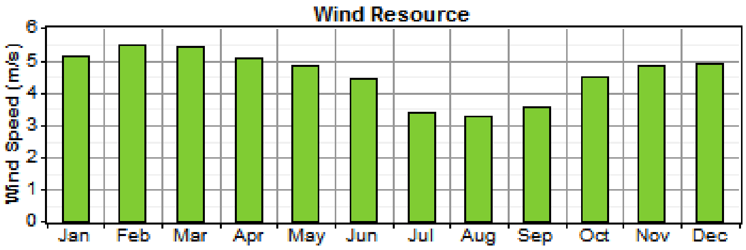


Fig 4.4 Average wind speed 4.55m/s

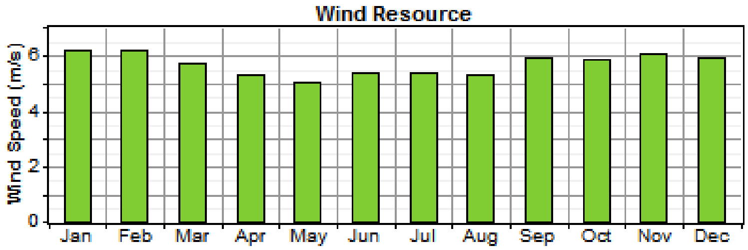


Fig 4.5 Average wind speed 5.67m/s

It also should be noted that the wind turbine in this system has been assumed to install at the height of 10 meter from the sea level. Hence all the wind speed level data used in this project has been collected from 10 m height and based on 10-year record by NASA.

4.2.4 The Real Interest Rate.

The real interest rate may have a significant impact on a country's economic development. The real interest rate of China has been obtained from the World Bank[12]. It is shown in Table 4.1

2006	**2007**	**2008**	**2009**	**2010**
2.1	-0.3	-2.3	5.4	1.1
2011	**2012**	**2013**	**2014**	**2015**
-1.5	3.5	3.7	4.7	--

Table 4.1 Annual Real Interest Rate Of China(2006-2015)

It can be seen that China’s real interest rate from 2012-2014 stood at around 3%. It was about 0% in 2007 and as high as 4.7 % in 2014. Besides, the negative values of the real interest rate have been recorded in the year 2007 and 2011. Given that the lifetime of this wind energy system is 25 years, it would be not reliable to estimate the real interest rate at the initial stage of this wind energy system project. It would be more reasonable to make the real interest rates different and anticipate the possible effect on the selection of the optimal system configuration. In this project, the real interest has been set at -3%,0%,3% and 5%.

4.2.5 Diesel Price

The diesel price in China varies from region to region. In this project , however, the main focus is to investigate the effect of the real interest and wind speed level on the system, hence, the diesel price has been fixed at 0.8 $/L based on the average diesel price of 5.2 RMB [13]and fluctuating exchange rate (1USD≈6.25

RMB)

4.2.6 Design Specification

A standalone wind energy system usually contain three main components,i.e., a wind turbine, an inverter and a battery bank. The wind energy is intermittent , however, the utilization of the a standalone wind energy system is very restricted. A common solution is to add a diesel generator to this wind energy system, so it turns into a hybrid wind/diesel energy system. In this project, a diesel generator has been considered, the specification of the selected components in this study are shown in Table 4.2

Description	Data
Wind Turbine	
Number	1 - 5 choices
Capital cost	$5000 each one
Replacement cost	$4000 each one
Operating and maintnenance cost	$50/year
Lifetime	25 year
Inverter	
Size	5-30 kw choices, 5 KW intervals
Capital cost	$700/KW
Replacement cost	$700/KW
Operating and maintnenance cost	$10/year
Lifetime	15year
Efficiency	85%
Battery	
Type of battery	S6CS25P
Nominal voltage	6V
Size	4 - 40 batteries choices
Nominal capacity	1156 Ah
State of charge	40%
Capital cost	$1100/KW
Replacement cost	$1000/KW
Operating and maintnenance cost	$10/year
Lifetime througput	9645 KWh
Diesel generator	
Number of generator	1
Size	35-200KW choices 50 intervals
Capital cost	$500/KW
Replacement cost	$500/KW
Operating and maintnenance cost	$0.025/h/KW
Lifetime	15,000h

Table 4.2 Design Specification

A study regarding A hybrid PV/Wind system in Urumqi ,China provides relatively reliable price for each of the component. What is more convincing, it resembles the price which has been provided from www.alibaba.com.

4.2.6.1 Wind Turbine

In this study, wind energy was used as the base-load power source. The quantities of wind turbine ranges from 1 to 5. The economics of the system and the different levels of renewable energy penetration in the system has been considered. In the situation where the excess electricity was generated by wind turbine, excess electricity would charge the battery. It should be underlined that the wind turbine only generate electricity when the wind blows strongly. Considering that there is no wind energy available at some time, the wind turbine is unable to generate electricity. Instead, the battery and/or the generator would be take that responsibility.

4.2.6.2 Inverter

The inverter or converter transform the electricity from AC into DC or DC into AC. In the project, the size of inverter ranges from 0 to 30 KW, with 5 KW intervals. It is on the basis of the size of the load.

4.2.6.3 Battery

The Battery store the excess electricity generated by the PV. In this project, the battery has been assumed to be configured at a 24 V bus, each string has four batteries. The maximum 10 strings has been considered , which is up to 40 batteries.

4.2.6.4 Generator

The size of diesel generator must meet the peak demand of the power, in this study, the size of the diesel generator ranges from 35 KW to 200 KW. It only would run when the wind turbine and battery fail to meet the demand. The lifetime of this generator has been assumed as 15,000 hours.

4.3 Result Analysis

In this project, there are two factors that need to be taken in to account, the real interest rate and the wind speed levels, this two factors will have a huge impact on the economic and technological performance of the wind energy system. To make the analysis more sensible, the diesel price and the load condition have been fixed. This may lead to four possible system configurations with different renewable penetration levels, i.e., the standalone diesel system (0% renewable penetration), the hybrid wind/diesel with or without battery systems(1-99% renewable penetration)and the standalone wind with battery systems(100% renewable penetration). However, due to the fact that the wind turbine is not able to generate enough electricity solely, the standalone wind with battery system has not appeared in the Homer simulation results.

4.3.1 Effects Of The Annual Real Interest Rate

Under the condition of different wind speed levels, imposing different annual real interest rate has make the Homer software select the hybrid wind/diesel with battery system as the optimal system configuration with the lowest net present cost. The Fig 4.6 shows the net present cost for different types of the configurations under different annual real interest rate when the wind speed is 5.67 m/s.

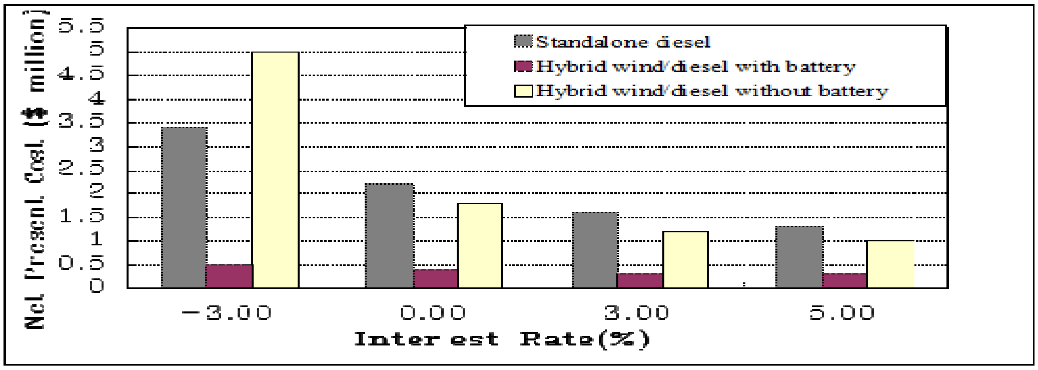


Fig 4.6 Net Present Cost (5.67m/s)

It can be seen that the hybrid wind/diesel with battery system possesses the lowest net present cost regardless of the annual real interest rate. With the increase of the annual real interest rate, the net present cost has decreased.

The Fig4.7,Fig4.8 shows the hybrid wind/diesel system is still in the possession of the lowest net present cost when the wind speed level reduce to 4.56m/s and 3.57m/s. And the analysis of the effect of the annual real interest rate on the net present cost for the case where then wind speed is 3.56 m/s can be applied to this two situations.

