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Potential of Hybrid System Powering School in Libya

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Abstract

This paper presents a techno-economic analysis of a hybrid system powering a school in Misurata, Libya. Potential of renewable power system for school is evaluated. HOMER optimization model is used to evaluate the different possible configuration options for supplying the electrical load. Daily typical energy consumption profiles the four seasons, design based on a medium size school. Spring, summer and autumn weather conditions are not as extreme as winter, this decreases the load demand during these seasons. Winter weather conditions are used as the basis where peak energy demand is expected because lighting and heating loads dominate in the climate of Libya. Winter electrical load is found to be the maximum load. HOMER software tool was used to determine the optimum size and specifications of renewable power system. When Solar radiation and wind speed are at their maximum values of (7 kWh/m^2/d, 5.50 m/s) and the fuel price is assumed as a minimum (0.10US$), the most feasible power system economically is (PV/Tur/Gen/Battery) with total net present cost (NPC) of 293961US$, cost of energy (COE) of US$0.191/kWh, and renewable fraction (RF) of 53%. When solar radiation, wind speed and fuel price are assumed at average values of (5.05 kWh/m^2/d, 4.84 m/s, and 0.40US$) the optimal solution is also (PV/Tur/Gen/Battery) with (NPC) of 384181US$ and (COE) of US$ 0.25/kWh, and (RF) of 79%. When the solar radiation and wind speed are presumed at minimum values of (3 kWh/m^2/d, 3.50 m/s) and the fuel price is assumed maximum (1.25US$), the most feasible economical system is still (PV/ Tur/Gen/Battery) with (NPC) of 753505US$ and (COE) of US$ 0.489/kWh, and (RF) of 71%. The excess electricity from the hybrid power system during spring, summer and autumn can be sold to the utility (General Electrical Network) or used for other applications. This will enhance the economical feasibility of hybrid power systems in schools.

Keywords: Renewable energy, HOMER software, (A.D.M.D) After Diversity Maximum Demand.

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1. Introduction

Libya, a country in the middle of North Africa, borders the Mediterranean Sea to form a coast 1900 km long, 1,750,000 km^2 deep in the Sahara, the vast desert, with a population of no more than 6 million. This vast country is exposed to a solar radiation reaches to 2300 kWh/m^2/year annually, and sunshine duration is 3500 hr/year [1]. Libya is a member of the OPEC organisation, and considered as one of the biggest countries in exporting oil reserves to 46 billion barrel oil wealth.

Despite of the various energy sources and huge income, oil is hardly the only exploited source of energy and income in Libya. Without paying any attention to the infrastructure, Sustainable development or even to the renewable energy, Libya has been under the control of exhaustive and dictatorial regime for more than four decades that depleted the wealth of the country to fulfil its personal objectives.

Many Libyan cities peacefully protested against the massive corruption in the 17^{th} of February 2011. These peaceful demonstrations turned into armed confrontations with the dictatorial regime who does only believe in bloodshed. Misurata City had received the greatest allocation of fight. These clashes had destroyed the infrastructure of the city and especially the electricity network. Almost nine months, the length of the liberation war, the students who survived stayed at home. After the declaration of the liberation, no effort has been spared to reconstruct and rehabilitate schools. This article studies the alternative power supplies for supplying schools which hard to reconnect with the destroyed electricity network with power.

The HOMER software (Free version 2.19), NREL has developed the HOMER micro power optimization model, can evaluate a range of equipment options over different constraints to optimize small power systems. Such way of analysis could help in the planning off grid electrification projects. The results could then serve as a starting point for the design of individual installations. HOMER simulated the operation of thousands of different system designs, with and without a backup generator. It is then capable of identifying the most economic system in terms of load size and other variables [2-5].

This article seeks to fulfil the following objectives:

- Resupply schools with power as soon as possible in order to facilitate studying
- Test and try the renewable energy in local environment to convince authorities to adopt these new projects
- Enlighten students about the importance and the role of the renewable energy in protecting the environment

This study has been applied on a typical school in Misurata City total area 500m^2 includes ten classrooms, four offices, two water circulation WC. The electricity consumption has been defined and calculated, and then HOMER programme has been applied to process the economic analysis and suggest possible alternatives.

