DESIGN AND DEVELOPMENT OF SOLAR-POWERED IRRIGATION SYSTEM FOR SUGARCANE CULTIVATION

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ABSTRACT

The objectives of this research were to design and examine the performance of solar-powered irrigation system on different daytime for sugarcane cultivation in Udon Thani. This study was conducted at the experimental area of the Faculty of Technology of Udon Thani Rajabhat University on an area of 6,480 m^2, utilizing the sugarcane of the Khon Kaen 3 variety during the dry season. The study was divided into two parts: the design of a solar-powered irrigation system and the study of technical performances of the solar-powered irrigation system across different times of day. The payback period was calculated by comparing energy costs between using a solar pump with a petrol engine pump. As a result, a 2,200 W solar water pump and a 3 inches water pipeline with a pipe length of 167 m were designed for the 6,480 m2 sugarcane fields. A drip irrigation system was selected to be used in sugarcane irrigation system because it turned out that the drip irrigation system improved the efficiency in irrigating sugarcane plantations. The drip tape had holes with a diameter of 16 mm and 20 cm apart. It was placed into two areas for the water to flow to the end of the tape. The solar panel used in this study was 445 W with a maximum voltage of 45.18 V/panel, and a string of 10 panels, connected in series. The result revealed that the system worked well at every time of the day, morning, noon, and afternoon. According to that, sugarcane met its water requirement by an hour. To be more specific, at the range of highest solar irradiance, it could produce a highest total system efficiency of 6.40% in the morning. In addition, the payback period was approximately 3.56 years comparing the solar pump with engine pump. Therefore, it could be concluded that the drip irrigation system was efficient in growing sugarcane, and also environmentally friendly.

Keywords: Solar-powered irrigation systems, Sugarcane, Solar pump, Pump efficiency,

Introduction

Udon Thani is a province where most of the land is used for the purpose of agriculture. Sugarcane is considered as a significant industrial drop in Udon Thani since 926,699,200 m2 are used for sugarcane cultivation - the 4th largest area of the country (Office of Agricultural Economics, 2022). Nevertheless, sugarcane cultivation requires irrigation at all stages of growth (Chontanaswat et al., 2020, p.66; Gunarathna et al., 2018, p.2). The average sugarcane irrigation around Udon Thani is 3.75 mm/day (Thai Meteorological Department, 2008; Royal Irrigation Department, 2011). Planting seasons of sugarcane in Thailand are pre-rainy season (April - June), dry season (January - March), and post-rainy season (November – December). Pre-rainy season allows the sugarcane to maximize water uptake during the rainy season. In dry season, irrigation is needed for sugarcane to store water before the rain comes in the next season. For post-rainy season, the soil is still humid (Office of the Cane and Sugar Board, 2016). However, sugarcane cultivation in the Northeast is mostly based on rainfed cultivation. Sugarcane plants may lack water if there is little or no rain in the growing year. Especially now that the world is facing an El Niño situation (Office of the Cane and Sugar Board, 2020). These drought problems have directly affected the growth and production of sugarcane (Office of the Cane and Sugar Board, 2020; Wonprasaid, 2015) Providing additional water according to the sugarcane's needs is necessary.

A drip irrigation system is an irrigation system that benefits the environment by conserving water, increases efficiency of growing sugarcane in the dry season or in water scarcity areas, and increases quantity and quality of sugarcane yields (Parnthon, et al., 2017, p.341). The water is applied either on the surface, next to the plant, or subsurface, near the root zone. (Office of the Cane and Sugar Board, 2020) Comparing sugarcane cultivation using drip irrigation with farmers' current irrigation method, which is based on soil moisture and rainwater only, it was found that the cost of growing sugarcane until harvesting using the drip irrigation method was only 6.8% higher than the current irrigation method for farmers, but yields a higher returned of up to 22.5%, or approximately 2.28 TB/m2/year (Mekdan, 2013). It is consistent with the study of in the northeastern region, it was found that drip irrigation increased sugarcane production and returns (Wonprasaid, 2021; Inthawut & Suphanchaimat, 2011, p.57).