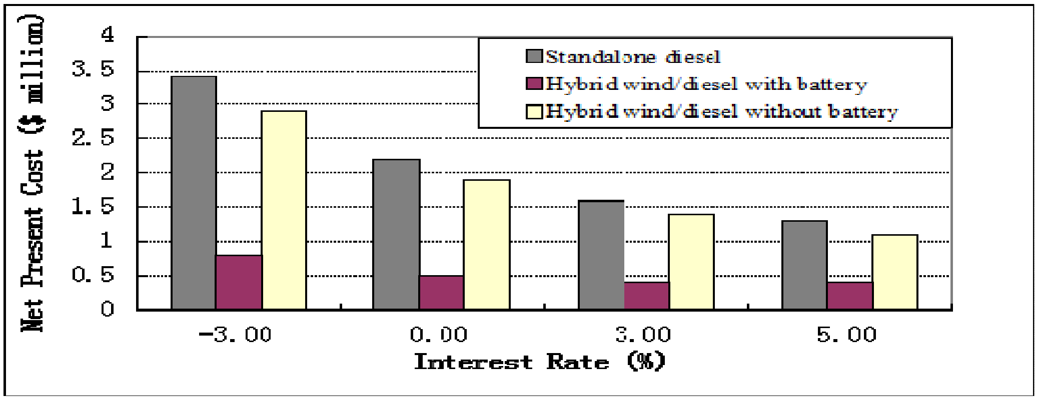


Fig 4.7 Net Present Cost (4.56m/s)

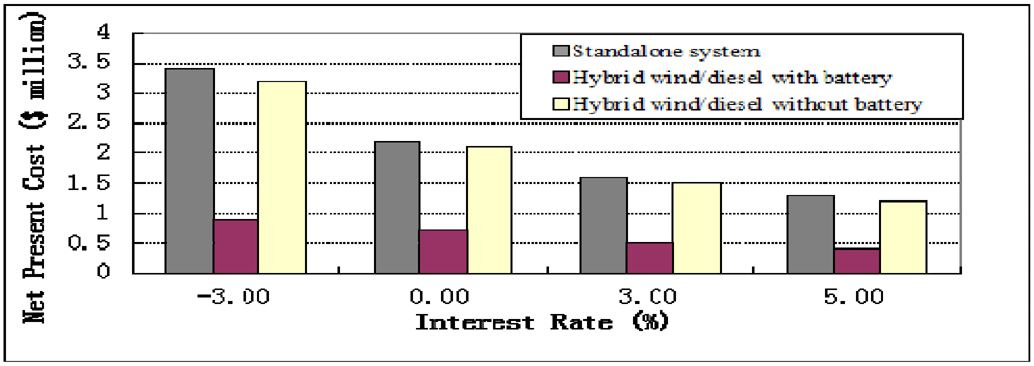


Fig 4.8 Net Present Cost (3.57m/s)

4.3.2 Effects Of The Wind Speed

The wind speed level deeply affect the net present cost of the system, the Fig 4.9 is the net present cost of different types of configurations under different wind speed levels when the annual real interest is 5%.

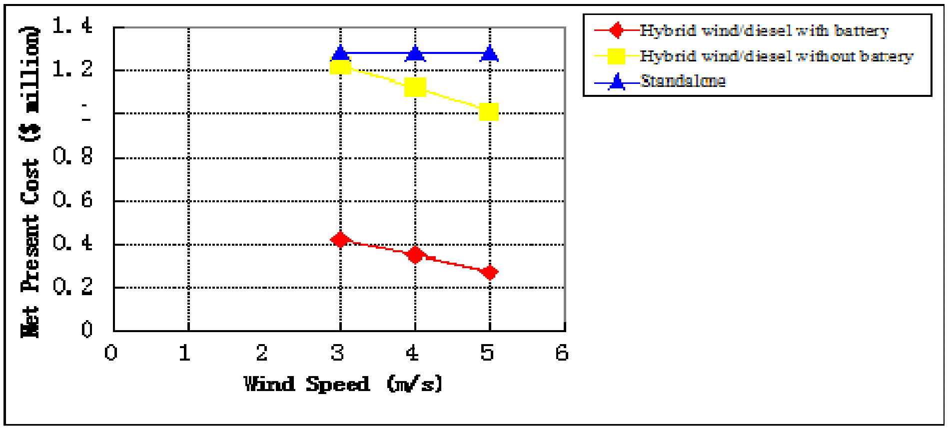


Fig 4.9 Net Present Cost (5% Real Interest Rate)

It can be seen that the hybrid wind/diesel with battery system possesses the lowest net present cost regardless of the wind speed levels. With the increase of the wind speed levels, the net present cost has decreased.

The Fig4.10, Fig4.11 and Fig4.12 shows the hybrid wind/diesel system is still in the possession of the lowest net present cost when the annual real interest rate varies at 3%,0% and -3%. And the analysis of the effect of the wind speed levels on the net present cost for the case where then the annual real interest rate is 5% can be applied to this three situations.

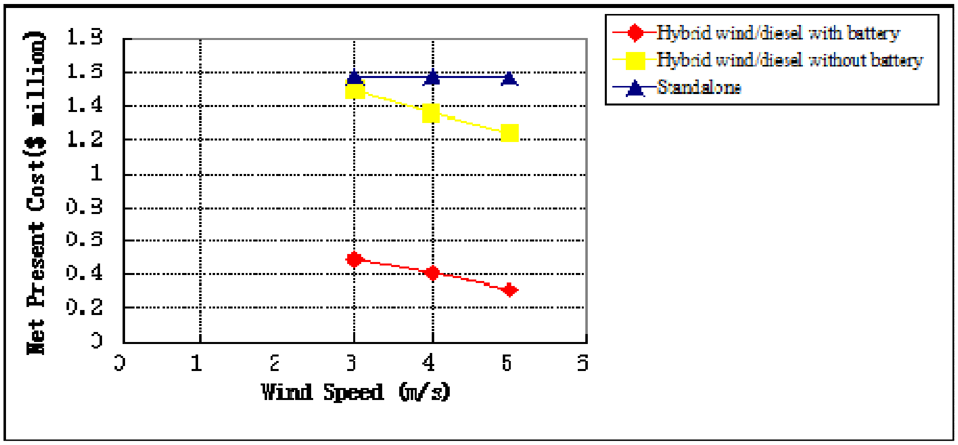


Fig 4.10 Net Present Cost (3% Real Interest Rate)

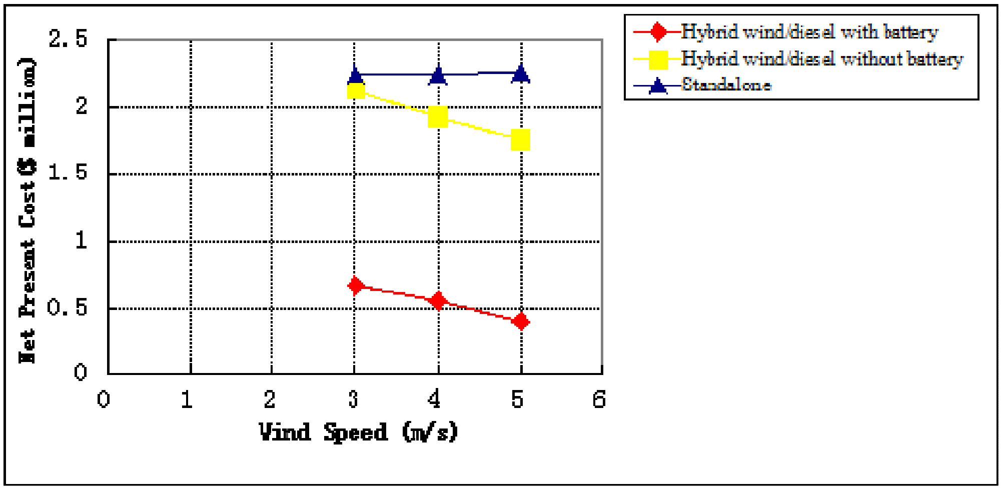


Fig 4.11 Net Present Cost (0% Real Interest Rate)

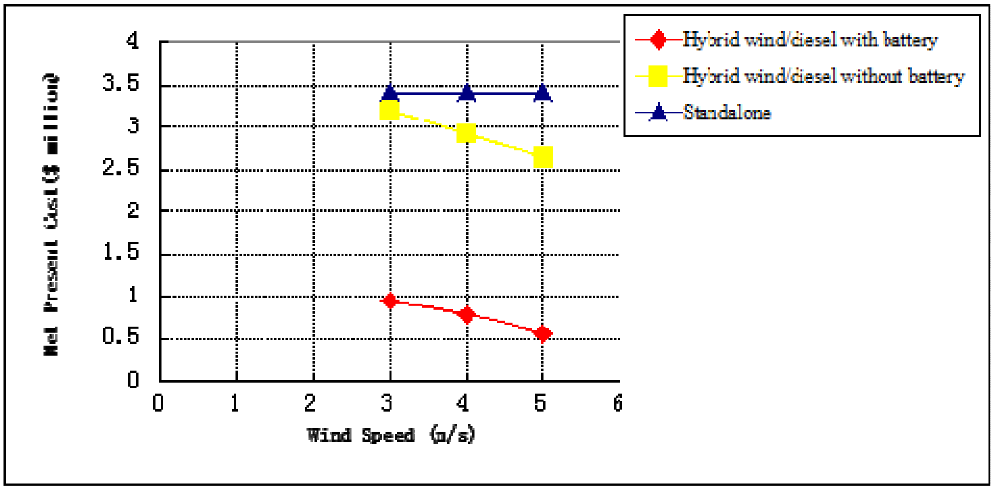


Fig 4.12 Net Present Cost (-3% Real Interest Rate)

