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Research of the Energy Saving and Emission Reduction Potential of Distributed Energy with Multiple Energy Resources in Pharmaceutical Industry of Yunnan

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Abstract. Through analyzing the characteristics and advantages of DES with multiple energy resources, the thesis drew a conclusion that DES especially solar-diesel complementary system had great potential of energy saving and pollution reduction in Yunnan pharmaceutical industry. The thesis concluded that wind energy utilization plays a leading role for the profit to investment rate of the DES complemented with solar, wind and fossil energy. DES can overcome the limitation of the development for Yunnan pharmaceutical industry and make a contribution to energy saving and pollution reduction.

Keywords: multiple energy resources, solar-diesel complementary system,distributed energy.

1. Introduction

Improving potential of the pharmaceutical industry constructs one of the highest added value industries in 21 century[1]. Biodiversity and local unique climate in Yunnan Province backs up the advantages in the pharmaceutical industry development[2]. Yunnan government has drafted pharmaceutical industry as another significant pillar industry after the tobacco industry[3]. While GDP was growing in Yunnan Province, energy consumption and pollution increased and energy consumption per 10,000 yuan was up to 0.2217 in Yunnan Province in 2009[4].Therefore, the environmental advantages of distributed energy with multiple energy resources complement in local pharmaceutical industry also have large development potential. Based on combined heat and power technology, distributed energy system (DES) is a new kind of separate power supply formed in energy system integration, varied in small-sized gas turbo-generator, wind power generation, photovoltaic power generation, solar thermal electric power generation, fuel cell generation and etc. Under the energy structure adjustment and series energy problems, DES draws more and more attention in China. Solar, wind and fossil energy reasonable matching is the trigger to accomplish environmental and eco-technical destination. Distributed energy with renewable energy and fossil energy complement instead of small distributed boilers, not only reduces enterprises' environmental cost, but also improves local energy efficiency and decreases emission as well.

2. DES with multiple energy of pharmaceutical industy in Yunnan

Pharmaceutical industry needs heat supply while manufacturing, which guarantees stable heat and cold load input. Therefore, Yunnan should be prior to develop DES in pharmaceutical industry. Heat from steam and emission of turbine was supplied for household use in instinct four season areas of China. Many successful established cases in China has already accomplished as cold load is produced by absorption refrigerator in summer and heat by thermal equipment in winter[5]. But the weather in Yunnan Province has not distinct four seasons and no requires for cold in summer nor for heat in winter.

2.1. Heat supply charicetristics of pharmaceutical industry in Yunnan

Pharmaceutical industry in Yunnan produces heat by small distributed boiler and cold by distributed refrigeration system, high energy consumption and low efficiency. Pharmaceutical factories are the backbone enterprises of manufacturing with high energy consumption. They require stable cold and heat load such as

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steam for disinfection, concentration and power for medicine refrigeration. DES consists of a power generation system by steam or gas turbine, improving the energy use efficiency principle[5]. Document researching indicated that DES in manufacturing factories returns investment in longer term than constructional projects. Considerable high annual benefit or revenue makes it prior to develop DES, even with high initial investment.

In general，few DES projects are established in industrial park now. However, stablishing DES in industrial park is very convenient for enterprises and factories and propitious to invite business investment in long term. Moreover, governments such as Kunming, Qujing, Lijiang make intensive efforts to implement "coal abandon" policy in Yunnan Province .Coal abandon policy is a bottleneck of establishing coal use and reducing the pollutant emission[5]. The whole cogeneration process confines to energy step utilization pharmaceutical factory at the outskirt of the cities. Additionally, relatively large amount of pollutants centralized pharmaceutical factory in industrial park. Industrial parks are equipped with infrastructure, auxiliary facility, sewage treatment plant, solid waste treatment center ,but rarely with independent distributed energy and power grid for itself .Every factories and units still employs oil burning boilers and electricity boilers for their own and a power system supported by external power grid. Compared to coal boilers, electrical or diesel boilers are more environmental .But they separately provide cold and power, increasing annual cost of enterprises. For industrial park, administrative permits of DES projects are complicated and more investment has to be appended.

