FEASIBILITY STUDY OF ON-GRID SOLAR-WIND HYBRID SYSTEM AT WONGSAKORN PLAZA MARKET

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Abstract - The global warming is caused by burning the fossil fuels for human activities. Renewable energy widespread equips for household activities, facilities and offices. This paper is to investigate the reduction of electricity consumption of Wongsakorn Plaza market, Saimai district, Bangkok by 10 percent. The solar-wind hybrid system is introduced to improve the efficiency of the electricity performance. The theoretical equations of solar photovoltaic and wind turbine are applied in the calculations, which the solar and wind data were collected from NASA and the Department of Energy Development and Promotion Thailand. The results shown that solar power output was 508.2 kWh/day and wind power generation was 31.2 kWh/day. The total hybrid system production was 539 kWh/day, therefore, it reduces the electricity consumption by 16.8 percent. The costs of this project were estimated to be around $240,000 USD which the income from electricity saving was around $29,510.25 USD, Therefore, the turnover period was approximately 8 years.

Index Terms - Energy saving, Hybrid system, On-gird, Solar photovoltaic and Wind turbine,

I. INTRODUCTION

The consumption of fossil fuels by human activities such as transportation, electricity generation and industry activities has been released carbon dioxides into the atmosphere which causing global warming [1]. Hence, renewable energy resources such as solar, wind, hydro and biomass have been introduced as an alternative source of energy production. These technologies are unlimited resources, environmentally friendly and economical [2]. According to Renewable 2017 Global Status Report, the renewable energy power of 2017 GW have been installed worldwide. From Figure 1, the renewable energy in Thailand has produced 9 percent of overall electricity generation which it is about 4,712 MW in 2015 [14].

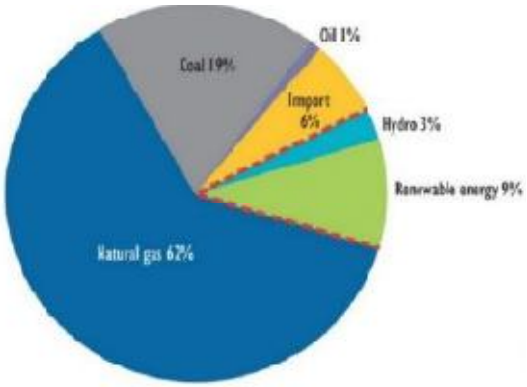


Figure 1. Electricity Generation Share from Several Sources in Thailand [14].

The renewable energy electric systems have been widely installed in households, offices and facilities by using solar rooftop panels, wind turbines, hydropower systems and biomass reduce the electricity consumptions. These systems could be operated with either on/off electric grid connections [3]. There are many companies such as Apple, Intel and Walmart have successfully installed the renewable energy systems in their facilities [4]. Furthermore, the hybrid systems have been introduced to maximize the continuous supply of energy due to climate variations. The weaknesses of each one can be implemented by the strength from other systems. These systems can be installed in both grid-connected and stand-alone systems. The hybrid systems provide more reliability and economical for renewable energy generation, especially electricity generation for household purposes [9][10]. In this paper the on-grid solar-wind hybrid system will be analyzed to reduce the electricity consumptions in the market by approximately 10 percent.

II. DESCRIPTION OF HYBRID ENERGY SYSTEM

Hybrid energy system is a system that combines between renewable energy resources such as solar panels and wind turbines as shown in Figure 2.

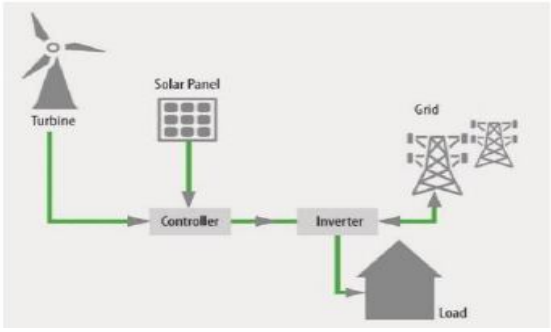


Figure 2. On-Grid Solar-Wind Hybrid Systems [27].

