

The Design and Construction of the PV-Wind Autonomous System for Greenhouse Plantations in Central Thailand

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Abstract—The objective of this research is to design and construct the PV-Wind hybrid autonomous system for the greenhouse plantation, and analyze the technical performance of the PV-Wind energy system. This design depends on the water consumption in the greenhouse by using 24 of the fogging mist each with the capability of 24 liter/min. The operating time is 4 times per day, each round for 15 min. The fogging system is being driven by water pump with AC motor rating 0.5 hp. The load energy consumed is around 1.125 kWh/d. The designing results of the PV-Wind hybrid energy system is that sufficient energy could be generated by this system. The results of this study can be applied as a technical data reference for other areas in the central part of Thailand.

Keywords—Central part of Thailand, fogging system, greenhouse plantation, PV-Wind hybrid autonomous system.

I. INTRODUCTION

NOWADAYS, many countries emphasize on the research of the variety of renewable energy or clean alternative energy. Solar energy has attracted most of the attention due to the fact that such energy is clean, carbon-free and inexhaustible. It is suggested that solar power generation has a very broad prospect of development [1]-[4]. Stand-alone photovoltaic (PV) system is one of the most important applications in solar energy power generation system, and has high practical value in the areas which is uncovered by the power grid, such as remote area, desert and border outpost. However, the power of PV module is greatly influenced by solar irradiance and temperature [5], [6].

The PV Hybrid energy system is designed for the combined usage of the PV system with another power generation equipment, for instance, PV system with a wind energy system, and diesels engine. PV energy system with wind energy and hydro power are also possible systems that could be applied in this case. The system features are based on a design by project objective of a particular case. The benefit of hybrid system is that various energy sources help to increase the potential in generating more electricity, and for a longer duration as long as that source is renewable energy [7]-[9].

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In Thailand, there exist a lot of agricultural areas that no electricity supplies from the grid system are available. However, they also need to use electricity to supply water pumping, green house farms, and other applications. We can use the benefit of solar energy and wind energy at daytime, and at night time, when there is no Sun; we have the wind energy to convert to electricity.

The study [10] estimates the mean power densities of surface winds over the whole country are typically in the range 10–20 Wm^{-2} . Upper level climatic charts indicate that mean free-stream wind power densities above the surface boundary layer are typically in the range 100–600 Wm^{-2} . Similar power densities would be accessible to wind machines on high ground in many places, depending on mountain topography and machine sitting. The wind potential in Thailand especially in the central of country is ideal. This area receives south-west monsoon for around six months, which are from May to October, and north-east monsoon during November to January. Moreover, Thailand has several areas with great solar power potential including southern and northern parts of the Northeastern region and certain area in the Central region. The combine solar potential area accounts for around 14.3% of the country's overall area, gaining average daily solar exposure at around 19 – 20 $\text{MJ/m}^2\text{-day}$, while the other 50% the country gains around 18 – 19 $\text{MJ/m}^2\text{-day}$ or average 5.05 $\text{kWh/m}^2\text{/day}$ [11].

The electricity supply of PV hybrid systems in rural areas of Thailand range about 10–220 kWh/day , and this type of applications appears to be cost-effective especially when utilize for rural electrification. Turcotte and Sheriff [12] have also said that PV hybrid systems are generally cost-effective for small loads of typically less than 40 kWh/day . Consequently, the PV-Wind Hybrid energy system is appropriate for providing continuous supply of electricity to the farm and other applications in rural area in Central Thailand [13].

The goal of this research is to design and construct the PV-Wind hybrid autonomous system that is able to supply the electrical energy to the pumping and fogging system of the greenhouse plantation of Rajamangala University of Technology Suvarnabhumi Phra-Nakhon-Si Ayutthaya. The author will analyze the technical performance of the PV-Wind stand-alone system. The results of this study can be applied as a technical data reference for other areas in the central part of Thailand.