2. Assumptions and Model Inputs

2.1 Load demand

The loads of winter season were calculated by using Diversity Maximum Demand factor and shown in Tables (1, 2). It assumed A.D.M.D, which is the max load expected during the day and need it from the electric source all the days. The differences in the weather conditions and the solar time have led to four different load profiles as shown in figures (1, 2, 3, and 4).

The major load in schools is used for lighting, because of lack of developed laboratories and electronic machines. It assumed equalized load during the week, due to utilization of schools for social activities during the week ends because of damaging the most buildings during the liberation war.

Table 1. Winter load

Load type	No. of units X Rated power (kW)	A.D.M.D (kW)
1- Lighting:		
Classrooms (10)	6x0.2 kW x 10	12
Adm. Offices (4)	3x0.2 kW x 4	2.4
Corridors	6x0.1 kW	0.6
Bathrooms	5x0.1 kW	0.5
Outdoor	6x0.1 kW	0.6
2- A/C- Heating:		
Offices (4)	4x2 kW	4
3- Power outlets:		
PC's, Printer,..etc	8x0.25 kW	0.4
4- Water heater:		
Bathrooms	2x1.5 kW	1.5
5- Fans:		
Classes (10)	2 x 10 x 0.2 kW	4

A.D.M.D: After Diversity Maximum Demand

Table 2. Distribute the load during the day

Load (kW)	Time (hour)		
	0:00-6:00	6:00-18:00	18:00-0:00
Lighting	-	12	-
	-	2.4	-
	-	0.6	-
	-	0.5	-
	0.6	-	0.6
A/C	-	4	-
Power sockets	-	0.4	-
W/H	-	1.5	-
Total load during 24 hours (Load pattern)	0.6	21.5	0.6

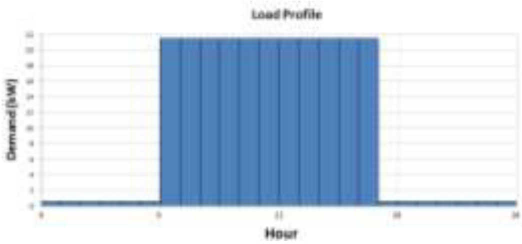


Fig. 1 winter season load

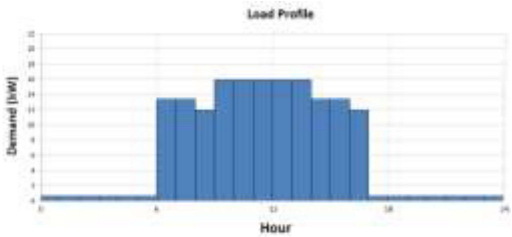


Fig.2 Spring season load

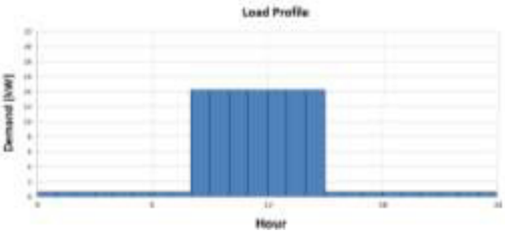


Fig. 3 summer season load

Fig. 4 Autumn season load

2.2 Wind and solar recourses

The average monthly wind speed of the site was obtained from the meteorological station in Misurata is shown in Figure 5. The school intended far about 1 km from meteorological station where it located near the sea 8 km from the city center. The solar resource of the site was obtained automatically by Homer software from the NASA Surface Meteorology and Solar Energy web site for Misurata city

32°22' North latitude and 15° 6' East [6]. The annual average solar radiation for this area is 5.05kWh/m2/d. Figure 7 shows the solar resource profile over a one-year period.