Unfortunately, most sugarcane cultivation areas are remote from communities and lack access to electricity. This results in farmers having to irrigate sugarcane by themselves. Except that sugarcane is planted in rainy season, rain will help farmers alleviate their workload (Chontanaswat et al., 2020, p.66). On the contrary, in summer and winter, farmers may need equipment and tools for water pumping and irrigation systems which require fuel. This increases the expense to farmer, including air pollution (Islam & Hossain, 2022, p.2).

According to that, irrigating sugarcane by solar-powered water pump may offer farmers the opportunity to reduce energy costs related to pumping system. This is because Thailand is located in the equator, it is a country with great potential for solar energy (Iamtrakul & Kritsanawonghong, 2019, p.9). Moreover, the installation of solar power generation system can also be installed off-grid, which is suitable for areas without access to electricity (Jovanović et al., 2023, p.2; Mukda et al., 2020, p.124). Several studies of solar-powered irrigation systems have been reported in previous literature. In Saudi Arabia, research undertaken by Rehman and Sahin (2015, p.712) which aimed to investigate and compare the performance of both diesel and solar PV stand-alone power generating systems for underground water pumping purposes. It found that the solar PV power generating system did not only help to decrease carbon emission to the atmosphere but also was comparable to the unit cost of energy with the diesel only system in many sites even though the unit price of the diesel fuel was very low. A study undertaken by Islam and Hossain (2022, p.1), which aimed to conceive solar irrigation pump's economic feasibility in northern Bangladesh by conducting standard financial and net environmental benefit analyses. The financial analysis revealed that a typical solar irrigation pump with 4kWp solar panels and 2.5kW pump were the most profitable option (20% IRR) for investment. Moreover, the net environmental benefit was found to be almost equal to the given subsidy for installing them.

In addition, the performance of solar-power system depends on solar irradiance. It also depends on the weather conditions and solar panel temperature. Imjai et al. (2020, p.18) studied performance of an integrated solar irrigation system for isolated agricultural areas in Thailand. The results showed that water flow generated by solar PVs and performances of the system were different depending on weather conditions. Choosakul et al. (2011, p.177) studied application of solar cells for daytime weather study, The results showed that the variation of generated electric current might be plausible to the daily weather condition. Cotfas et al. (2018, p.1) reported that the solar panel temperature is one of the most important factors which affect the performance of the solar panel. Leow et al (2020, p.1) simulated photovoltaic panel temperature under different solar irradiance using computational fluid dynamic method. The results showed that an increase in solar irradiance along with the PV panel operating temperature increase. It can be concluded that solar irradiance and solar panel temperature affect the performance of the solar-powered system. Solar irradiance will change as the daytime period changes.

The objectives of this research were to design and develop a solar-powered irrigation system in combination with drip irrigation for sugarcane cultivation in Udon Thani Province, and to examine the effect of daytime on the performance of the solar-powered irrigation system, focusing on planting during February which is outside the rainy season.

Research Objective

1. To design of the solar-powered irrigation system for sugarcane cultivation in Udon Thani
2. To study of technical performances of the solar-powered irrigation system during daytime for sugarcane cultivation in Udon Thani

Research Methodology

The sugarcane plantation of this study had the area of 6,480 m^2 and this study was conducted at the experimental area of the Faculty of Technology, Udon Thani Rajabhat University, Udon Thani Province (17°26'56.2"N, 102°56'33.6"E), during the dry season (February) of 2023 as shown in Figure 1. The soil was considered a laterite soil mixed with sand. The so-called Khon Kaen 3 was used in this study since the variety was suitable for Udon Thani geography. Sugarcane cultivation was spaced 2 m between rows and 0.3 m between trees, representing an area of each tree as 0.6 m2 (A_c). The total number of sugarcanes planted (N) in the study area was 10,800 stems. This study included design of a solar-powered irrigation system and study of technical performances of the solar-powered irrigation system on different daytime for sugarcane cultivation in Udon Thani, the details are as follows.