4.3.3 Cost Type

The breakdown of the NPC by cost type for three different types of configuration is shown in Fig4.13, this is the case where the wind speed level is 5.67m/s and the annual real interest rate is 5%

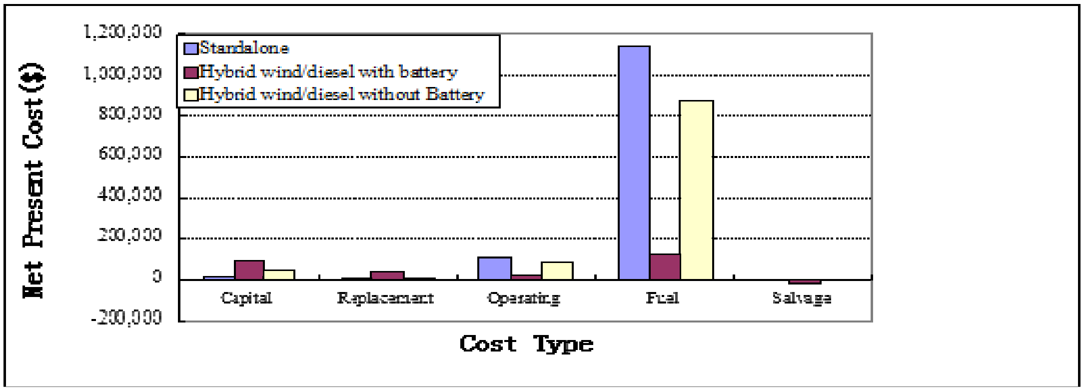


Fig 4.13 Cost Type (5.67m/s, 5% real interest rate)

It is suggested that the standalone system requires highest capital cost for the fuel due to the fact that the diesel generator is used as the only power source. However, the cost of the initial capital for standalone system is the lowest among all the systems .it is because that the price of the generator is more economical than the wind turbine which requires highest initial capital. But for the long-term run, the hybrid wind/diesel with battery system is still the most optimal configuration considering that the diesel price would increase with the decrease in the number of oil reserves and the rising concern on the environmental protection.

Fig 4.14, Fig4.15, Fig 4.16are the cost type for the different configurations under different annual real interest rates when the wind speed level remains as 5.67 m/s.

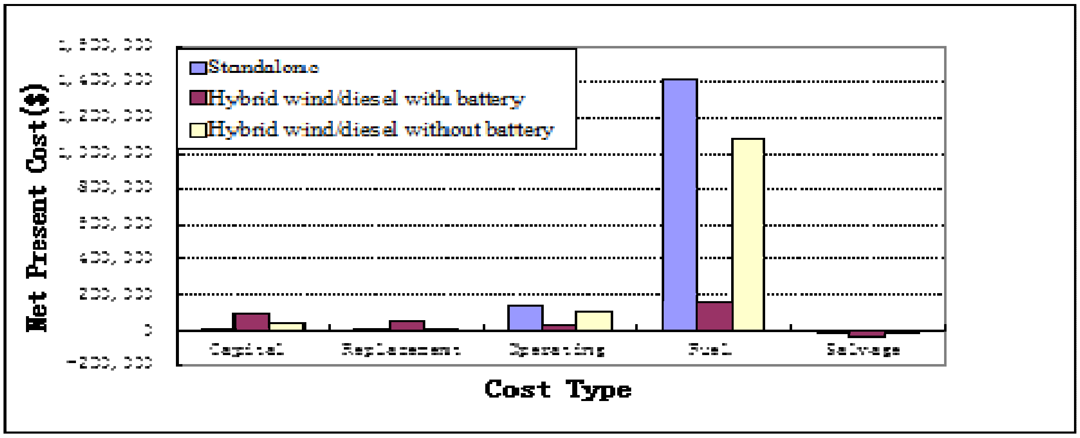


Fig 4.14 Cost Type (5.67m/s, 3% Real Interest Rate)

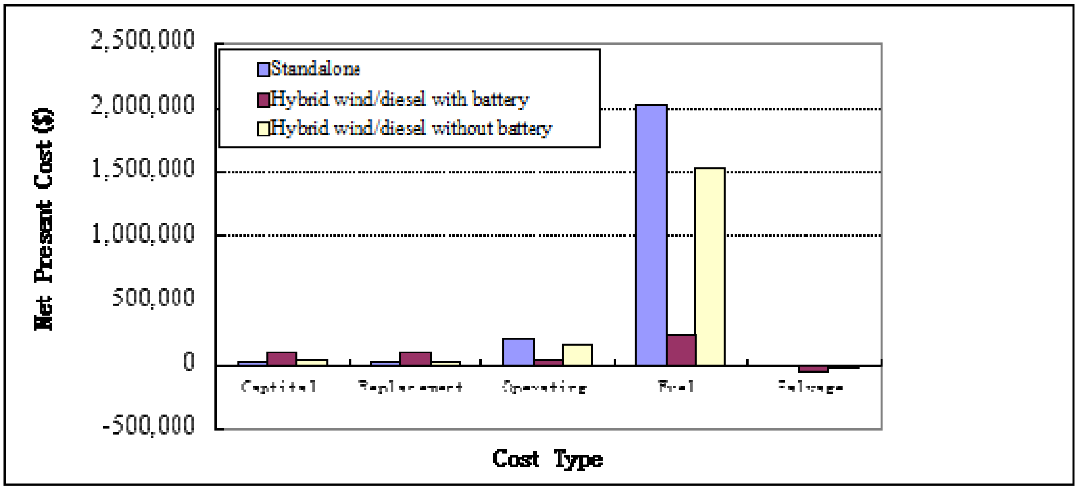


Fig 4.15 Cost Type (5.67m/s, 0% Real Interest Rate)

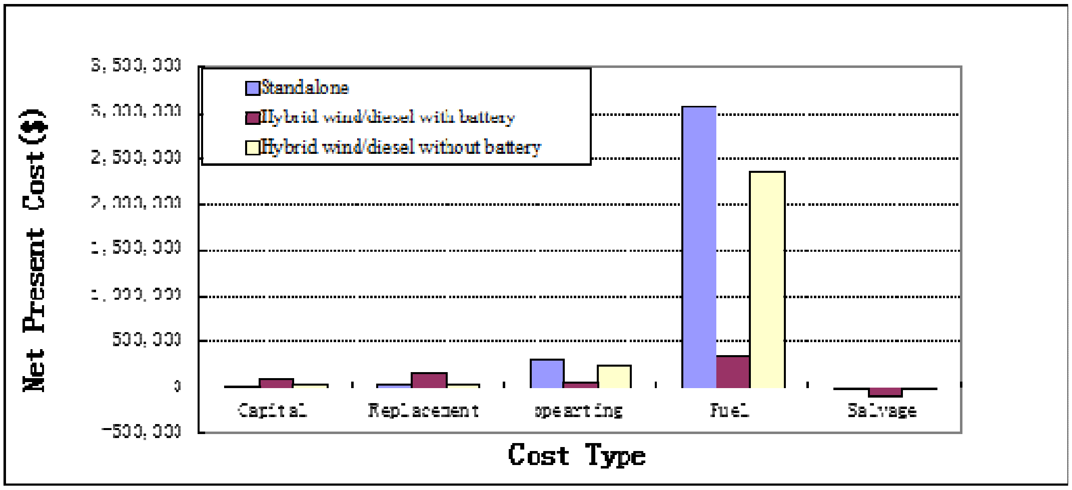


Fig 4.16 Cost Type (5.67m/s, -3% Real Interest Rate)

When wind speed is 4.55 m/s , the cost type for different types of configurations under the condition of annual real interest rates 5%, 3%, 0% and -3% are shown in Fig 4.17, Fig 4.18, Fig 4.19 and Fig 4.20.

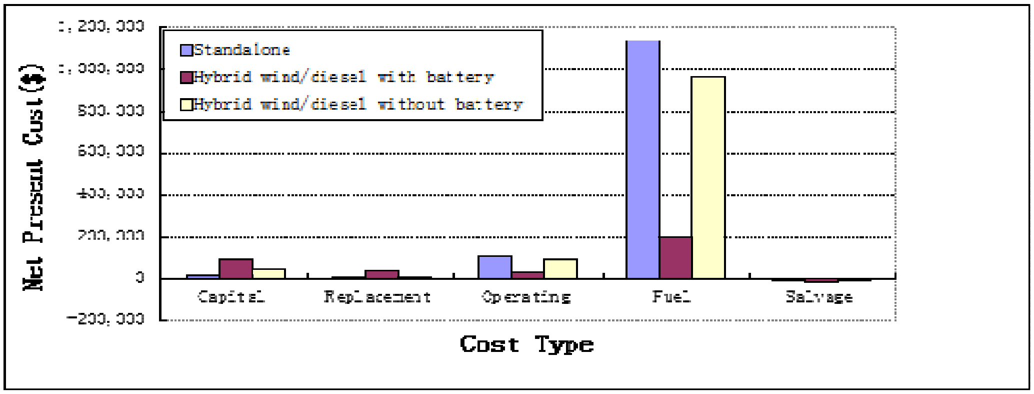


Fig 4.17 Cost Type (4.55m/s, 5% Real Interest Rate)