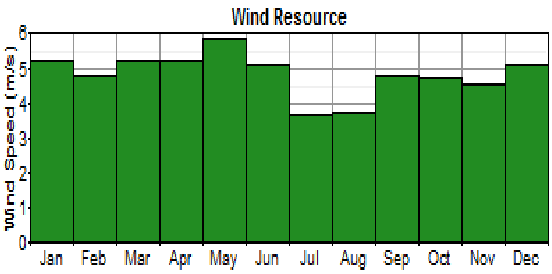


Fig. 5 Monthly wind speed

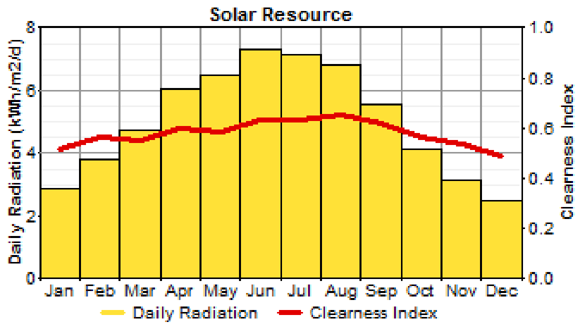


Fig. 6 Average daily Solar Radiation of Misurata city

2.3 Economics

All the calculations have been done, depending on the decision of the General National Congress, which nullified the interest rate from all projects. Comparing the calculations with the interest rate which is 5 %, at fuel price 0.1 as shown in the fig 8

2.4 Equipment Considered

The maximum load calculated thus far is constant for each day of the month. In reality, we used Diversity Maximum Demand factor. This has scaled up the annual peak load to 21kW, as observed in figure 7. Other information which has been input to the calculation program is summarized in Table3. This information includes the sizes and prices of the hybrid setup components which have been obtained from the respective journals.

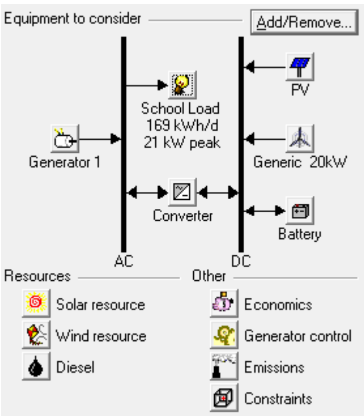


Fig. 7 HOMER Diagram for the Hybrid system Setup

Table 3. Power system Components Considered in this study *

Components	Size (kW)	Capital Cost(US$)	Replace Cost(US$)	O&M Cost(US$)	Life time	References
Generator	1	1000	800	0.05/h	15000 hours	[7]
PV panels	1	5600	5600	0	25 years	[8]
Wind turbine	20	45000	30000	900	25 years	[9]
Trojan L-16 battery		275	275	3	1075 kWh	[7]
Converter	1	700	700	0	15 years	[9]

* the prices (United States dollar) (US$) considered for 2009

2.4.1. Diesel Generator

Among all the different information that manufacturers provide on the broad range of generators, the partial load efficiency is one of the most important parameter that HOMER requires when simulating this component. The Operation and maintenance costs for the generators are listed per hour of operation. HOMER calculates the duration that the generator must run in a year and finds the total operating costs from this value. For this study the generator is AC and the capital cost was considered on basis of 1000US$ per 1kW and its replacement costs US$ 800/kW. The operation and maintenance is 0.05 US$ per hour. The lifetime of the generator is estimated at 15000 operating hours. A sensitivity analysis on the price of diesel fuel also included. This price can vary considerably based on region, transportation costs and current market price. Diesel is priced at 0.10, 0.40, and 1.25 per liter in this study.

2.4.2. Wind turbine

The wind turbine for this study is DC and has a capacity of 20 kW. Its capital cost is 45000US$ and its replacement at 30000US$. Annual operation and maintenance cost is 900US$. Its hub and anemometer is located at 25 meter height. The life time of the turbine is estimated to be 25 years.

2.4.3. Photovoltaic Panels (PV)

Photovoltaic panels were specified with capital and replacement costs of 5600US$ this cost includes shipping, tariffs, installation, and dealer mark-ups. Some maintenance is typically required on the batteries in a PV system, but very little is necessary for the panels themselves. A derating factor of 80% was applied to the electric production from each panel. This factor reduces the PV production by 20% to approximate the varying effects of temperature and dust on the panels. The panels were modeled as fixed and tilted south at an angle equal to the latitude of the site.