2.2. Characteristics of renewable energy in Yunnan Province

Renewable energy of Yunnan Province is abundant such as solar energy and wind energy. According to the different absorption level of sun's radiation in China, Yunnan Province belongs to the third area. Sunlight time lasts between 2200 hours to 3000 hours a year, giving the solar intensity between 502×10^4 kJ/cm^2 to 586×10^4kJ/cm^2 yr[18]. "Wind energy evaluation of Yunnan Province" indicated that local gross reservoir capacity of wind energy was 123 million kilowatt (kW).Available wind energy area covers 452,000 square kilometers (km^2), 11.48% of the land area in Yunnan. Yunnan provincial government will construct 13 wind power stations with the installed capacity upto 1,341,000 kilowatt (kW). As low-carbon demonstration settling out, multi-technological cooperation will be launched such as nuclear energy, wind energy, hydro energy, solar energy, biomass energy, electric power equipment, non-powered nuclear technology and etc.

2.3. Characteristics of DES

DES projects implemented in thepharmaceutical industry of Yunnan Province will play an important role in accomplishment of energy saving and emission reduction destination. The data from Yunnan Province Statistics Department indicated that the energy consumption per 10,000 yuan was constantly decreasing in 2010 for 4 years by 14.11%, in order to achieve 82% of energy saving and emission reduction destination of the eleventh five-plan in Yunnan Province. Industrial energy consumption per unit of GDP averagely was decreased by 17%. The energy consumption of scaled industrial added value of 10,000 yuan was decreased by 2.5%. The data of Chinese DES projects indicated that successful operation DES projects were located in natural gas covered areas such as Shanghai, Beijing, Guangdong and etc. DES is applied in hotel, office building, university, hospital, airport and industrial park. For example, one of the pharmaceutical factories in Guangzhou, employs a set of solar20 internal combustion engine, a set of 3.5t/h oil burning boiler and a set of 14t/h heat recovery steam generator(HRSG) as supplement. This project is programming [6].

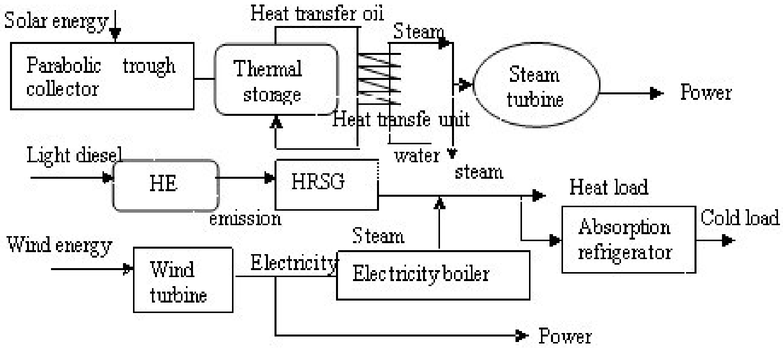

Fig.1: Diagram of DES mainly on solar and wind energy

Presently, natural gas is not available in Yunnan, but fuel of the DES can be replaced by light diesel as auxiliary driving force.Overall energy efficiency of DES mounts up to 90 %, due to step utilization of energy [7]. Solar and wind power DES generates electricity with trough the solar power technology [14], which is about to put into commercial use in China. Parabolic mirror can heat the heat transfer oil, widely known as its nice thermal stability, up to 300-400°C [10]. Then, the high-temperature oil was pumped into heat exchanger unit. Finally, parabolic concentrators generate steam about 350°C [9]. However, the steam pharmaceutical factories needed is only 180°C, can directly come from the heat transfer unit or the electricity generation unit. The steam from HRSG generated by high temperature emission from internal combustion engine can make up the intermittence of trough solar technology.