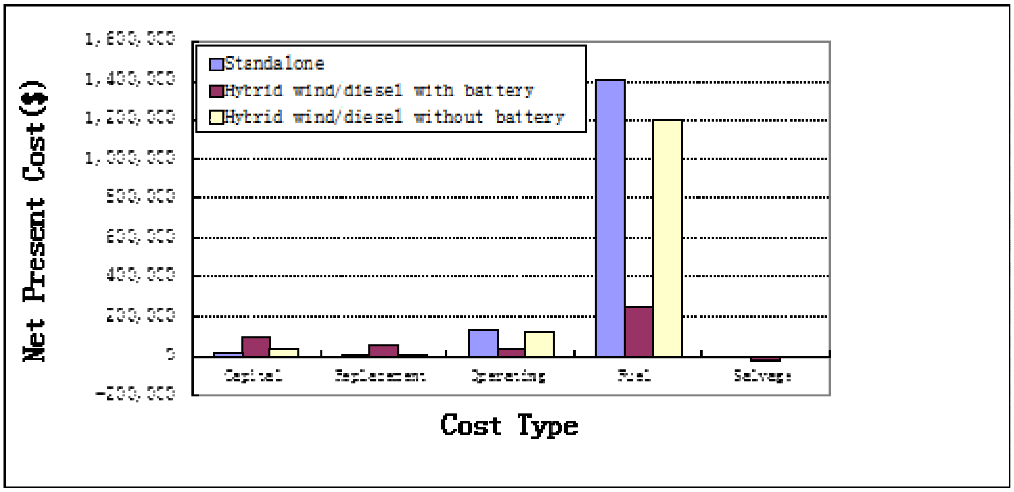


Fig 4.18 Cost Type (4.55m/s, 3% Real Interest Rate)

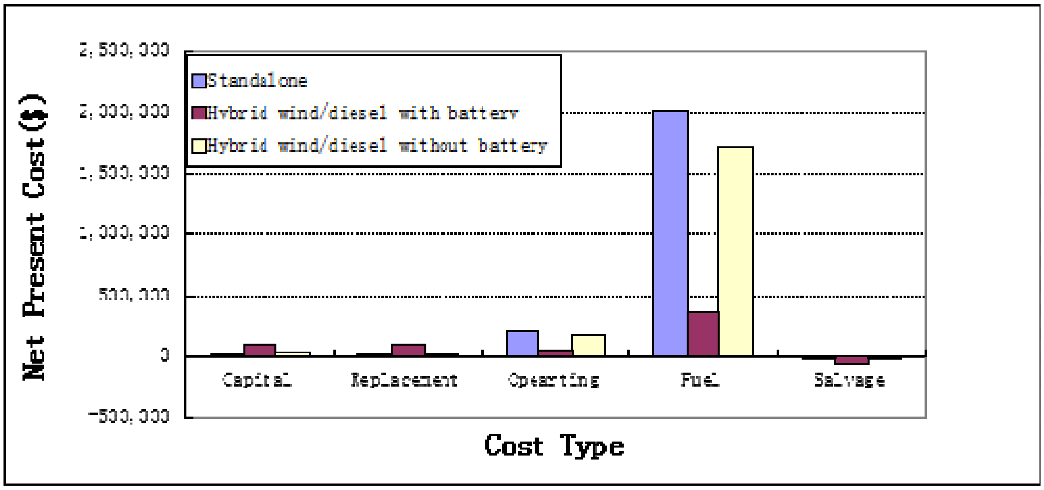


Fig 4.19 Cost Type (4.55m/s, 0% Real Interest Rate)

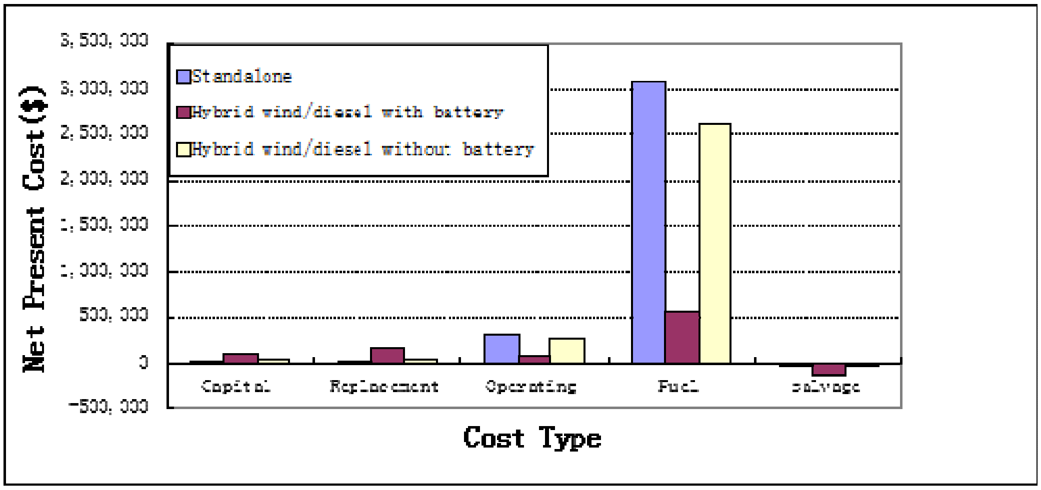


Fig 4.20 Cost Type (4.55m/s, -3% Real Interest Rate)

When wind speed is 3.56 m/s , the cost type for different types of configurations under the condition of annual real interest rates 5%, 3%, 0% and -3% are shown in Fig 4.21, Fig 4.22 ,Fig 4.23 and Fig 4.24.

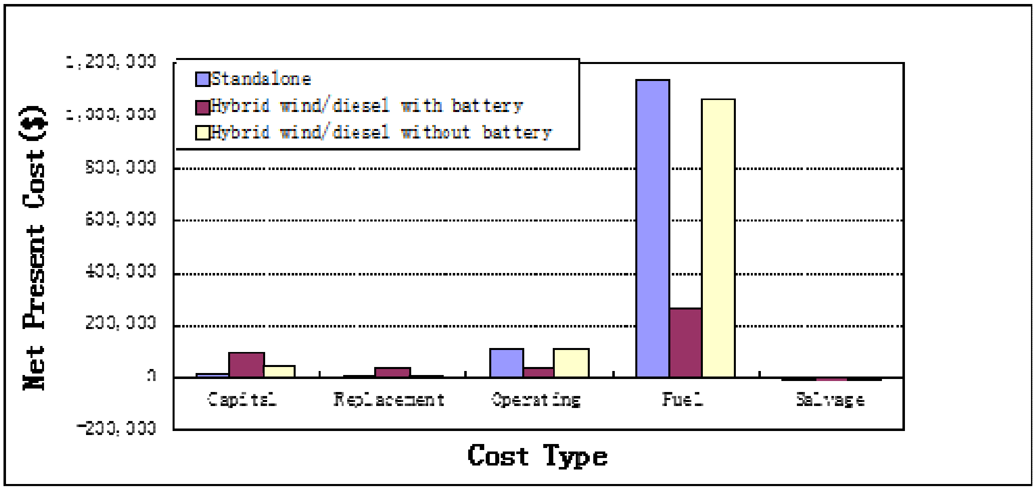


Fig 4.21 Cost Type (3.56m/s, 5% Real Interest Rate)

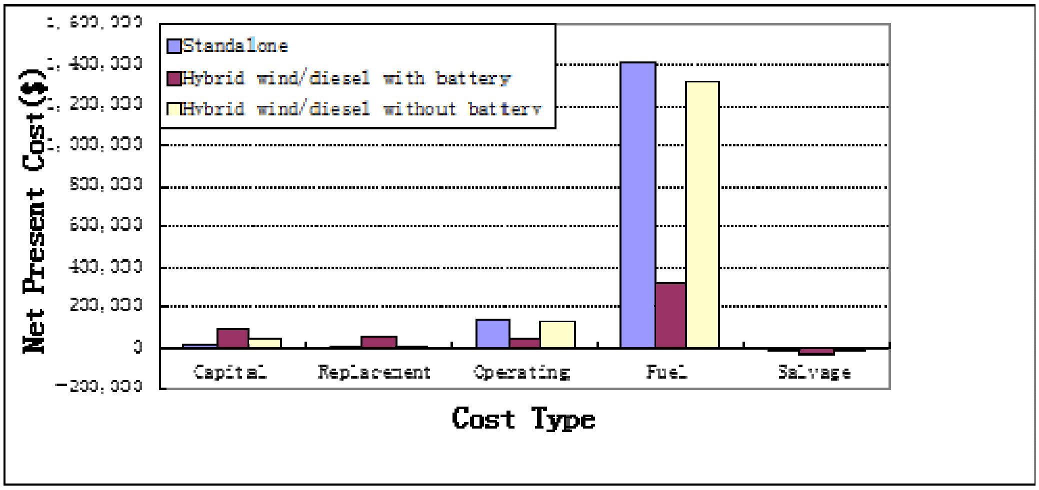


Fig 4.22 Cost Type (3.56m/s, 3% Real Interest Rate)