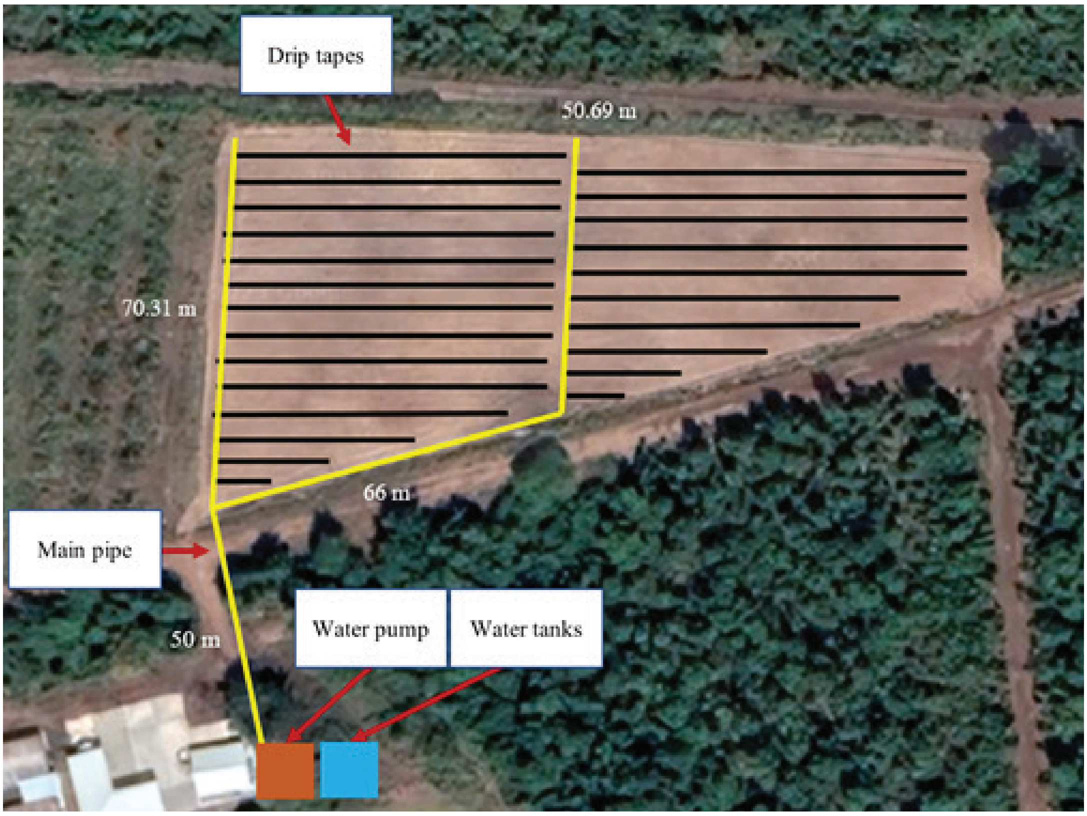

Figure 1 A sugarcane field in this study

1. Design of a solar-powered irrigation system for sugarcane cultivation in Udon Thani

Irrigation requires of sugarcane and total dynamic head were considered in this study. The irrigation requires sugarcane or crop evapotranspiration (ETc, mm/day) was calculated by the formula of Kaewruang (2022); Bhingardeve et al. (2017, p.975); Costa et al. (2022, p.3) (Equation 1). Crop coefficient (Kc) was obtained from the Royal Irrigation Department (2011). Pan coefficient (Kp) was obtained from Royal Irrigation Department (2011). Pan evaporation (Ep, mm/day) was obtained from Thai Meteorological Department (2008). Air temperature (Ta) and solar irradiance (G) were collected daily.

$$ET_C = K_C \times K_P \times E_P \qquad (1)$$

ET_C was the data used to calculate water discharge rate or flow rate (Q, m^3/s) which was a parameter used in considering the size of pump, together with the total dynamic head (H, m).