II. DESIGN PROCEDURE

A. Design of the PV Energy System

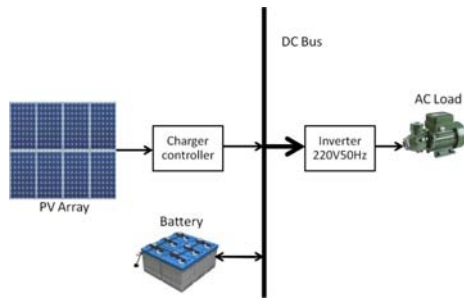


Fig. 1 PV Stand-Alone Energy System

The water pump load is equal to 375 W running for 3 h/day. The system requirements are as follows: days of autonomy is 2 days, the DOD (Depth of Discharge) of battery is 0.6 (60%), the Peak Sun Hour /day is 4.839(PSH measure on site), DC voltage = 24 V, PV module is 85 % of distortion factor, the Inverter efficiency is 90%, the safety factor of inverter is 1.25, the solar charger efficiency is 80% safety factor of charger is 1.2, and battery efficiency is 80%. The equation that was used to calculate the sizing and capacity of equipment in this system as follow:

$$\text{Load Energy} = \text{Load power} \times \text{hours} \quad (1)$$

$$\text{Energy from battery} = \frac{\text{Load Energy}}{\text{Inverter efficiency}} \quad (2)$$

$$\text{Energy charge to battery} = \frac{\text{Energy from battery}}{\text{Battery efficiency}} \quad (3)$$

$$\text{Energy from PV array} = \frac{\text{Energy charge to battery}}{\text{Charger efficiency}} \quad (4)$$

$$\text{Inverter size} = \text{Load power} \times \text{safety factor} \quad (5)$$

$$\text{Battery capacity} = \frac{\text{Energy from battery} \times \text{Day of autonomy}}{(0.85 \times \text{DOD} \times \text{Vdc})} \quad (6)$$

$$\text{PV size} = \frac{\text{Energy from PV array}}{\text{PSH} \times \text{Distribution factor}} \quad (7)$$

$$\text{Solar charger size} = N_0 \text{ string} \times \text{Current/string} \times \text{safety factor} \quad (8)$$

From (1)-(8), the results of the design calculation of the PV stand-alone energy system is shown in Table I. The PV module specification that was used in this system is as follow: $P_m = 50W_p$, $V_m = 12V_{dc}$, $I_m = 2.86 A$, $V_{oc} = 21A$, and, $I_{sc} = 3.07A$.

From the calculated result, the author chose the equipment in PV energy system as shown in Table II. The PV array consists of 10 of 50Wp single crystal module. The solar charger is 24V/30A. The battery used are four 12V 100Ah batteries connected in a series of two and parallel with each other. The inverter used is 1000 VA 24V.

TABLE I

THE CALCULATED RESULTS OF PV STAND-ALONE ENERGY SYSTEM

Items	Result	Unit
PV array		
-Peak Sun hour	4.839	h
-DC Voltage	24	V
-Distribution factor	85	%
-Energy from PV	1.953	kWh
-PV sizing	474.85	W
PV Charger		
-DC Voltage	24	V
-Efficiency	80	%
-Safety factor	1.2	
-Energy charged to battery	1.563	kWh
-Current rating	18.42	A
Battery		
-Depth of Discharge	60	%
-Dc voltage	24	v
-Efficiency	80	%
-Energy from battery	1.250	kWh
-Capacity	204	Ah
Inverter		
-DC Voltage	24	V
-AC Voltage	220	V
-Efficiency	90	%
-Safety factor	1.25	
-Rating	469	W
Load		
-Water pump	375	W
-Working hour	3	h/d
-Day of autonomous	2	d
-Energy	1.125	kWh
-Rating	469	W

TABLE II

THE EQUIPMENT OF THE PV STAND-ALONE ENERGY SYSTEM

Equipment	Rated	Amount
PV array 500W	50Wp	10
Charger/Controller	24V/30A	1
Battery	12V/100Ah	4
Inverter	1000VA/ 24Vac/220Vac	1

B. Design of the Wind Energy System

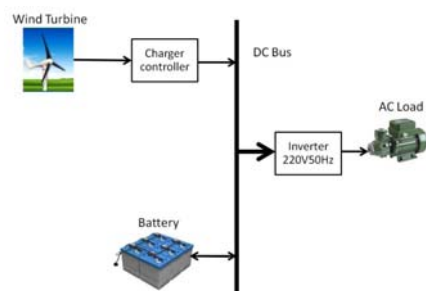


Fig. 2 The Wind Turbine Stand-Alone Energy System

The design was based on divided load power of 50% from the full load of the PV system (187.5 W). Then, the measured wind energy running hours per day is 9 hr./day and wind speed at the site is 4.8 m/s. The author let the total system loss equals to 30% of the total energy. The battery capacity is