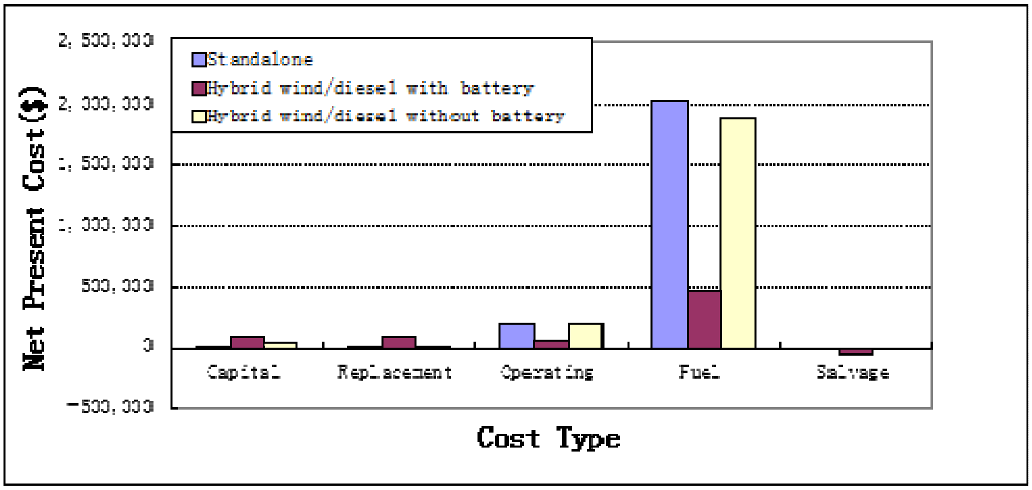


Fig 4.23 Cost Type (3.56m/s, 0% Real Interest Rate)

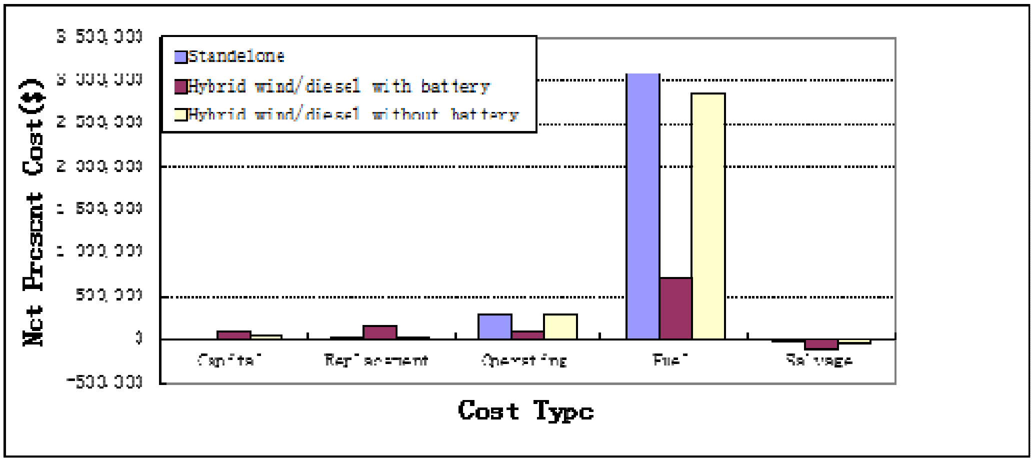


Fig 4.24 Cost Type (3.56m/s, -3% Real Interest Rate)

It has been found that the same conclusion has been come up with based on the above figures.The hybrid wind/diesel with battery is the most optimal configuration under different wind speed levels and annual real interest rates.

4.3.4 Hybrid Wind/Diesel System

After the analysis of the different types of configuration, it has been confirmed that the hybrid wind/diesel system with battery is the most optimal configuration.Therefore, the following analysis will focus on hybrid wind/diesel system.

It is well known that the number of batteries and the wind turbines is significant to the performance of the wind energy system , hence it is important to investigate the relationship between the number of batteries and the wind turbines. In order to make this investigation ease, the size of the generator has been fixed at 35 KW.

The net present cost for the hybrid wind/diesel with battery system under different numbers of wind turbine and batteries is shown in Fig 4.25. In this case, the wind speed is 5.67m/s and the annual real interest is 5%.

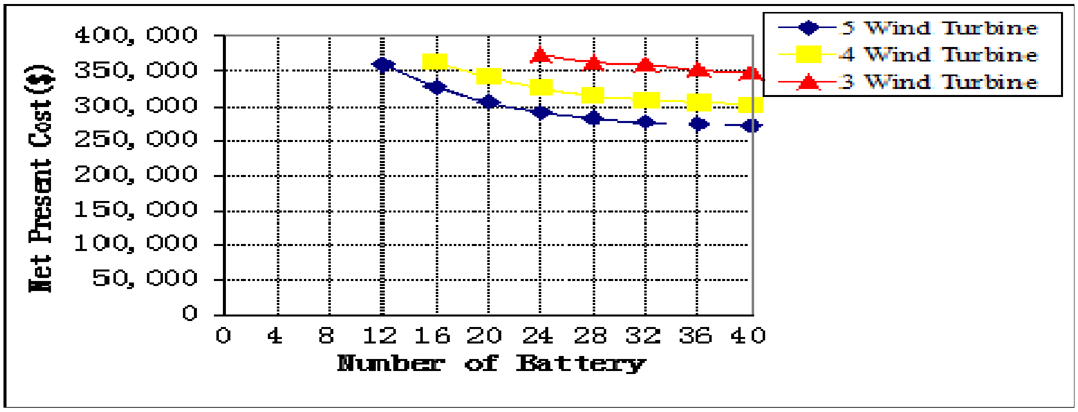


Fig 4.25 Net Present Cost (5.67m/s, 5%)

It is suggested that the increase in the number of the battery and the wind turbine results in the decrease in the net present cost. Generally, the more components purchased lead to more net present cost, but in this case, the more wind turbine and batteries make the system less reliable on the diesel which is the bulk cost of the system. It explains why the more use of the wind turbine and battery doesn’t cause a sharp increase in the net present cost. The lowest net present cost occurs when there are 5 wind turbines and 40 batteries.

When the annual real interest rate is 3%, 0% and -3% respectively, the net present cost for the system is shown in Fig 4.26, Fig 4.27 and Fig 4.28.

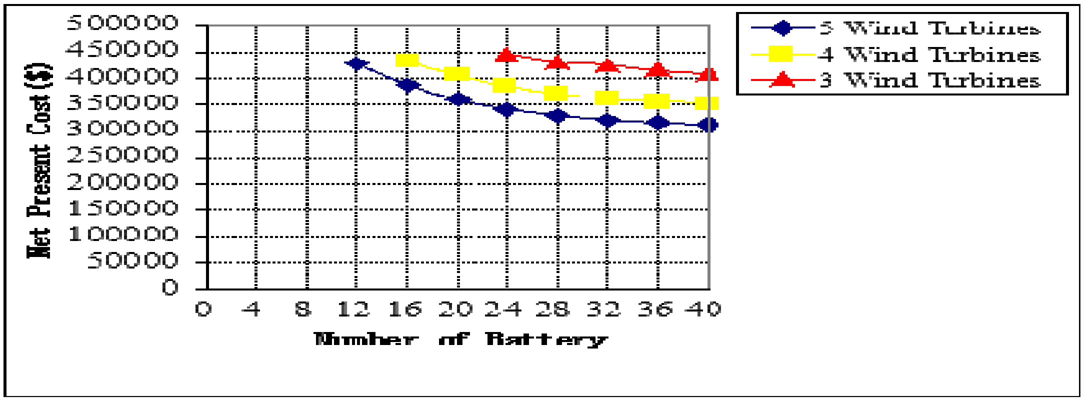


Fig 4.26 Net Present Cost (5.67m/s, 3%)

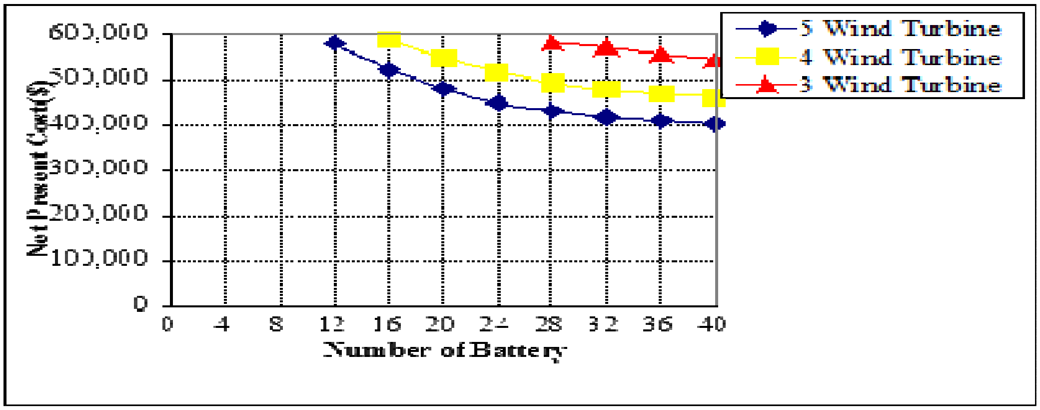


Fig 4.27 Net Present Cost (5.67m/s, 0%)