This technology could improve the energy efficiency by compensating the limitation of each resource, for example, wind turbines can still generate power while the sunlight is not appearing. Also the site would depend upon climate and weather conditions. This

systemoffers more power efficiency and economical. Also it improves grid-connected distribution which the electricity is supported into inverter and controller at all time. Therefore, it improves systems stability [25] [26].

A. Solar Power

Solar energy can be directly converted to electricity by using photovoltaic or as known as solar cells. Solar radiation is comprised of photons, which, when photons impact a solar cell, there might be absorbed or reflected of the radiation. Thus, only the absorbed photons produce energy to generate electricity [5]. Thailand has high potential of solar power due to the average solar radiation is 18.2 MJ/m2 with the highest amount of sunlight occurs during April and May as shown in Figure 3 [6]. According to Annual Report 2015 Thailand's Department of Alternative Energy Development and Efficiency, the total solar photovoltaic installations are 2,076 sites with a capacity of 4.7 MW nationwide.

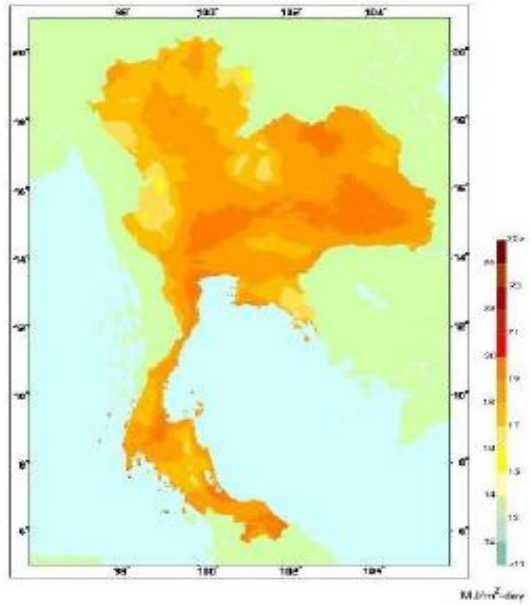


Figure 3. Thailand Solar Radiation [6]