according to Table I is 24V 200Ah. Finally, the equations that were used in this design are as follow:

$$\text{Load Energy} = \text{Load power} \times \text{hours} \quad (9)$$

$$\text{Wind turbine power} = \left[\frac{\text{Load Energy}}{\text{running hours per day}} \right] \left[1 + \frac{\% \text{ loss}}{100} \right] \quad (10)$$

$$\text{Battery discharging time} = \frac{\text{Battery capacity}}{\left(\frac{\text{Load power}}{\text{Battery voltage}} \right)} \quad (11)$$

$$\text{Energy discharge} = \frac{\text{Load power}}{\text{Battery discharging time}} \quad (12)$$

$$\text{Wind charger size} = \left[\frac{\text{Wind turbine output power}}{\text{Battery voltage}} \right] \text{safety factor} \quad (13)$$

From (10) and (12) the wind turbine power means the power calculation from the load rating. The wind turbine output power means the power output from wind turbine specification.

TABLE III
THE CALCULATED RESULTS OF THE WIND ENERGY SYSTEM

Items	Result	Unit
Wind Turbine		
-Wind energy	9	h/d
-Wind speed	4.8	m/s
-Energy to load	562.5	Wh/d
-Total system loss	30	%
-Power	81.25	W
-Size	300	W
Charger		
-DC Voltage	24	V
-Efficiency	80	%
-Safety factor	1.2	
-Current Rating	15	A
Battery		
-DC Voltage	24	V
-Current	7.813	A
-Discharge time	26.14	H
-Energy from battery	4.902	kWh
-Capacity	204.2	Ah
Load		
-50% of water pump	187.5	W
-Work days	3	D
-Day of autonomous	2	D
-Energy	0.563	kWh

From (9)-(13) the results of design calculation of the wind turbine stand-alone energy system are shown in Table III. From the power curve of the wind turbine (300W 24V) that will be used in this system, it can be found that when the wind speed is 4.8m/s, the wind turbine could generate power around 60W. But due to the fact that the desired output is more than 81.25W, the size of the wind turbine should be bigger than this one. In this project we chose two 300W24V wind turbines. The charger and controller selected has the rating of 20A 24V. The equipment's of the wind energy system are as shown in Table IV.

TABLE IV
THE EQUIPMENT OF THE WIND ENERGY SYSTEM

Equipment	Rated	Amount
Wind Turbine	300W/24V	2
Charger/Controller	24V/30A	1
Battery	Include PV energy system	

C. The PV-Wind Hybrid Energy System

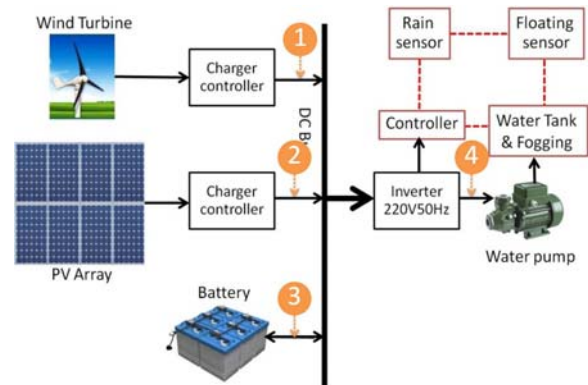


Fig. 3 The Diagram of the PV-Wind Hybrid Autonomous Energy System for the Greenhouse Plantation

TABLE V
THE EQUIPMENT OF THE PV-WIND AUTONOMOUS SYSTEM

Equipment	Rated	Amount
PV array	50Wp/12V	10
Charger/Controller	24V/30A	1
Wind Turbine	300W	2
Controller/dummy load	24V/30A	2
Battery bank	12V/100Ah	4
Inverter (pure sine)	1000VA/24Vac/220Vac	1
Fogging System		
-AC Motor/Motor pump	220V50Hz/0.5H.P.	1
-Springer/mist spray and valves	24L/min	24

The PV-Wind hybrid autonomous energy system for greenhouse plantation comprise of two parts as follow: 1) The PV-Wind energy system 2) The fogging system. The details of complete system are as shown in Table V.