3. Energy optimal configuration mathematical model establishment of DES for the pharmaceutical industry in Yunnan

Energy configuration mathematical model of DES for the pharmaceutical industry in Yunnan is established in order to optimize energy configuration of the best economical and environmental effect. There are abundant thermal power generation and hydropower plants in Yunnan, but rarely parabolic trough solar thermal plants, showed in Table 1. The results of the researching on the investment per kilowatt ($/kW), revenue per kilowatt ($/kW), operation and maintenance costs per kilowatt (kW/$) of solar, wind and fossil energy DES from China and abroad, are summarized in Table 2.

Table 1 Several examples of solar energy and wind energy distributed energy project

Types of DES	Location	Refere -nce	Main description of economic and technological of parameters			
			Location	Total investment	Generation capacity	Output
Parabolic trough solar thermal plants	China	[12]	inner Mongolia	6billion RMB	120 million kWh	180 million RMB
		[13]	Lhasa, Tibet			
	Abroad	[14]	California, USA	3011$/kW	354 MW	150 million $
	Yunnan		None			
Wind power generation projects	China	[15]	Keshan	2.4 billion RMB	11 MW	
		[11]	inner Mongolia		44.18 MW	
	Abroad	[16]	Illinois, USA	84 million $	400MW	
	Yunnan	[17]	Qiubei County, Wenshan Prefecture	1.1 billion RMB	99MW	
		[17]	Luxi County, Honghe Prefecture	2 billion RMB	200 MW	
		[17]	Dali Prefecture	1.5 billion RMB	1475 MW	

3.1. Objectives

(1) Environmental energy saving target

Energy saving parameters directly influence on the pollution volume of DES. Reduction of carbon dioxide, nitrogen oxide and sulfur dioxide can be calculated from standard coal saving per yr. Therefore, fossil energy minimum is selected as environmental target ($\min(Z_1)$) in this model.

(2) Economic target

Profit to investment rate can be calculated from investment, revenue, operation and maintenance cost which comes from different energy configuration of pharmaceutical industry in Yunnan. Minimum profit to investment rate is selected as economic target ($\min(Z_2)$) in this model. Following high efficiency principle, profit to investment rate is selected as economic target.

Table 2 Economic indicators of optimizing model

Economic indicators	Parabolic trough solar thermal plant projects	Wind power generation projects	Fossil energy heat supply projects
Project investment（＄/kW）	4000 (K_s)	1100 (K_w)	350 (K_c)
Project revenue（＄/kW）	450(R_s)	950(R_w)	150(R_c)
Operation & maintenance cost （＄/kW）	40(M_s)	17.6(M_w)	90(M_c)
Profit to investment rate （＄/kW）	0.11	0.85	0.34

Note: investment parameter of parabolic trough solar thermal plant projects are from Table 1. The rest parameters are from document [7]. Revenue parameters of fossil energy heat supply projects are from document [8],wind power generation projects' from document [15], parabolic trough solar thermal plant projects' from document [14]. Operation & maintenance cost of parabolic trough solar thermal plant projects are from document [10] i.e.1% of total investment, wind power generation projects' are from document [11] i.e.1.69% of total investment. Profit to investment rate are calculated from the above parameters of revenue,operation & maintenance cost in Table 2.

3.2. Constraints

(1)Total energy consumption of the constraint in Yunnan Provincial pharmaceutical industry

Using Longjin Vaccine Base (LVB) as example of average energy consuming level,Yunnan provincial pharmaceutical industry total energy load is 1.48×10^6 kilowatt(kW).Incomplete statistics from National

Union Yellow page indicated that 88 pharmaceutical factories in Yunnan such as (LVB) employed small individual boilers. The LVB's manufacturing process needs 20t/h steam and the electricity comes at industrial electricity price from High and New Technology Industrial Park in new city of Kunming. Sperate electrical refrigerator supplies cold load of 1349 kilowatt (kW) for medicines and chemical reagents. The total energy consumption of LVB is 16821.2 kilowatt (kW).