B. Wind Power

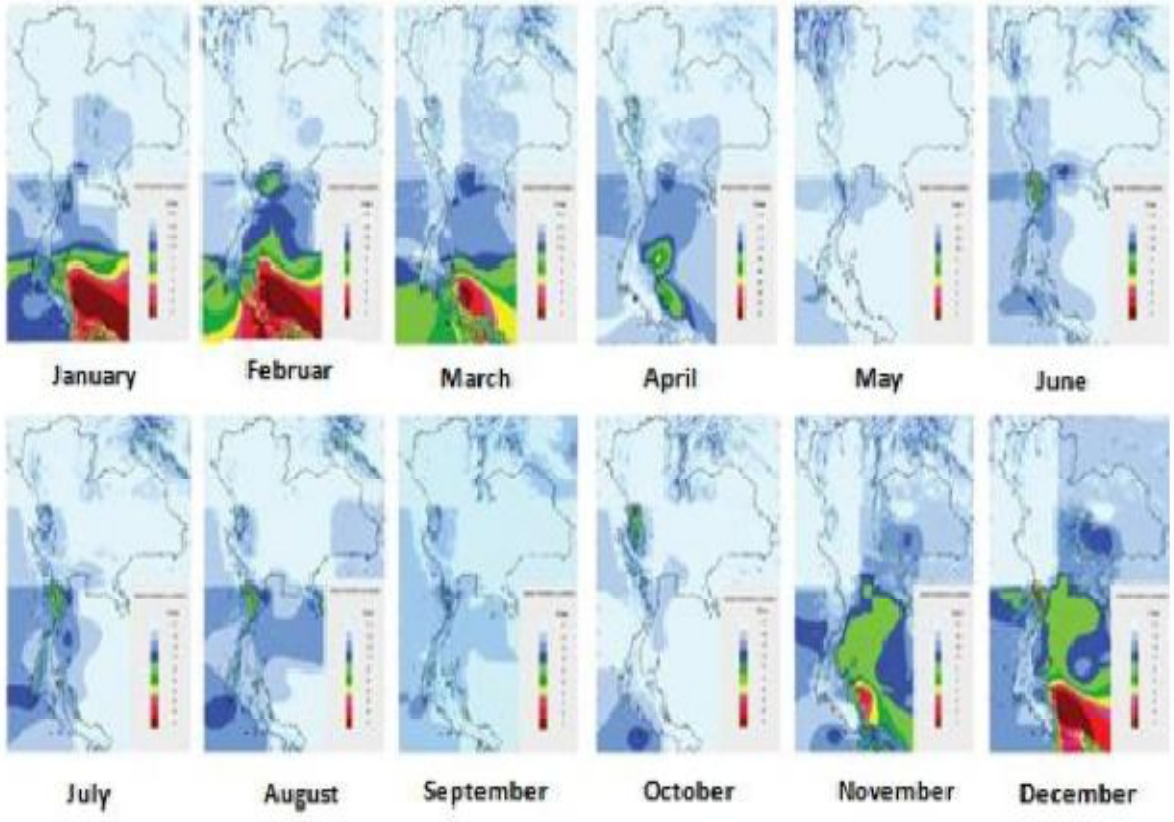
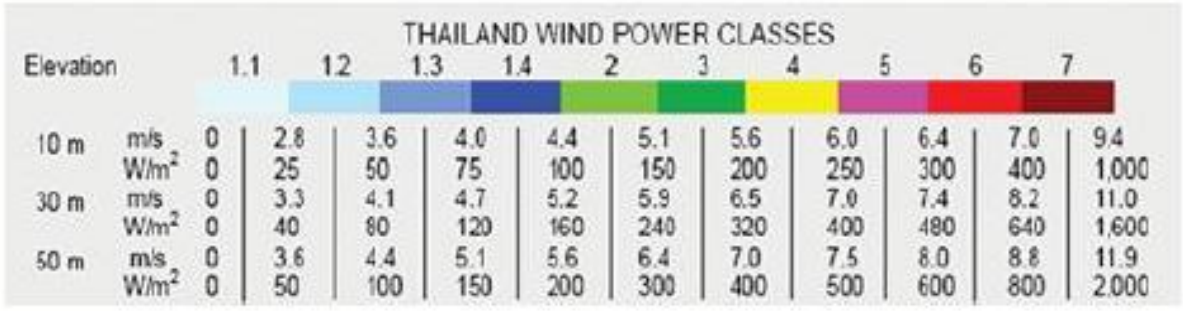


Figure 4. Thailand Wind Potential in Each Month [13]

Wind energy can be generated electricity by using wind turbines to convert wind's kinetic energy to produce electricity power. The wind flows over the blades creates lift which causes them to turn. The blades are connected to a drive shaft that turns an electric generator to produce electricity. The best wind farm sites are at the tops of smooth hills, rounded hills, shorelines and mountain gaps that produce wind tunneling [5]. In Figure 4 and 5 the average wind speed in Thailand is around 4-5 m/s with cut-in speed is 3-4 m/s and rated power output at 12 m/s, which it is suitable for small wind turbines [7]. In 2015, the total capacity of wind power generation in Thailand is 3.8 MW [8].



Elevation		1.1	1.2	1.3	1.4	2	3	4	5	6	7
10 m	m/s	0	2.8	3.6	4.0	4.4	5.1	5.6	6.0	6.4	7.0	9.4
	W/m²	0	25	50	75	100	150	200	250	300	400	1,000
30 m	m/s	0	3.3	4.1	4.7	5.2	5.9	6.5	7.0	7.4	8.2	11.0
	W/m²	0	40	80	120	160	240	320	400	480	640	1,600
50 m	m/s	0	3.6	4.4	5.1	5.6	6.4	7.0	7.5	8.0	8.8	11.9
	W/m²	0	50	100	150	200	300	400	500	600	800	2,000

Figure 5. Thailand Wind Power Classes [13]

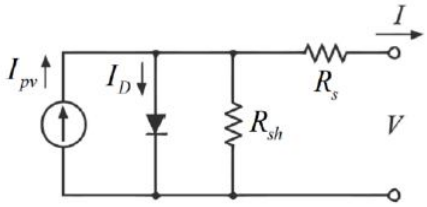
C. Controller

The main function of the charge controller is to monitor the solar and wind power to charge the battery or discharge to the load. The voltage level of the systems would be observed by the controller to release the suitable sources of energy into the loads. It could also extract the power from the grid when hybrid systems do not produce enough electricity power. Finally, it consists the functions of over – charge protection, short – circuit protection, pole confusion protection and automatic dumpload function [22] [23].