D. The Installation

The author installed two of 300W Wind turbine and 500 W of the solar panels on the roof top of agricultural plantation house. The charger and controller and battery bank of the PV-Wind energy system installed inside of the house as shown in Figs. 4-6



Fig. 4 The PV-Wind Charger and Controller and Battery Bank Installation



Fig. 5 The Fogger Installed Inside the Greenhouse

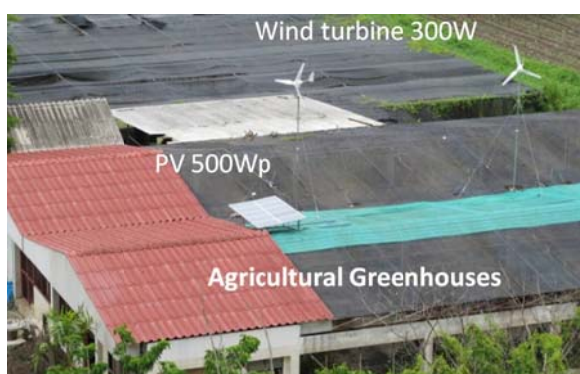


Fig. 6 The PV-Wind Hybrid Autonomous Energy System for Greenhouse Plantation

III. METHOD OF EXPERIMENT

1. Set up the fogging system and test the function of fogging spray and timing program until the system completed working.
2. Set up the instrument as follow diagram in Fig. 3.
3. Connected the ACV meter, ACA meter, and 1 phase kWh meter at position 4.
4. Connected the DCV meter DCA meter at point 1, 2 and 3.
5. Turn on the PV-Wind hybrid autonomous energy system as shown in Fig. 3.
6. Measure and record the instrument that was installed in Fig. 3.
7. The experimental period was from April to June 2013.

IV. RESULTS AND DISCUSSION

The PV-Wind hybrid autonomous energy system was running system status from April to June 2013. Fig. 7 shows the energy consumption of load, DC bus voltage, and the AC bus voltage versus time.

According to Fig. 7, the average DC bus voltage is about 32.1V and the average AC bus voltage is equal to 229.8V. Therefore, the average energy supply to load is equal to 0.1064 kWh. The author found that the load energy in an hour is 0.4252 kWh/d or equal to 1.276 kWh/d. The estimated energy generation by PV-Wind hybrid energy system is $1.9531 + 0.5175 \text{ kWh/d} = 2.4706 \text{ kWh/d}$. This means that the system could supply energy enough for the load and in addition to that, the system has an excess of energy which is equal to $(2.4706 - 1.2756 = 1.195 \text{ kWh/d})$ 43.36% of total energy. The excess energy was stored in the battery bank.

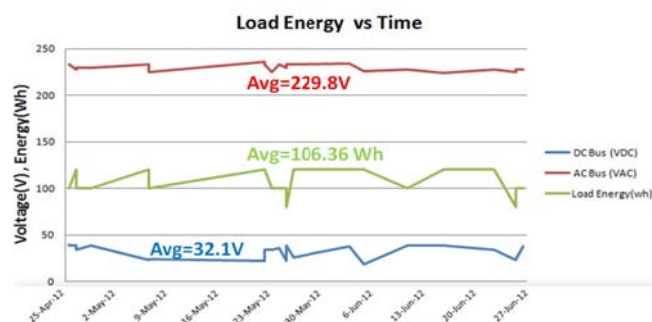


Fig. 7 The DC bus voltage, AC bus voltage and load energy vs time when the PV-Wind hybrid energy system was running

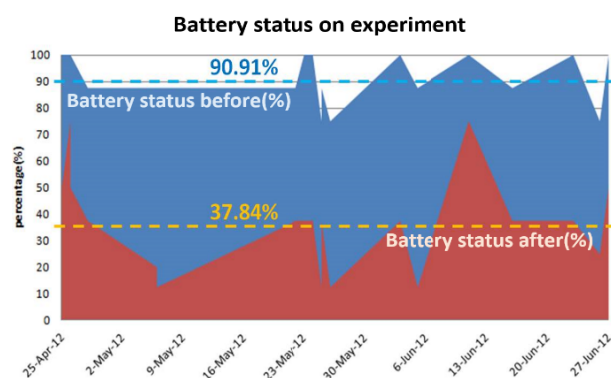


Fig. 8 The Status of the Battery Bank on PV-Wind Hybrid Autonomous Energy System

The energy supply from the PV-Wind hybrid energy system that was accumulated in battery bank in average is equal to 90.91% of energy. After the battery supply the electrical energy to load the level of energy accumulated will decrease and the average energy storage will be reduced to about 37.84% as shown in Fig. 6. Nevertheless, the PV-Wind hybrid autonomous energy system can work perfectly during the testing periods. The system could generate enough electricity for the load of the greenhouse plantation. However, the energy left in battery storage will be less than the estimated value which is about $(43.36 - 37.84) = 5.52\%$. For future work, the author should extend the PV module for about 10% of its installation capacity. It will compensate the storage energy in the battery bank enough to maintain this autonomous system to complete supporting our project.