$$\sum_{i=1}^{88} Q_{hi} \leq 1.48\times 10^{6}$$

(2)Non-negative constraints: $Q_{si}\geq 0, Q_{wi}\geq 0, Q_{ci}\geq 0$

3.3. Objective function

$$F(Z)=\begin{cases}\text{Min } Z_1\\ \text{Max } Z_2\end{cases}$$

(1) fossil energy consumption minimum

$$Z_1=\sum_{i=1}^{88} Q_{ci}=\sum_{i=1}^{88}(Q_{hi}-Q_{si}-Q_{wi}) \Longrightarrow Z_1=\sum_{i=1}^{88} Q_{ci}=1.48\times 10^{6}-\sum_{i=1}^{88}(Q_{si}+Q_{wi})$$

In the formula, Qhi means total energy load of number i factory, Q_{si} means the heat load produced by solar energy in number i factory. Q_{wi} means the heat load produced by wind energy in number i factory. Q_{ci} means the heat load produced by fossil energy in number i factory.

(2)Target of economic maximum

$$Z_2=\sum_{i=1}^{88}\frac{R_sQ_{si}+R_wQ_{wi}+R_cQ_{ci}}{(K_s+M_s)Q_{si}+(K_w+M_w)Q_{wi}+(K_c+M_c)Q_{ci}} \Longrightarrow Z_2=\sum_{i=1}^{88}\frac{450Q_{si}+950Q_{wi}+150Q_{ci}}{4040Q_{si}+1117.6Q_{wi}+440Q_{ci}}$$

In the formula, Rs、Rw、Rc means the revenue of solar energy, wind energy and fossil energy in DES, respectively($/Kw).Ks、Kw、Kc means the investment of solar energy, wind energy and fossil energy in DES, respectively（$/kW）.Ms、Mw、Mc means the operation & maintenance costs of solar energy, wind energy and fossil energy in DES, respectively（$/kW）.Rs/(Ks+Ms) 、Rw/(Kw+Mw) 、Rc/(Kc+Mc) means the profit to investment rate of solar energy, wind energy and fossil energy in DES, respectively in pharmaceutical factories.

3.4. Model solution

This thesis uses pure calculation method to optimize the multi-objectives linear model for tens and thousands of times by GNUplot software. Three-dimensional graph and two-dimensional gradient graph of energy optimal configuration were obtained. Light color areas of the two graphs stand for the high profit to investment rate plots of the energy configuration. The DES makes relatively high profit to investment rate on the conditions of that the solar energy shares less than 60% against the total output of wind and solar energy, simultaneously, fossil energy share against the total output of the three types of energy is less than 20%. Therefore, the profit to investment rate of the light color area is from 0.6 to 0.8. Profit to investment rate decreases and gets the minimum point with solar energy share against the total output of wind and solar energy increasing, simultaneously, fossil energy share against the total output of the three types of energy increases. We may get the conclusion that the more solar and fossil energy input, the lower profit to investment rate will be, displayed in Fig.2.

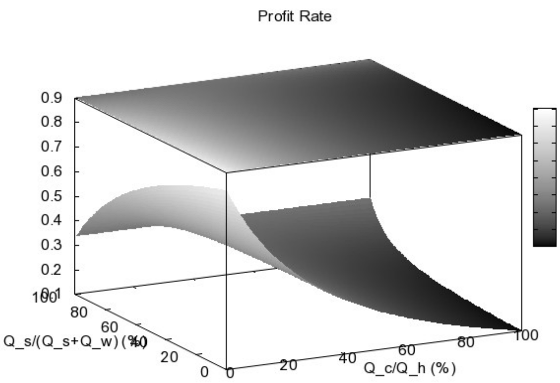

Fig. 2: 3D gragh of optimized energy configuration model on solar,wind and fossile energy resourses in Yunnan Provincial pharmaceutical industry