2.4.4. Converter

A converter is required for systems in which DC components serve an AC load or vice-versa. A converter can be an inverter (DC to AC), rectifier (AC to DC), or both. The capital and replacement cost for the converter is 700US$, without cost for operation and maintenance. The life time of the converter is 25 years. The efficiencies of the (converter); inverter and rectifier were assumed to be 90% and 85% respectively for all sizes Considered. The simulations were done for each system switching the power between the inverter and the generator. Both devices were not allowed to operate in parallel.

2.4.5. Batteries

The type of battery is Trojan L-16P. It was chosen because it is a popular and inexpensive option. The capital cost for one battery is 275US$. The replacement batteries will cost another 275US$. The operation and maintenance cost add further 3US$ with a minimum life time of 1075kWh. The valve regulated lead acid battery is rate at 6 V and has a capacity 360 Ah.

3. RESULTS AND DISCUSSION

3.1 Optimization Results

The calculation run takes into account the range of minimum to maximum values for the wind speed and global solar radiation at three fuel prices. In case 1 when the renewable resources are at their maximum values and the fuel price is at minimum value as in table 4 the PV/wind turbine/diesel generator/battery is looking as the best solution economically, while the first three systems in the list give promising renewable share with same cost of energy for second system with a little higher capital cost. In contrast between the third and first system, there is no significant cost in energy but there is a huge difference in capital cost.

Table 4. Optimization results for maximum renewable resources and minimum fuel price

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m2/d) 7 Wind Speed (m/s) 5.5 Diesel Price ($/L) 0.1

Double click on a system below for simulation results.

PV (kW)	G20	Gen1 (kW)	Batt.	Conv. (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
1	1	18	40	18	$ 92,200	$ 293,961	0.191	0.53	13,544	2,010
	1	18	40	18	$ 86,600	$ 294,088	0.191	0.51	14,024	2,872
20		17	60	18	$ 158,100	$ 295,975	0.192	0.63	9,088	1,885
		22	26	3	$ 31,250	$ 303,520	0.197	0.00	22,514	3,771
26	2		300	24	$ 334,900	$ 537,350	0.349	1.00		
	4		346	24	$ 291,950	$ 561,825	0.365	1.00		
	1	25		3	$ 72,100	$ 570,410	0.370	0.36	31,088	6,452
2	1	25		3	$ 83,300	$ 570,698	0.370	0.39	30,184	6,318
4		25		2	$ 48,800	$ 662,475	0.430	0.05	38,654	8,301
		25			$ 25,000	$ 675,107	0.438	0.00	41,743	8,760
62			550	24	$ 515,250	$ 794,575	0.516	1.00		

For the case 2 when the renewable resources and the fuel prices are at average values as in Table 5 PV/wind turbine/diesel generator/battery also economically the best solution and friendly to environment. The second and third systems in the list are hybrid with no significant increase in the cost of energy but with little lower capital cost for second system and third system.

Table 5. Optimization results for average renewable resources and fuel price

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m2/d) 5.05 Wind Speed (m/s) 4.84 Diesel Price ($/L) 0.4

Double click on a system below for simulation results.

PV (kW)	G20	Gen1 (kW)	Batt.	Conv. (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
20	1	14	87	24	$ 211,725	$ 384,181	0.250	0.79	5,897	1,343
26		16	87	18	$ 198,125	$ 395,169	0.257	0.65	8,591	1,769
	1	19	62	18	$ 93,650	$ 433,562	0.281	0.40	15,379	2,831
		22	33	4	$ 33,875	$ 472,004	0.306	0.00	22,433	3,747
35	3		346	24	$ 442,950	$ 690,325	0.448	1.00		
	5		500	24	$ 379,300	$ 746,750	0.485	1.00		
4	3	25		18	$ 195,000	$ 835,534	0.542	0.65	23,685	5,385
	3	25		18	$ 172,600	$ 841,618	0.546	0.61	25,236	5,586
10		25		6	$ 85,200	$ 945,235	0.614	0.19	35,766	8,045
		25			$ 25,000	$ 988,178	0.642	0.00	41,743	8,760

In case 3 when the renewable resources are at their minimum values and the fuel price is maximum, in Table 6 PV/wind turbine/diesel generator/battery still economically the best solution while the second system in the list gives promising renewable share with no significant increase in the cost of energy but with little higher capital cost.