V. CONCLUSION

The design of the PV-Wind hybrid autonomous energy system depends on the water consumption in the greenhouse. By using 24 mist foggers with the capability of 24 liter/min each and operating 4 times per day each round for 15 min, the fogging system is able to operate via the water pump with AC motor 220 V 50 Hz 0.5 HP. The load energy consumed around 1.125 kWh/d. The designing results of the PV-Wind hybrid energy system could generate enough energy to run the system. The results of this design can be applied with the other plants of greenhouse plantation in the central of Thailand.

However, the energy that will be used will be much more in the future because of the over-loading of the motor pump. This

maybe the case because of the drain waste or slag that blocked the flow of water at the valve and fogged the mist head. This in turn makes the efficiency of the system to decrease over time therefore the maintenance of the fogging system and the battery is necessary.



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REFERENCES

- [1] K Wu, T Kato, Y Yokomizu et al, "Economic value of the inverter in residence-use PV system applied for electricity storage at night," Power Engineering Society Winter Meeting, IEEE, New York USA, pp.195-198, 2002.
- [2] R Ramakumar, J E Bigger, "Photovoltaic systems," Proceedings of the IEEE, vol. 81, pp.365-377, 1993.
- [3] Bangyin Liu, Chaohui Liang, Shanxu Duan, "Research on topology of DC-module-based building integrated photovoltaic system," Proceedings of the CSEE, vol.28, pp.99-104, 2008.
- [4] H.Maammeura., A.Hamidatb, L.Loukarfia, "Energy intake of a PV system from grid-connected agricultural farm in CHLEF (ALGERIA) " Energy Procedia volume 36 ,pp1202 – 1211, 2013
- [5] S Duryea, S Islam, W Lawrance, "A battery management system for stand-alone photovoltaic energy systems," IEEE Industry Applications Magazine, vol.7, pp.67-72, 2001.
- [6] V Salas, M J Manzanos, A Lazaro, et al, "The control strategies for photovoltaic regulators applied to stand-alone systems," The 28th Annual Conference of the IEEE Industrial Electronics Society, Sevilla, Spain, 2002.
- [7] Rolando Soler Bientz, "Development of Hybrid Photovoltaic-Wind System for Academic Purposes", ISES 2005 Solar World Congress, Orlando, FL. USA, pp 32, 2005.
- [8] Napat Watjanatepin and Chaiyant Boonmee, "4.872 kW Grid-connected PV System Result and Testing at Rajamangala University of Technology (RMUT), Thailand" ISES 2005 Solar World Congress. Orlando, FL. USA, 2005.
- [9] Kellogg, W. D.; Nehrir, M.H.; Venkataramanan, G.; Gerez, V., "Generation unit sizing and cost analysis for stand-alone wind, photovoltaic, and hybrid wind/PV systems," Energy Conversion, IEEE Transactions on , vol.13, no.1, pp.70,75, Mar 1998
- [10] R.H.B. Exell, The wind energy potential of Thailand, Solar Energy, Volume 35, Issue 1, 1985, Pages 3-13, ISSN 0038-092X,
- [11] (Online) <http://weben.dede.go.th/webmax/content/areas-solar-power-potential> accessed on 27 December 2013
- [12] Turcotte D, Sheriff F. PV Horizon: workshop on photovoltaic hybrid - summary and conclusions of the workshop. Montreal, Canada, 10 September 2001.
- [13] Phuangpornpitak, S. Kumar, PV hybrid systems for rural electrification in Thailand, Renewable and Sustainable Energy Reviews, Volume 11, Issue 7, September 2007, Pages 1530-1543, ISSN 1364-0321, <http://dx.doi.org/10.1016/j.rser.2005.11.008>.



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