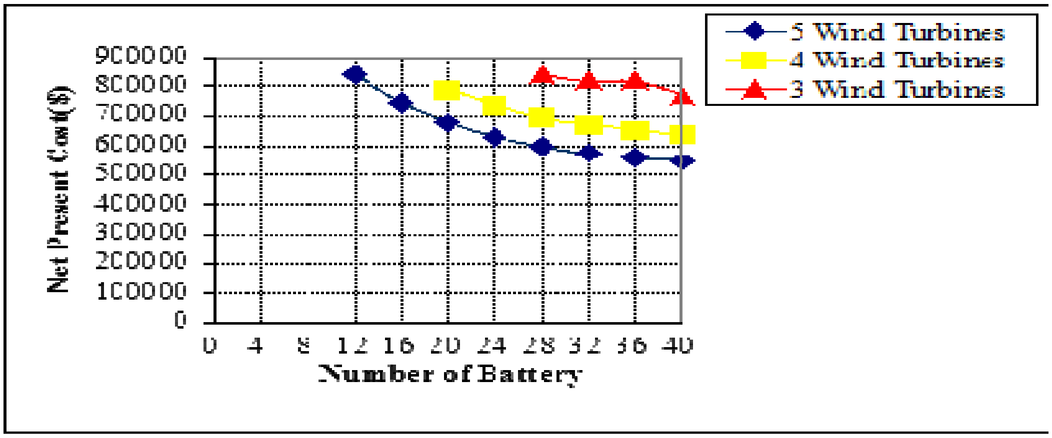


Fig 4.28 Net Present Cost (5.67m/s, -3%)

When the wind speed is 4.55 m/s, the net present cost for the system under different annual real interest rate is shown in Fig 4.29, Fig 4.30, Fig 4.31 and Fig 4.32.

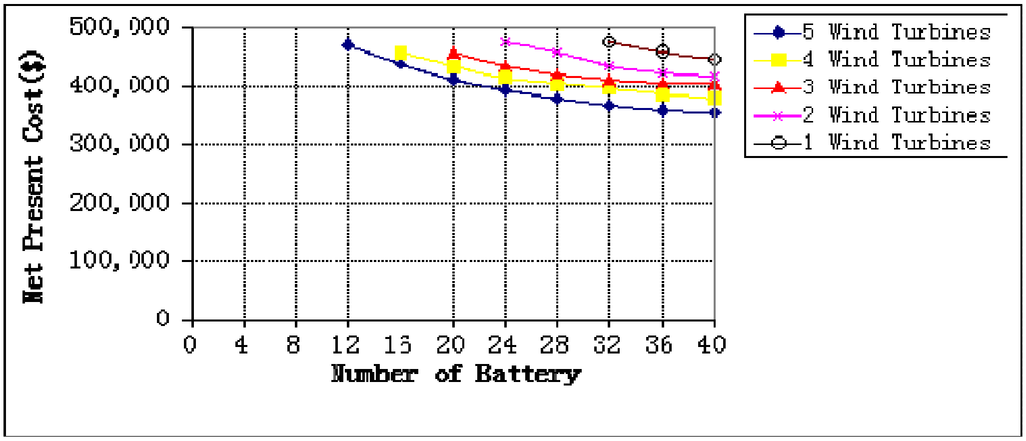


Fig 4.29 Net Present Cost (4.55m/s, 5%)

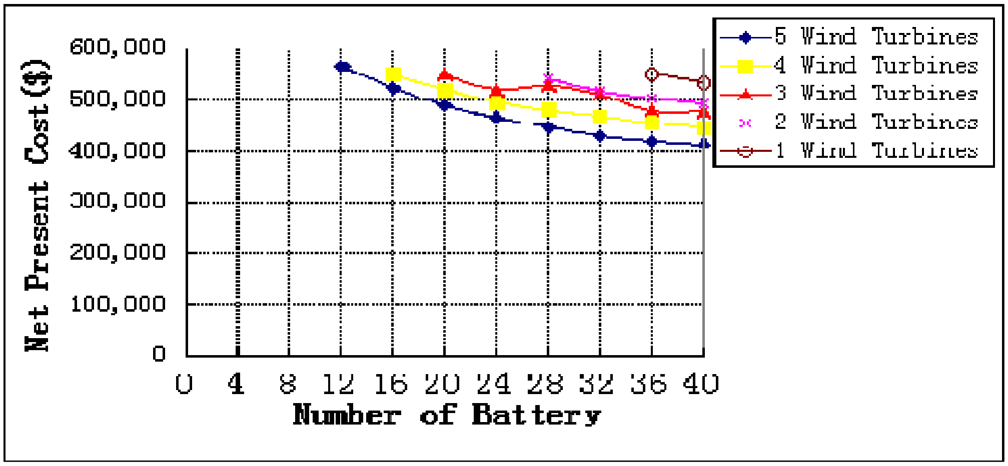


Fig 4.30 Net Present Cost (4.55m/s, 3%)

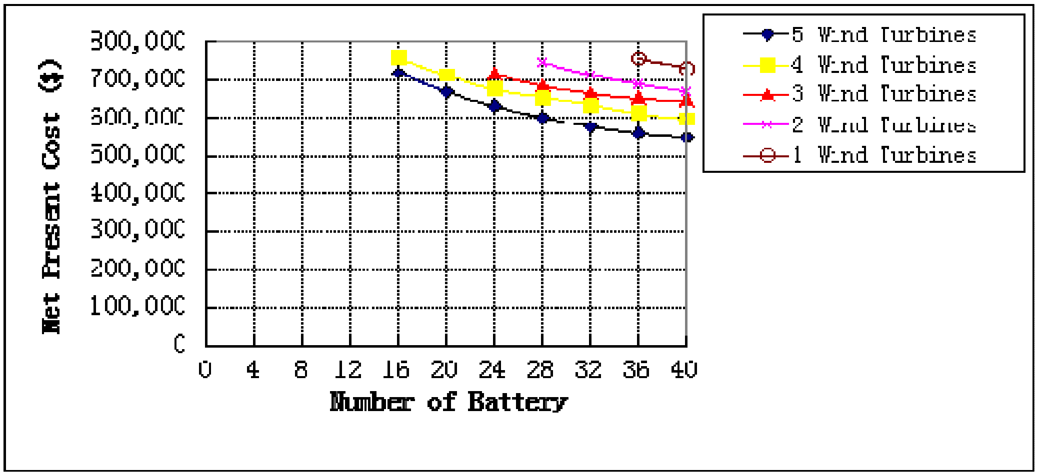


Fig 4.31 Net Present Cost (4.55m/s, 0%)

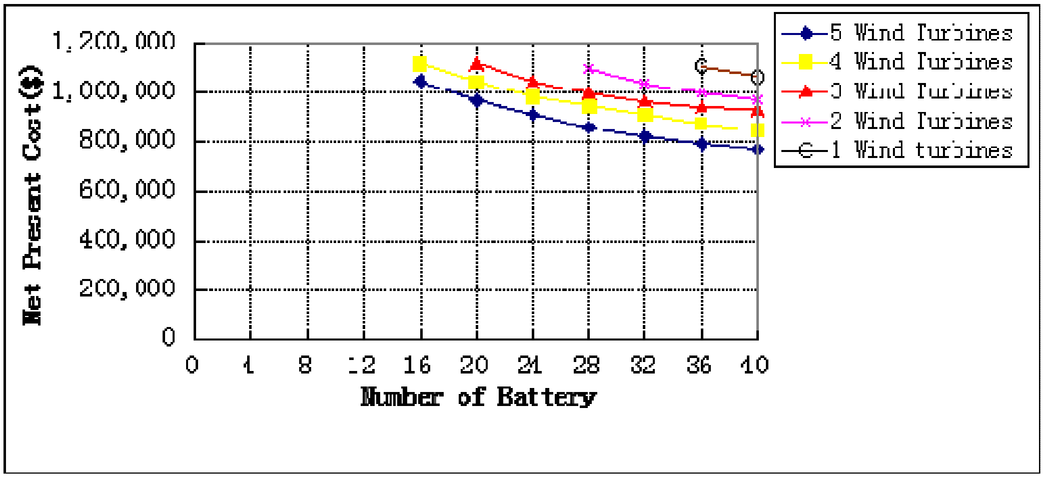


Fig 4.32 Net Present Cost (4.55m/s, -3%)

When the wind speed is 3.56m/s, the net present cost for the system under different annual real interest rate is shown in Fig 4.33, Fig 4.34, Fig 4.35 and Fig 4.56.