Table 6. Optimization Results for minimum renewable resources and maximum fuel price

Sensitivity Results | Optimization Results

Sensitivity variables: Global Solar (kWh/m2/d) 3 — Wind Speed (m/s) 3.5 — Diesel Price ($/L) 1.25

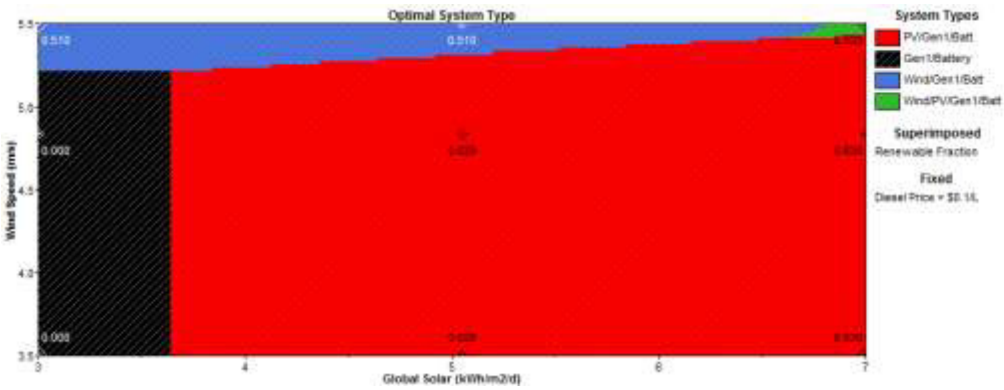
Double click on a system below for simulation results.

PV (kW)	G20	Gen1 (kW)	Batt.	Conv. (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
45	1	19	120	10	$ 361,600	$ 753,505	0.489	0.71	7,766	1,427
62		20	126	10	$ 414,450	$ 760,613	0.494	0.75	7,153	1,332
	1	22	15	15	$ 81,625	$ 943,752	0.613	0.15	20,203	3,516
		22	31	4	$ 33,325	$ 951,365	0.618	0.00	22,483	3,765
15	3	25		10	$ 256,600	$ 1,652,763	1.073	0.41	29,141	6,652
	4	25		10	$ 217,600	$ 1,709,058	1.109	0.36	31,266	6,751
62		25		10	$ 384,800	$ 1,741,063	1.130	0.50	29,315	6,995
		25			$ 25,000	$ 1,875,214	1.217	0.00	41,743	8,760

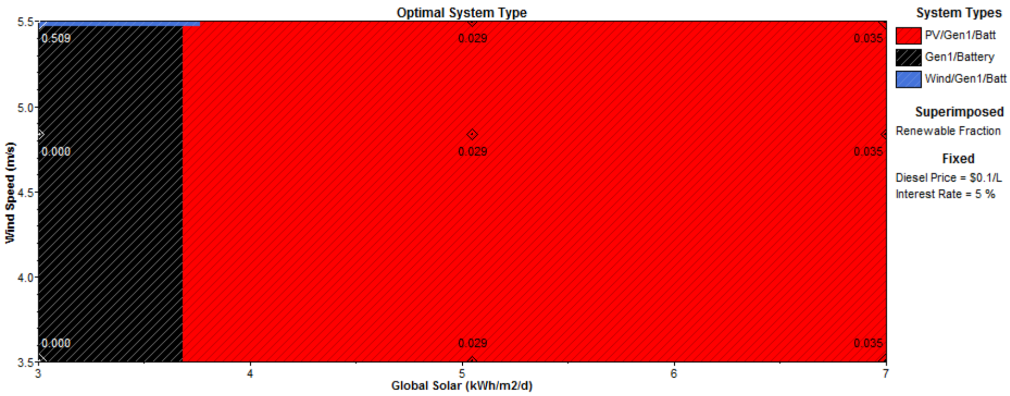
3.2 Sensitivity Results

Looking at the graphical sensitivity results give a different view for the results; it shows the whole range of the solar radiation versus the whole range of wind speed at the minimum, average and maximum diesel prices as shown in Figs 8-10 respectively.