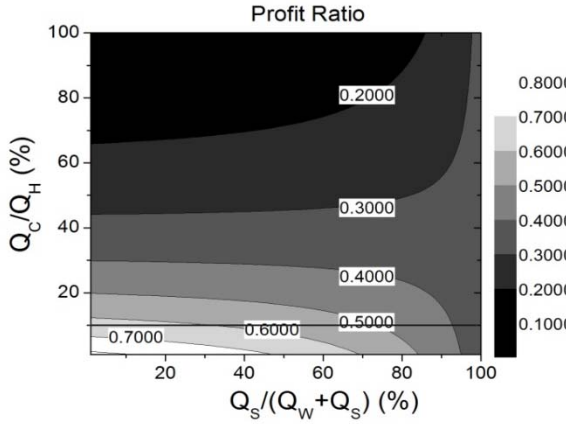

Fig. 3: 2D Gradient map of optimized energy configuration model (The black line means the situation of fossil energy less used.Q_C/Q_h=10%)

In addition, easy availability of fossil energy makes it a necessary supplement for other energies although it would be replaced by renewable energy sooner or later. The light colour of the Fig.3 indicated that projects can make from DES so long as project profit to investment rate is greater than the national economy profit to investment rate of China (0.235).As result, fossil energy consumption damages environment and energy saving, at the same time, reduce this industry profit to investment rate. However, fossil energy can not be ignored as a necessary supplement. Solar energy with fossil energy complemented used in DES can improve the profit to investment rate and minimize the energy consumption in pharmaceutical industry, balancing the environment and economy. The black line in Fig.3 means the example of fossil energy less used (10%). Constraints by wind courses of wind power generators are proved to be the decisive limitation of wind energy utilized in DES of pharmaceutical factories.

Table 3 Profit to investment rate change in different energy use proportion when fossil energy is less used

Fossil energy share against the total output（Q_c/Q_h）	Solar energy share against the total output （Q_s/Q_h）	Wind energy share against the total output(Q_w/Q_h)	Profit to investment rate
10%	13%	77%	0.6-0.7
10%	70%	20%	0.5-0.6
10%	90%	0%	0.4-0.5
50%	42%	8%	0.2-0.3

4. The result of energy saving and emission reduction by solar energy with light diesel complemented for DES of the pharmaceutical industry in Yunnan

4.1. Analysis of energy saving and emission reduction by solar energy with light diesel complemented DES

The DES device consists of solar energy heat supply system as the main operational device with internal combustion engine as auxiliary devices. Solar energy belongs to clean energy resources, while used, has no fuel cost and pollution. In the aspects of energy saving, the overall energy efficiency of DES is up to 90%[7]. However, "Energy and Thermal Engineering Design Handbook" indicated that the lowest thermal efficiency of 10t/h or larger industry boilers, combusting Category Ⅱ Anthracite, is only 74% and oil boilers' only as high as 85%. As to the aspect of pollution reduction, publications from National Development and Reform Commission indicated that saving a ton of standard coal in industrial boilers can reduce 2.62 tons of carbon dioxide (CO_2), 0.0085 tons of sulfur dioxide(SO_2) and 0.0074 tons of nitrogen oxide(NO_x).

4.2. The comparison of examples—energy saving and pollution reduction results of solar energy with light diesel complemented DES dominant in pharmaceutical industry.