III. THEORETICAL BACKGROUND

A. Solar Photovoltaic

The photovoltaic array contains many solar panels connected in series or parallel model to reach the required current, voltage and power [15]. A solar panel model is similar to a diode with p – n junction, and it includes one current, one diode and two resistors as shown in Figure 6. The process begins when the sun lights have absorbed by the junction which it would produce current by the photovoltaic effect [16]. The maximum power output from (I – V) and (P – V) characteristic graphs are shown in Figure 7.



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Figure 6. Equivalent Circuit of a Solar Panel [16]

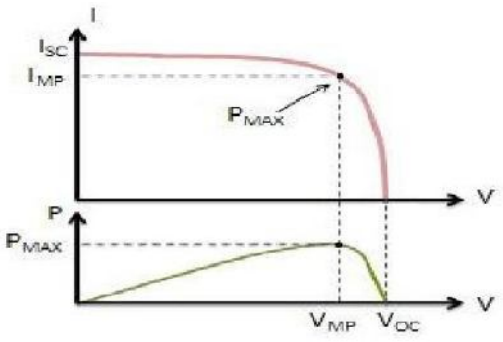


Figure 7. Output Characteristics of PV Array [15]

Therefore, the current equation of the solar cell can be written as follows [18]:

$$I = I_{ph} - I_0 \left[\exp\left(\frac{q(V+IR_s)}{Akt}\right) - 1\right] - \left(\frac{V+IR_s}{R_{sh}}\right) \quad (1)$$

Where: I_{ph} = Photo current (A)
I_0 = Diode reverse saturation current (A)
I = Cell current (A)
V = Cell voltage (V)
R_s = Series resistor (Ω)
R_{sh} = Shunt resistor (Ω)
q = Electronic charge (1.602 x 10^{-19} C)
k = Boltzmann constant (1.38 x 10^{-23} J/K)
A = Ideality factor
T = Temperature (K)

The peak power output of a solar panel can be described as follows [31]:

$$P_{peak} = \frac{E_{load} \times I_{STC}}{E_{glob} \times Q} \quad (2)$$

Where: E_{load} = Electricity loads (kWh/d)
E_{glob}= Solar Radiation (kWh/m^2/day)
I_{STC} = Solar Irradiation (1 kW/m^2)
Q = Power coefficient of the system

Component/System	Q
PV Module (Crystalline)	0.84 – 0.95
PV Array	0.80 – 0.90
PV System (Grid-Connected)	0.60 – 0.75
PV System (Stand-Alone)	0.10 – 0.40
Hybrid System (PV/Diesel)	0.40 – 0.60

Table 1.Typical Power Coefficients of Different System Types [31]

B. Wind Turbines

Wind turbine captures wind energy by using blades to turn the generator as kinetic energy into the electric power [19]. There are two types of wind turbines included horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs) as shown in Figure 8 [5]. The residential applications require around 400 W to 100 kW depending on electricity purposes [21]. The wind power output equation can be described as follows:

$$P_w = \frac{1}{2}\rho A V^3 C_p \quad (3)$$

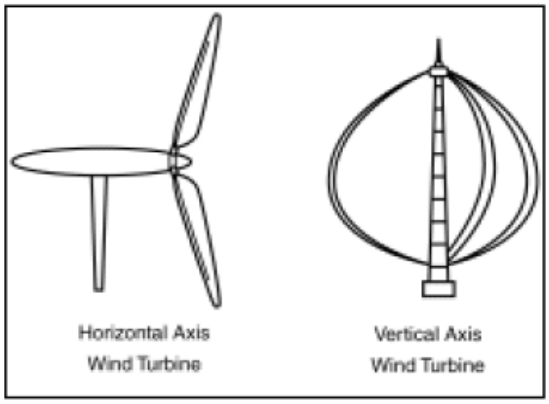


Figure 8. Types of Wind Turbines [19]