As we see in fig 8a, we notice a decrease in the renewable resources, wind speed, global radiation. At the minimal decrease in both resources we will have diesel generator/battery. While an increase in global solar with decrease in wind speed, PV/diesel generator/battery is the best solution. On the opposite, a decrease in global solar with an increase in wind speed, wind turbine/diesel generator/battery is going to satisfy our purposes. At the maximum values of the renewable resources, PV/wind turbine/diesel generator/battery meets the ultimate solution. As long as the interest rate is high, the more use of diesel generator system as shown in Figs 8b.



a) Interest Rate 0%



b) Interest Rate 5%

Fig. 8 Sensitivity results with diesel price of US$ 0.10

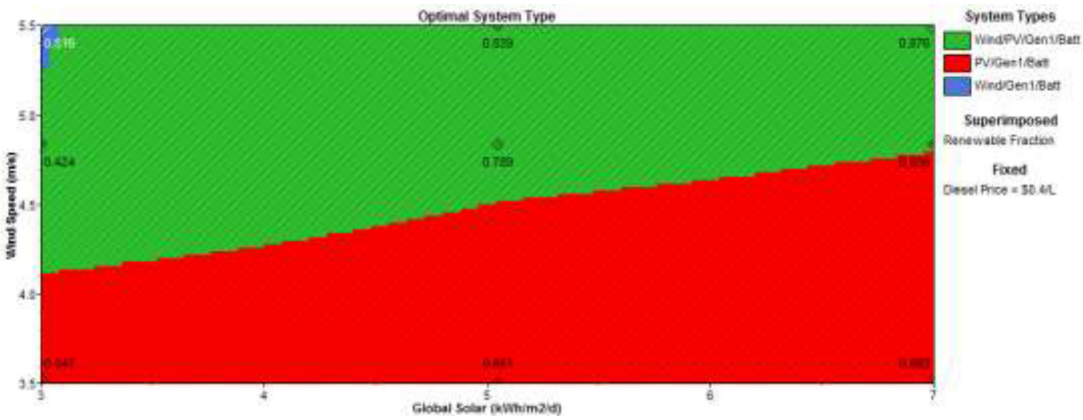


Fig. 9 Sensitivity results with diesel price of US$ 0.40

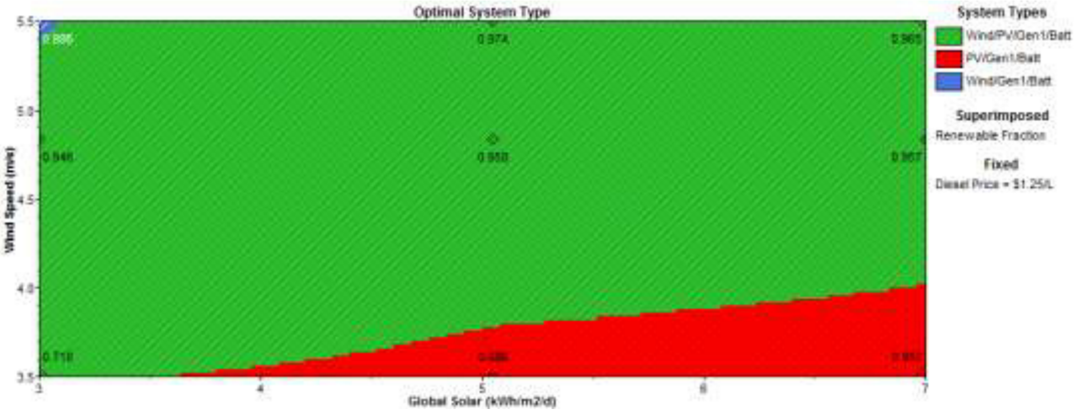


Fig. 10 Sensitivity results with diesel price of US$ 1.25

4 Conclusions

The simulation results indicate that the electricity supply for the school could be generated most economically and ecologically by hybrid renewable power system. The load profile in winter are much higher than spring, summer and autumn, the basic load is mostly lightening, which almost not necessary in summer cause of the availability of sunshine. The load profile seems to be the same in spring and autumn, higher in winter cause of the heating, and much less in summer. The excess electricity from the hybrid renewable power system in spring, summer and autumn can be used in other applications or it can be sold in the future to the utility grid to reduce the cost of energy.

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