2. Study of technical performances of the solar-powered irrigation system for sugarcane cultivation in Udon Thani

The examination of the solar-powered irrigation system was conducted in the beginning, the mid, and the end of February, and 3 times a day which were, morning (09:00-10:00 am.), noon (12:00-1:00 pm.), and afternoon (3:00-4:00 pm.). The morning and afternoon are the period which farmers can work in their fields and have more solar irradiance, and the noon is the period which and have highest solar irradiance. The technical performances in this study included pump efficiency (η_{pump}), solar panel efficiency (η_{PV}), and total system efficiency (η_{sys}) as suggested by Mindú et al. (2021, p.4) and total water discharge in the experiment area (Dw, m^3/day). In addition, this study analyzed the payback period as a comparative analysis with the study of (Limprasitwong & Thongchaisuratkrul, 2020, p.255). However, the quality and yield of sugarcane plants are not included in this study. It will be studied and analyzed in future research. The solar panel temperature was collected by an infrared thermometer (IRTEK, model: IR50i). The flow rate (Q, m^3/s) was collected according to 10 dropper heads distributed around the area. The solar irradiance (G, W/m^2) was measured by a solar power meter (Lutron, model: SPM-1116SD) and the same slope angle with a string of panels (17° from horizontal line), The voltage (V, V) and current (I, A) were measured by digital multimeters (DIGICON, model: DM-819T). These data were carried out in every 10 min by calculating technical performances. There were used together with water density (ρ, kg/m^3), gravity or acceleration due to gravity (g, 9.81 m/s^2), and solar panel area (A_{PV}, m^2). The following expressions were calculated based on equation as,

$$\eta_{PV}=\frac{\int_{1h}(V\times I)dt}{A_{PV}\int_{1h}(G)dt} \quad (2)$$

$$\eta_{pump}=\frac{\rho\times g\times H\int_{1h}(Q)dt}{\int_{1h}(V\times I)dt} \quad (3)$$

$$\eta_{sys}=\eta_{pump}\times\eta_{PVsys} \quad (4)$$

$$D_W=Q\times N \quad (5)$$

Payback period (PBP) was calculated to determine the financial for comparing energy cost between using a solar pump with a petrol engine pump as Equation 6, the PBP refers to the number of years or the period required to return the initial investment (Senanon et al., 2019, p.7; Duangjaiboon, 2018, p.72).

$$\text{PBP (years)} = \frac{\text{Initial investment (Baht)}}{\text{Net cash inflow per year (Baht/year)}} \quad (6)$$

Results

1. The solar-powered irrigation system for sugarcane cultivation in Udon Thani

A significant factor for considering size of the pump was that the amount of irrigation that sugarcane requires per day, including total dynamic head – calculated by the amount of irrigation that sugarcane requires (ET_c) in the study area of 6,480 m^2 with respective of local conditions turned out to be 24.32 m3/day and the total dynamic head was 8.17 m. A solar centrifugal pump which was 2,200 W, 90-580 V, and 8 A was therefore chosen. As for the pump power requirement, the power (445 W) and maximum voltage (45.18 V) of the solar panel and a string of 10 panels, connected in series, were selected as shown in Figure 2. The schematic design of the solar-powered irrigation system in this study is shown in Figure 3.

Figure 2 A solar-powered irrigation system unit

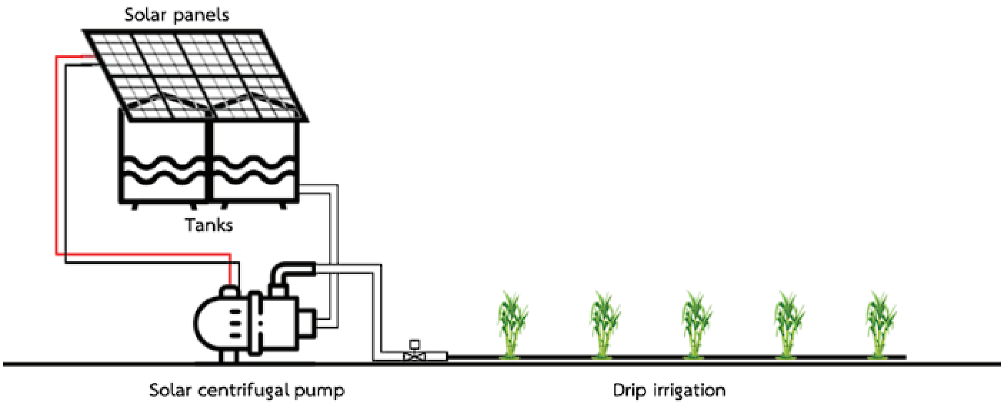

Figure 3 Schematic design of a solar-powered irrigation system for sugarcane cultivation in this project

A drip irrigation was used in the irrigation system for sugarcane cultivation. By doing this, each hole on a drip tape which its diameter was 16 mm, was distanced from each other 20 cm as shown in Figure 4. The drip tape was placed into two areas in order for the water could be flowable to the end of the tape which the length of the field was 146 m.