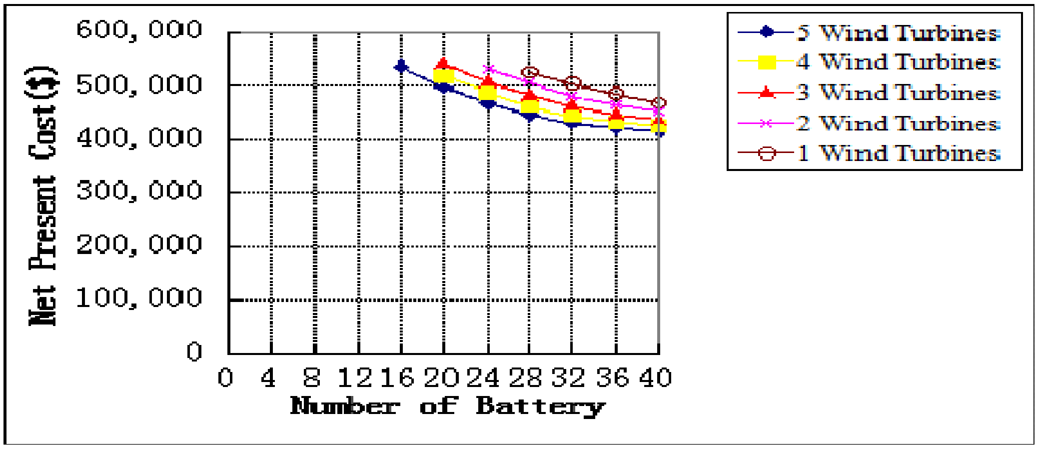


Fig 4.33 Net Present Cost (3.56m/s, 5%)

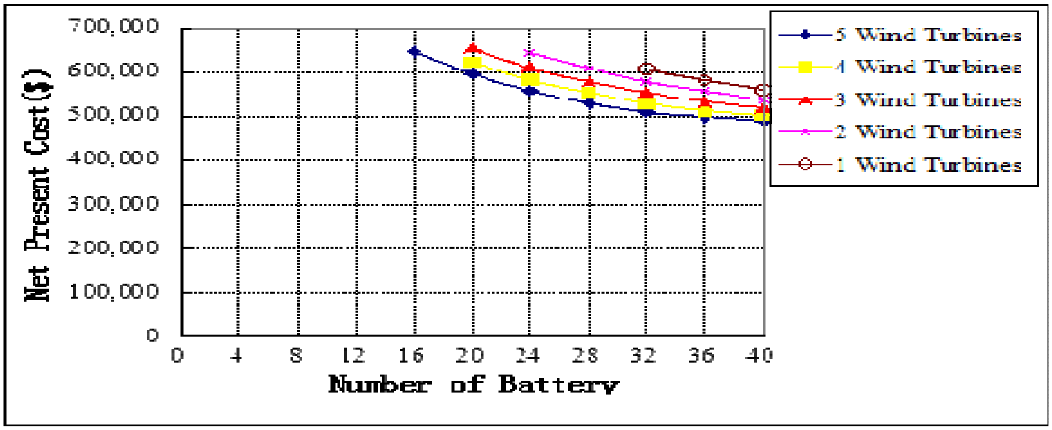


Fig 4.34 Net Present Cost (3.56m/s, 3%)

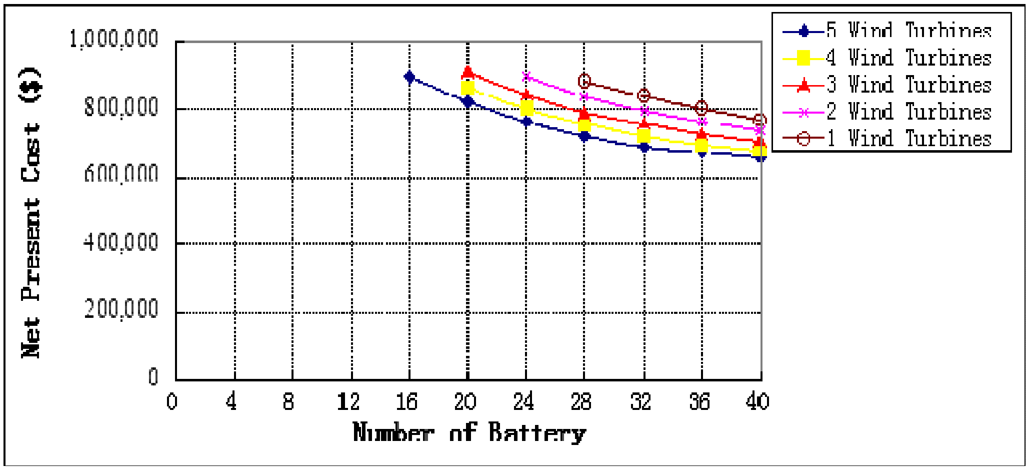


Fig 4.35 Net Present Cost (3.56m/s, 0%)

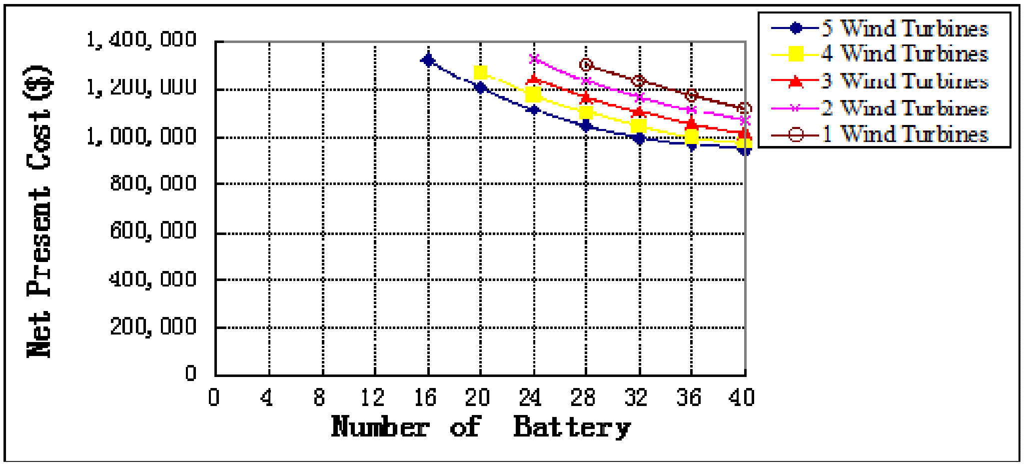


Fig 4.36 Net Present Cost (3.56m/s, -3%)

It has been found that the same conclusion has been come up with based on the above figures. The more wind turbines and batteries, the less net present cost. The least present cost take place when there is maximum number of battery and wind turbines.

As the concern about the environmental protection and sustainable development has risen around the world, it is essential to investigate the use of the renewable energy and the system's impact on the environment. The renewable penetration and the carbon dioxide emission for the system are shown in Fig 4.37, Fig 4.38, this is the case where the wind speed levels is 5.67m/s. Because the annual real interest rate has no effect on the system's environmental performance, in this analysis, the annual real interest rate has been neglected.

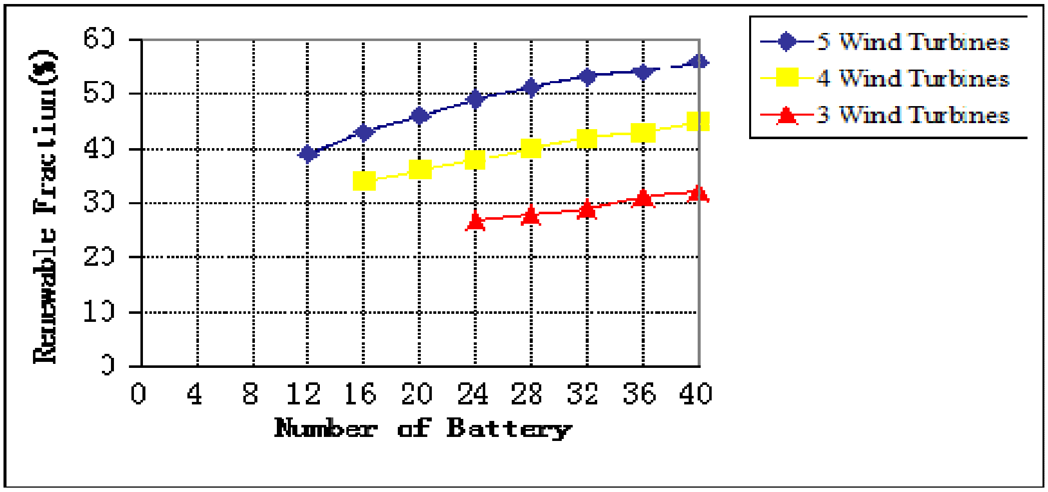


Fig 4.37 Renewable Fraction (5.67 m/s)

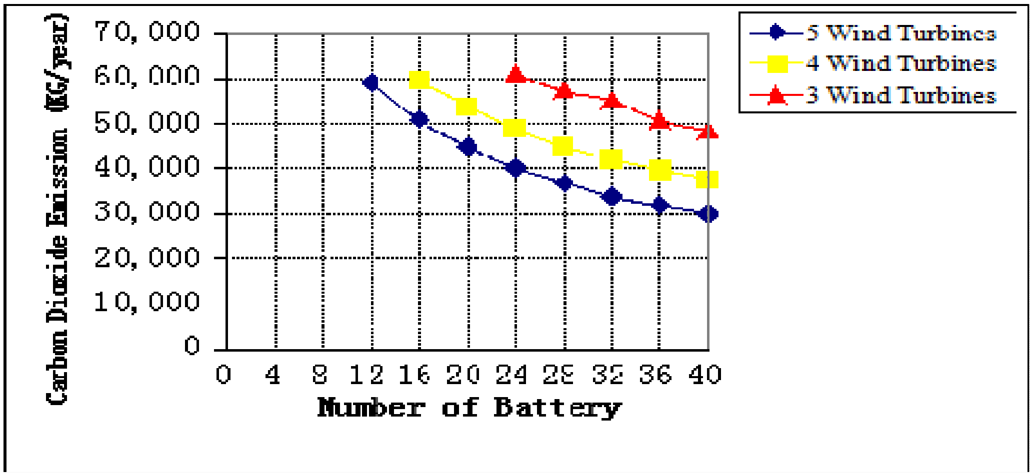


Fig 4.38 Carbon Dioxide Emission (5.67 m/s)

It is suggested that the more batteries and wind turbines may lead to the more renewable energy penetration and the decrease in the carbon dioxide emission. The most renewable penetration and the least carbon dioxide emission take place when the there are 40 batteries and 5 wind turbines.