Where: ρ = Air density (1.225 kg/m^3)
A = Swept area (m^2)
V = Wind speed (m/s)
C_p= Power coefficient of the wind turbine

The Betz's limit, C_p is a nonlinear function represents the efficiency of mechanical power that extract from wind power. The maximum theoretical power coefficient is 0.59. The power coefficient depends on two variables which are tip speed ratio (TSR) and the pitch angle. The pitch angle is defined as the angle of the blade with respects to the longitude axis [21].
TSR can be found as follows:

$$TSR = \lambda = \frac{\omega R}{V} \quad (4)$$

Where: ω = Turbine rotor speed (rad/s)
R = Radius of the turbine blade (m)
V = Wind speed (m/s)

The typical value of C_p for high speed turbines would be around 0.4 – 0.5 and for low speed turbines are 0.2 – 0.4 [15]. The values of tip speed ratios with respect to rotor power efficiency can be shown in Figure 9.

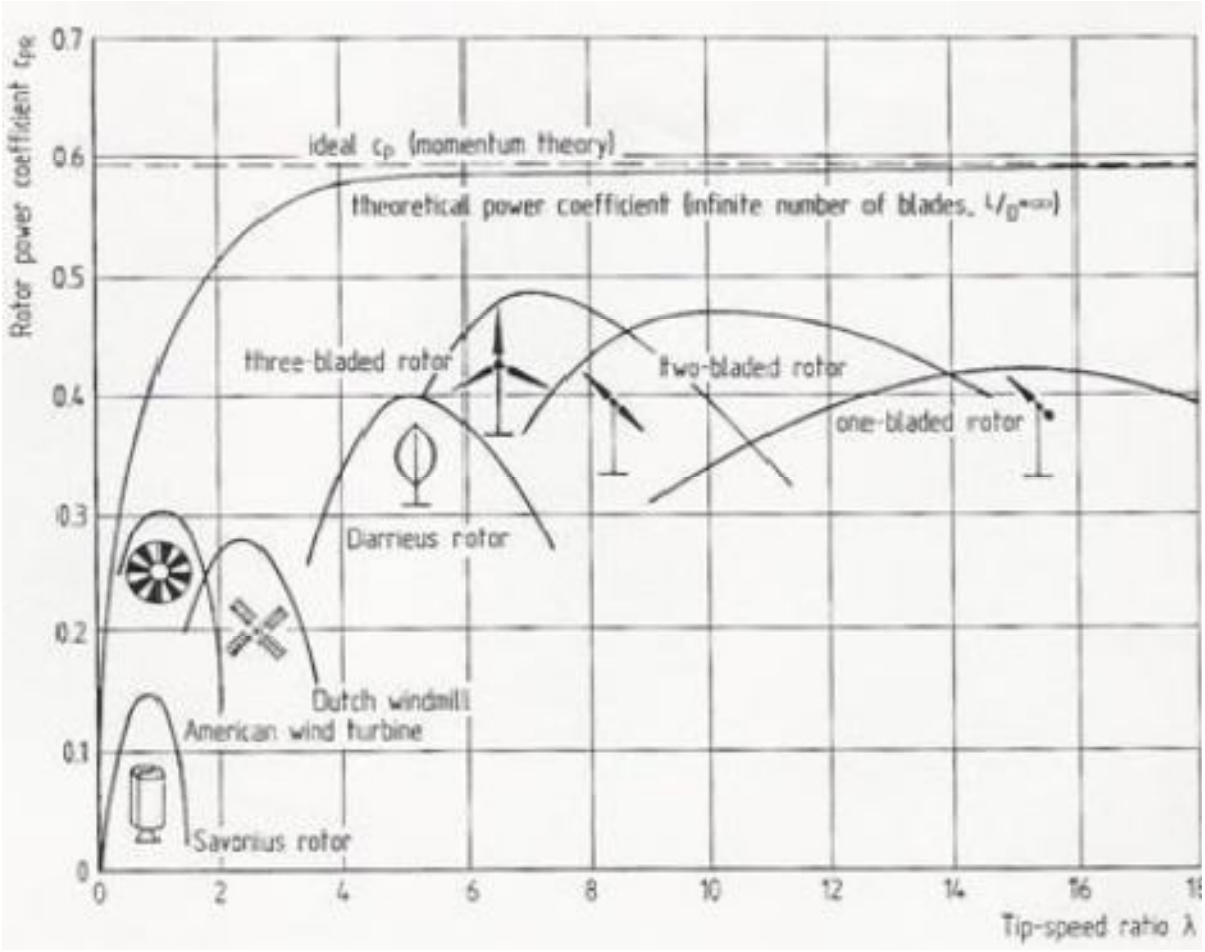


Figure 9. Typical Power Coefficients of Different Rotor Types over Tip Speed Ratio [24]

IV. CALCULATIONS

A. Locations

The study site is located inWongsakorn Plaza market, Saimaidistrict, Bangkok as shown in Figure 10. This district is located at the boundary of Bangkok, therefore, there is not affected by large obstacles such as the tower and building. The electricity consumptions are mainly large user household purposes such as lighting and air conditioning.



Figure. 10 Wongsakorn Plaza Market Map [28]

B. Data

The following tables express the monthly electricity consumptions, wind speed data and solar radiation data respectively in the area of Saimai district, Bangkok. The data have been collected from Wongsakorn Plaza market, the Department of Energy Development and Promotion and Atmospheric Science Data Center.

Electricity Consumption

Month	Electricity Consumption (kWh)
January	103,000
February	97,000
March	90,000
April	68,000
May	99,000