Figure 4 Drip irrigation by drip tapes in this study

2. Technical performances of the solar-powered irrigation system for sugarcane cultivation in Udon Thani

For the study of technical performances of the solar-powered irrigation system, indicators of this study included solar panel efficiency, pump efficiency, total system efficiency, and total water discharge based on Equations (2)–(5). The solar-powered irrigation system parameters were collected 3 times during the day. Table 1 presents the parameters and values of the solar-powered irrigation system for sugarcane cultivation.

Table 1 Parameters and values of the solar-powered irrigation system for sugarcane cultivation

Parameter	Value		
	09:00-10:00 am	12:00-01:00 pm	03:00-04:00 pm
Solar panel temperature (°C)	39.6	54.7	48.6
Solar irradiance (G, W/m^2)	582.87	1025.03	759.12
Water flow rate (Q, m^3/s)	0.0067	0.0094	0.0074
Solar panel efficiency (η_{PV}, %)	17.30	12.38	9.56
Pump efficiency (η_{pump}, %)	37.00	32.15	41.14
Total system efficiency (η_{sys}, %)	6.40	3.98	3.93
Amount of discharge* (m^3/day)	27.35	38.64	31.25

* Calculated based on 10,800 stems

The result of solar irradiance and power output were used to calculate the efficiency of the solar panel. The solar irradiance in the morning increased from 580.1 W/m2 to 742.3 W/m^2. The power output increased from 2,124 W to 2,321 W. Unlike the solar panel efficiency that decreased from 18.3% to 15.6% and had an average of 17.30% (Figure 5). At noon, the solar irradiance was quite stable – it was between 1,020.1 W/m^2 and 1,030 W/m^2. The solar panel efficiency was also stable – it averaged 12.38%. However, in the afternoon, the solar irradiance decreased from 776.5 W/m^2 to 545.9 W/m^2. The power output also decreased according to the solar irradiance which was from 2,158 W to 828 W. The result of efficiency the decrease from 13.9% to 7.6% and average 9.56%.

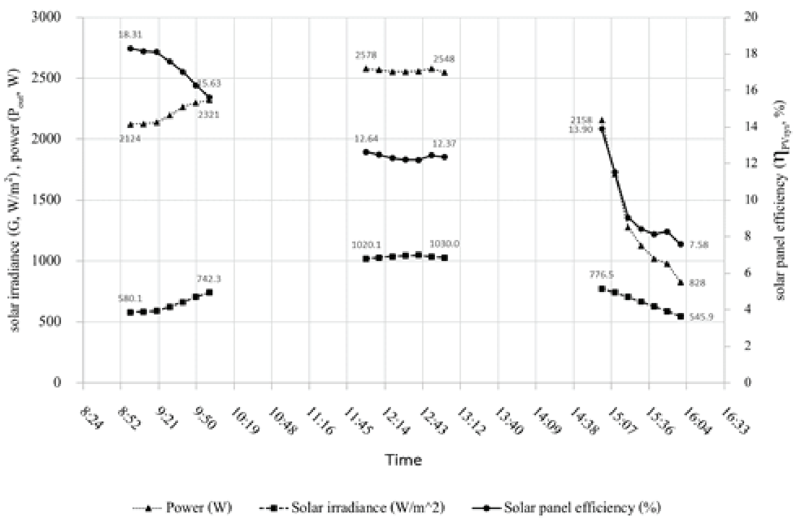

Figure 5 Relationship between solar irradiance, power output and solar panel efficiency over the daytime

Table 1 shows the tend of water flow rate which depend on solar irradiance, by this means, once the solar irradiance increased, the water flow rate would accordingly increase. To clarify, the solar irradiance in the morning was 582.87 W/m^2, the water flow rate was 0.0067 m^3/s. It was calculated as 37.0% of the pump efficiency. At noon, the solar irradiance increased to 1,025.03 W/m^2, the water flow rate increased to 0.0094 m3/s, and the pump efficiency was 32.1%. And in the afternoon, the solar irradiance decreased to 759.12 W/m^2, the water flow rate decreased to 0.0074 m^3/s, however, it was found that the pump efficiency increased to 41.1%. The calculation of total system efficiency shows that solar-powered irrigation system worked most efficiently in the morning. To clarify, the total efficiency of the system was 6.40%, and the lowest efficiency was found in the afternoon that was 3.93%.