When the wind speed is 4.55 m/s, the renewable penetration and carbon dioxide emission for the system is shown in Fig 4.39 and Fig 4.40

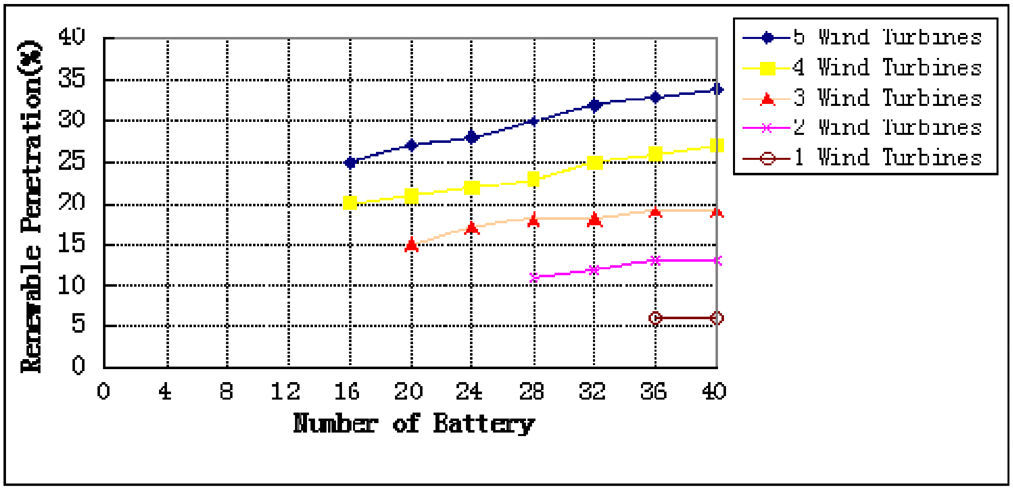


Fig 4.39 Renewable Penetration (4.55 m/s)

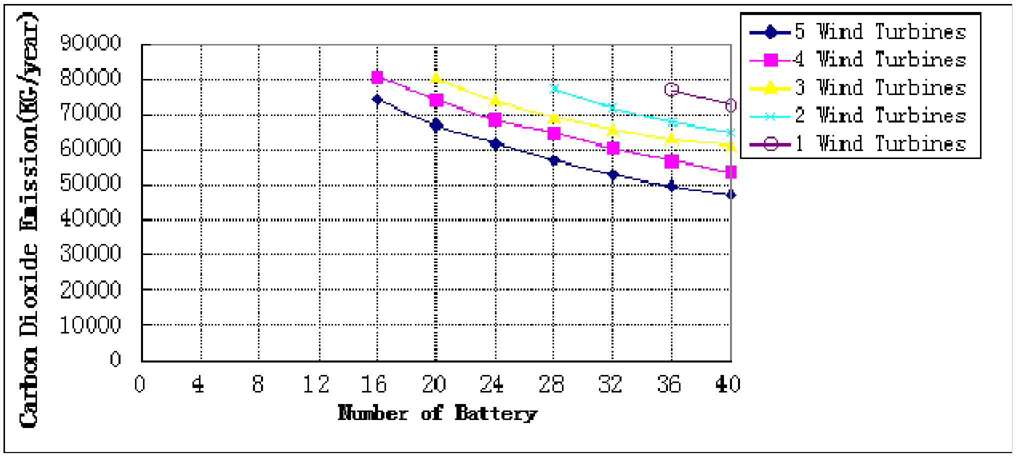


Fig 4.40 Carbon Dioxide Emission (4.55 m/s)

When the wind speed is 3.56 m/s, the renewable penetration and carbon dioxide emission for the system is shown in Fig 4.41 and Fig 4.42.

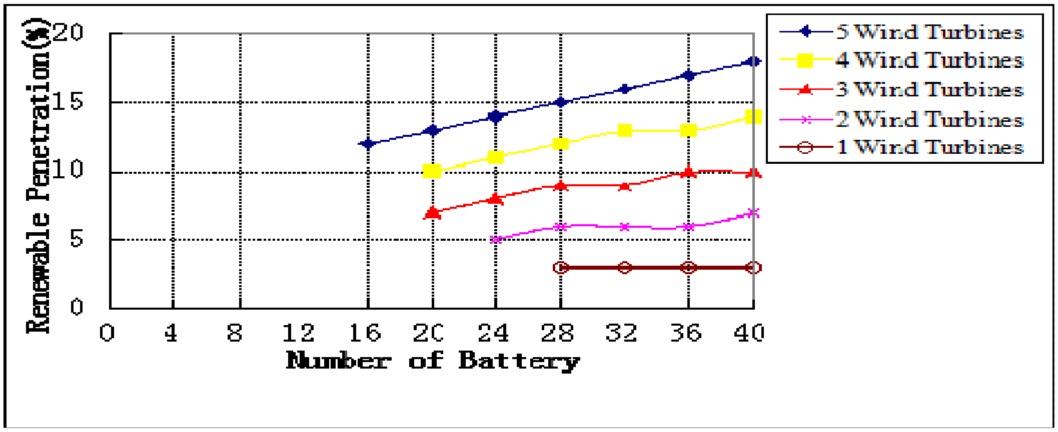


Fig 4.41 Renewable Penetration (3.56 m/s)

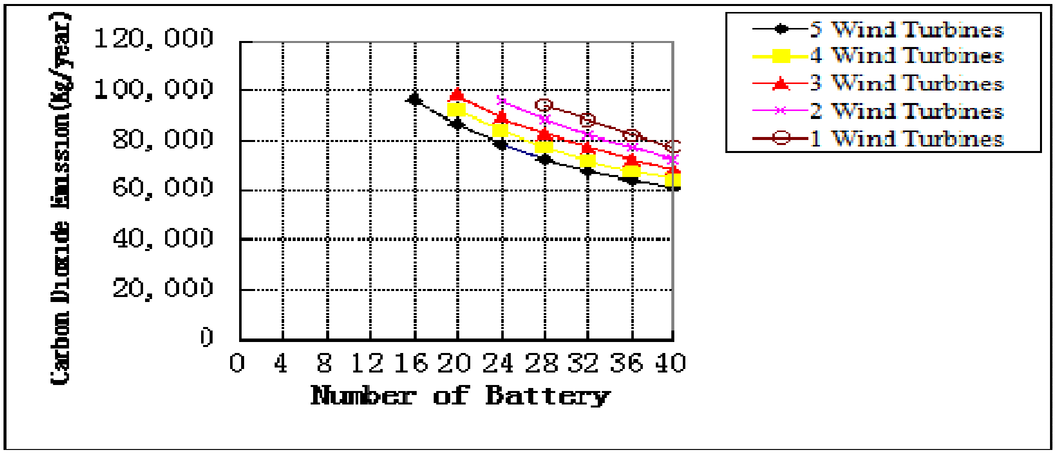


Fig 4.42 Carbon Dioxide Emission (3.56 m/s)

It has been found that the same conclusion has been come up with based on the above figures. The more wind turbines and batteries, the more renewable penetration and less carbon dioxide emission. The most renewable penetration and the least carbon dioxide emission take place when there is maximum number of battery and wind turbines. It also has been found that the higher wind speed levels will lead to more renewable energy penetration and the reduce in the emission of carbon dioxide.

CHAPTER 5

CONCLUSION

Based on the geographical information obtained, the performance of wind turbine varies under different wind speed levels and real interest rate.The higher wind speed level may reduce the cost of the wind turbine system and the high real interest rate may make the whole project less expensive. Also, the number of the component like battery plays a significant role on the system's technological and economic performance. The larger number of wind turbine and battery make the whole system more reliable on the renewable energy and have less negative impact on the environment.

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[12] Real interest rate, The World Bank. http://data.worldbank.org/indicator/FR.INR.RINR [assessed 30.09.15]

[13] Diesel Price, http://youjia.chemcp.com. [assessed 10.11.15]