June	101,000
July	97,000
August	92,000
September	104,000
October	100,000
November	104,000
December	98,000

Table 2. Average Electricity Consumption

Solar Radiation

Month	Average Solar Radiation ($kWh/m^2/day$)
January	5.07
February	5.62
March	5.99
April	6.23
May	5.37
June	4.93
July	4.82
August	4.81
September	4.73
October	4.49
November	4.74
December	4.86

Table 3. Average Solar Radiation at Saimai District [29]

Wind Speed Data

Month	Average Wind Speeds (m/s)
January	3.9
February	4.4
March	4.7
April	4.6
May	4.6
June	4.7
July	4.7
August	4.7
September	4.5
October	3.9
November	4.0
December	3.9

Table 4. Average Wind Speed at Saimai District[30]

C. Calculations

Average electricity consumption = 96,000 kWh
Average solar radiation = 5.14 kWh/m2/day
Average wind speed data = 4.4 m/s

Solar Panels

A solar panel has an area of 1.65 m^2per 270 W_p, and the maximum area of the roof is 1,700 m^2. The

capacity of solar panels would be 190 kW.

Therefore,

$$\text{Area of the solar panels} = \frac{190{,}000\ \text{W} \times 1.65\ \text{m}^2}{270\ \text{W}} = 1161\ \text{m}^2$$

The peak power output can be calculated as (2):

$$P_{peak} = \frac{190 \times 1}{5.14 \times 0.4} = 92.4\ \text{kW}$$

Where: E_{load} = Electricity loads = 100 kWh/d
E_{glob}= Solar Radiation 5.14 kWh/m^2/day
I_{STC} = Solar Irradiation = 1 kW/m^2
Q = From Table 1. Assuming to be 0.4

The peak power output per day can be calculated by the maximum power of solar panels multiply by 5.5, which is a factor of absorption hours of solar panels and power losses, therefore, it shows as follows:

$$P_{solar} = 92.4\ \text{kW} \times 5.5 = 508.2\ \text{kWh/day}$$

Wind Turbines

The wind turbine capacity of 10 kW has been selected for this site. The power curve shows that the wind turbine is already generating the power at wind speeds of 4.4m/s and producing 2.7 kW of electricity as presented in Figure 11.