In Figure 6 it shows locations of water collection. There were 10 locations where the water containers were placed. As seen in Figure 5, the location number 1, 2, 3, 6, 7, and 8 were the locations where the water was collected by normal tube. The location number 4, 5, 9, and 10 were the locations that collect the amount of water for considering whether water was flowable to the end of the line.

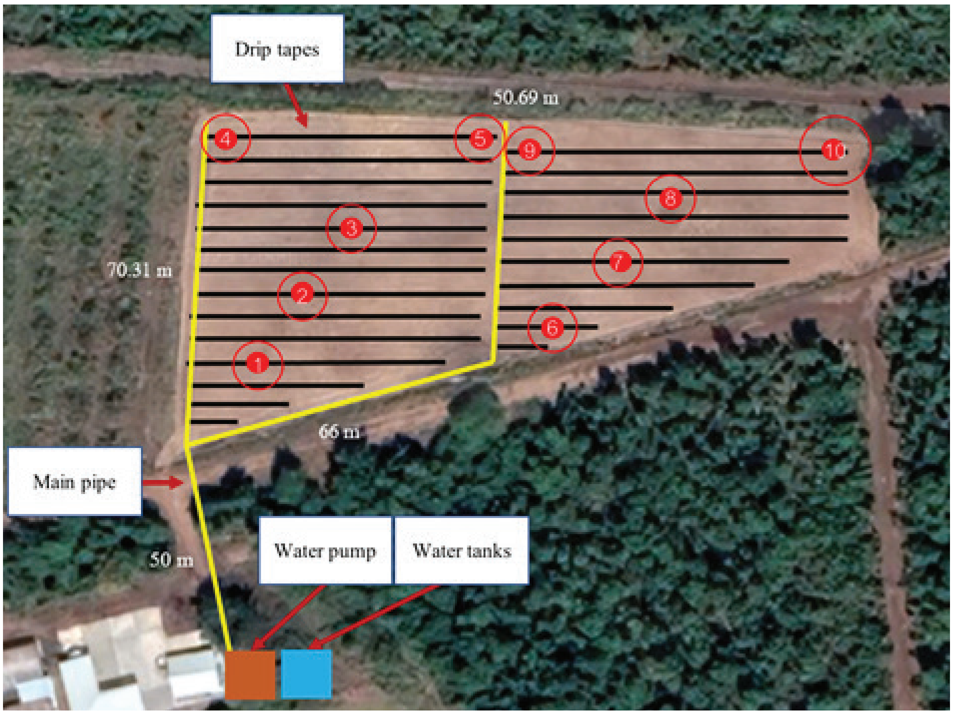

Figure 6 Locations of water collection

The results shown the water supply was flowable to the end of the line at every particular location. It also finds that the water discharge shows a relationship with solar irradiance as varied directly. The maximum amount of water discharge obtained for 10,800 sugarcane stems in this study was 38.64 m^3/day with maximum solar irradiance at noon. Since the water requirement of 10,800 sugarcane stems was 24.30 m^3/day, the average total water discharge for the experiment area in the morning and afternoon were 27.35 and 31.25 m^3/day, respectively. It shows that the total water discharge for just an hour is sufficient to meet the water requirement of all sugarcane stems in this experiment area.