If the total energy demand is fixed for 88 pharmaceutical factories in Yunnan, the thesis setups 3 examples of energy configurations for comparison, understanding energy saving and pollution reduction results of those factories in different energy configurations. Energy configuration A uses solar energy dominant DES complemented with diesel boiler. Solar energy covers 90% of the total load and the rest 10% is for diesel boiler. Annual profit to investment rate can be as high as 0.4-0.5. Energy configuration B uses fossil and solar energy dominant DES complemented with wind energy. Annual profit to investment rate is

0.2-0.3, lower than energy configuration A. Energy configuration B reduces more emission and saves more energy than energy configuration A. Energy configuration D has the properity that the whole pharmaceutical factories in Yunnan use diesel boilers. For example, annual oil consumption of LVB is up to 1788.5 tons. The factory is located in High and New Technology Industrial Park in new city of Kunming. Energy configuration C is that the whole pharmaceutical factories in Yunnan use coal boilers. If LVB is compacted with DES using the model of energy configuration one, the energy saving results will be 3227.8 tons of the standard coal equivalent comparing with that compacted with energy configuration D. If it is compared with that compacted with energy configuration B, the energy saving results will be 2605.8 tons of the standard coal equivalent. Likewise, the result is multiplied by 88 times. Yunnan pharmaceutical industrial would annually save energy by 284046.6 and 203837.8 tons of the standard coal equivalent respectively. At the same time, the emission volume of CO_2, NO_x and SO_2 will decrease. The results are displayed in Table 4.

Table 4 Comparisons on energy comsuption and polutants reductions of solar-diesel complementary distributed energy system and traditional heat supply in a year

Technical index	A. Solar-diesel complementary distributed energy system (Q_c/Q_h=10%)	B. Solar-diesel complementary distributed energy system (Qc/Q_h=50%,Q_s/Q_h=42% ,Q_w/Q_h=8%)	C. Coal burning boiler (Q_c/Q_h=100%)	D.Diesel burning boiler (Q_c/Q_h=100%)
Capicity(kW)	2688	2688	3269	2846
Efficiency %	90	90	74	85
Output (GJ)	7.6×10^7	7.6×10^7	7.6×10^7	7.6×10^7
LHV（kJ/kg）	42652（light diesel）	42652（light diesel）	19700（Category II Anthracite）	42652 (light diesel)
Fuel consumption (t/a)	198.7 10%of total consumption	198.7 50% of total connsumption	4827.9	1788.5
Energy stantard coefficiency	1.457	1.457	0.672	1.457
Energy consumption（tons of standard coal/yr）	289.5	1447.5	3517.3	2605.8
A pharmaceutical factory in Yunnan			compare to A/B	compare to A/B
Energy saving（tons of standard coal/yr）			3227.8/2069.8	2316.3/1158.3
CO_2 reduction（t/a）			8456.8/5422.8	6068.8/3034.7
NOxreduction（t/a）			23.9/15.3	17.1/8.5
SO_2 reduction（t/a）			27.4/17.5	19.7/9.8
88pharmaceutical factories in Yunnan			compare to A/B	compare to A/B
Energy saving（tons of standard coal/yr）			284046/182142	203837/10193
CO_2 reduction（t/a）			744202/47721	534055/207657
NOx reduction（t/a）			2101.9/1374.8	1508.4/754.2
SO_2 reduction（t/a）			2414.4/1548.2	1732.6/866.4

5. Conclusion

When clean energy is dominated, DES with multiple energy resources should be implemented to improve the environmental performance of Yunnan pharmaceutical industry.Most separate oil boilers and coal boilers are still employed in Yunnan pharmaceutical industry. Therefore, the industry consumes relative high energy and produces large quantity of pollution.

(1) Utilizing solar energy, wind energy and fossil energy to satisfied cold, heat and power load, DES can overcome the limitation of the development for Yunnan pharmaceutical industry and make a contribution to energy saving and pollution reduction.

(2)After researching on the parameters of investment, revenue and operation & maintenance cost of established and programming parabolic trough solar thermal plants, wind power generation plants and fossil energy heat supply projects and calculating by GNUplot software, the thesis concluded that wind energy utilization plays a leading role for the profit to investment rate of the DES complemented with solar, wind and fossil energy.

(3) Model calculation results indicated that solar energy with light diesel complemented DES, if constructed in Yunnan pharmaceutical industrial, had large potential of saving energy and reducing pollution, comparing with traditional distributed oil and coal boilers.

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