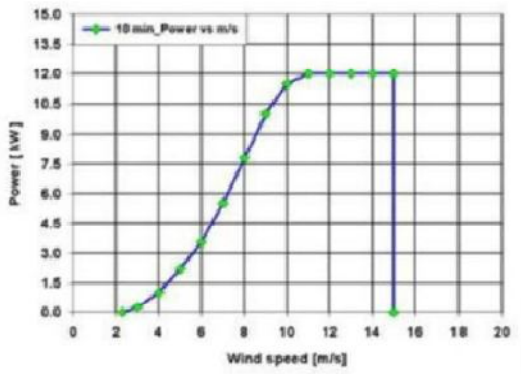


Figure 11. Wind Power Curve of FT-10 kW [32]

The wind power equation can be written as (3):

$$P_w = \frac{1}{2}\rho A V^3 C_p$$

Therefore,

$$P_w = \frac{1}{2} \times 1.225 \times 55.4 \times 4.4^3 \times 0.45 = 1300\ \text{W}$$

Where: A = Swept area = 55.4 m^2
V = Wind speed = 4.4 m/s
C_p= Power coefficient = 0.45

The wind power generation per day can be calculated:

$$P_{wind} = 1300\ \text{W} \times 24\ \text{hours} = 31.2\ \text{kWh/day}$$

The total electricity generation is

$$P_{solar} + P_{wind} = P_{hybrid}$$

Therefore,

$$508.2 + 31.2 = 539.4\ \text{kWh/day}$$

The average electricity consumption per is 96,000 kWh. Therefore, the average electricity consumption per day is

$$96{,}000 \div 30 = 3{,}200\ \text{kWh/day}$$

The reduction of electricity consumption can be calculated as:

$$539\ \text{kWh} \div 3{,}200\ \text{kWh} = 0.168 = 16.8\%$$

Costs

The average cost of solar-wind hybrid system is assumed to be around $1.20 USD per 1 watt of the capacity of the system. ($1.00 USD = 33 Baht). This price already includes wind turbine devices, solar panels, inverter, controller and installation fee.
Therefore,

$$200{,}000\ \text{W} \times \$1.2 = \$240{,}000\ \text{USD}$$

The electricity price for 1 unit is $0.15 USD
Hence,

$$\text{Energy Production per day} \times \$0.15\ \text{USD}$$

$$539\frac{\text{kWh}}{\text{day}} \times \$0.15\ \text{USD} = \$80.85\ \text{USD per day}$$

$$\$80.85\ \text{USD} \times 365 = \$29{,}510.25\ \text{USD per year}$$

Therefore, the turnover period can be calculated as

$$\frac{\$240{,}000\ \text{USD}}{\$29{,}510.25\ \text{USD}} = 8.1\ \text{years}$$

RESULTS AND DISCUSSION

This paper has shown the reduction of electricity consumption byWongsakorn Plaza market by 10 percent. The solar-wind hybrid systems has been introduced in this study. From the results shown that the peak power output of solar panel with a capacity of 190 kW was 92.4 kW. There were some factors that must be considered due to the sunlight does not shine at all time, therefore, the factor of 5.5 has been introduced as a reality situations that solar panels absorption and loss factors. Hence, the solar power output would be 508.2 kWh/day. A 10 kW wind turbine was chosen for this site. The wind turbine power generation was 1300 W. And the wind power generation per day was 31.2 kWh/day. Consequently,

the total solar-wind hybrid power generation was 539 kWh/day. The average electricity consumption per day was 3,200 kWh, therefore, the electricity consumption was reduced by 16.8 percent. Finally, the cost estimation for this project was around $240,000 USD, which, the electricity price was reduced by $29,510.25 USD. The turnover period was approximately around 8 years.

CONCLUSION

The fossil fuels cause global warming, which renewable energy will be the solution in the future. The renewable energy widely installs for household purposed, facilities and offices to reduce electricity consumptions. The hybrid system is introduced to improve the efficiency and economics to the consumers. The solar-wind hybrid system has been investigated to reduce the electricity consumption of Wongsakorn Plaza market by 10 percent. The result shown that the hybrid system was produced around 539 kWh/day, and it decreases the electricity production by 16.8 percent.Also, this project estimates to cost around $240,000 USD which it can save electricity costs around $29,510.25 USD per year, so, the payback period is 8 years.

The limitations of this paper are the solar radiation and wind speed data might not be up-to-date and it could affect the results. Also the assumption factors might not be accurate. The future recommendation of this project is to improve and precise the efficiency of the solar and wind generation by using computer software which it provides much more reliable results.

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