For payback period analysis, in this study, the data of a 3.4 kW petrol engine pump was used for comparing energy costs with a 2.2 kW solar pump as well as the study of Limprasitwong and Thongchaisuratkrul

(2020, pp.251-252). The fuel consumption rate of the petrol engine pump was 1.4 liter/hour, but maintenance cost was not included to analyze. If the petrol engine pump is used for an hour per day and the price of gasoline is 36.44 THB per liter (PTT Oil and Retail Business Public Company Limited, 2023), then the energy cost of the petrol engine pump is 51 THB/hour. The total cost of the solar pump system in this study was around 60,000 THB. Chontanaswat et al. (2020, p.66) has been reported that irrigation duration of sugarcane cultivation is 330 days in a crop season. Therefore, the payback period was approximately 1,177 hours or 3.56 years comparing the solar pump with the petrol engine pump. An investment project was accepted because the payback period was less than the solar pump lifetime, this system has a lifetime of approximately 20 years (Limprasitwong & Thongchaisuratkrul, 2020, p.255). The details are shown in Table 2.

Table 2 Data list and details for comparison between cost of a solar pump system and a petrol engine pump system for sugarcane cultivation

Data list	Details	Unit
Project life	20	Year
Irrigation duration of sugarcane cultivation	330	day in a crop season
Irrigation period of a day	1	Hour/day
Solar pump system	60,000	THB
Fuel consumption rate of the petrol engine pump	1.4	Liter/hour
Price of gasoline	36.44	THB/liter
Energy cost of the petrol engine pump	51.02	THB/hour
Energy saving (Gasoline)	16,835.28	THB/year
Payback period	3.56	Year

Discussions

For the result in the morning, it can be said that the solar panel efficiency starts to decrease even though the solar irradiance increases, which was resulted by the increasing of the solar panel's temperature (Leow et al., 2020, p.6). In the afternoon, the solar irradiance and the power output decreased, the efficiency of the solar panels also decreased according to the solar irradiance and the power output. The reason for that was, although the decrease of the solar irradiance was found, the temperature of the panel was still considerably high. It appeared that the lowest efficiency of the solar panels was found in the afternoon and noon, respectively. The highest efficiency of the solar panels appeared to be found in the morning. It showed that the temperature of the solar panel greatly affected the panel efficiency, this was consistent with the study of Leow et al. (2020, p.7) and Cotfas et al. (2018, p.11).

For the pump efficiency, which depends on the water flow rate and the power output. From the results, it was found that the water flow rate was directly varied to the solar irradiance. The power output is inversely varied to the temperature of the panel. Although the solar irradiance in the afternoon was higher than the one in the morning, but the temperature of the solar panel was still considered high which was affected from the decrease of power output, and that caused the pump efficiency to be higher than the one in other times. The range of solar pump efficiency obtained between 32.1-41.1% which was close to the study of Korpale et al. (2016, p.524). The total system efficiency denoted that the solar-powered irrigation system for sugarcane cultivation could have a good technical performance in Udon Thani, this was consistent with the study of Mindú et al. (2021, p.14). In addition, the payback period obtained from this study is relatively short, in accordance with Limprasitwong and Thongchaisuratkrul (2020, p.257). A shorter payback period indicates a quicker return on investment, which should be favorable for most farmers.

The study results of the total water discharge showed that the solar-powered irrigation system for sugarcane in this study was found sufficient within less than an hour and met the water requirement of the sugarcane. Irrigation during noon took 38 minutes which was considered the least time taken. Thus, it can be said that the solar-powered irrigation system was available to be applied for sugarcane at any daytime. Moreover, it could also be contributed for the greatly and efficiently saving of water resources.

Conclusions and Suggestions

Conclusions

The solar-powered irrigation system has already been implemented in many rural areas in Thailand. It shows that this technology has been widely used. The most common use of solar-powered irrigation systems is an off-grid or stand-alone PV system with a direct-coupled system, where there is no electrical energy storage (batteries). Moreover, this system is easily used and stable for small-size pumps 3-25 m^3/day. For the reason of that, it can be used in both small irrigations and domestic use. The outcomes of this research showed the potential to enable sugarcane farmers in the Northeast Thailand to use water efficiently and conserve energy.

Nevertheless, the factors considered in choosing a solar-powered irrigation system technology which could significantly influence on the efficiency of the system were water requirements, total dynamic head, technology of solar panel, temperature of the solar panel, and solar irradiance. The solar-powered drip irrigation system had highest of solar panel efficiency, pump efficiency, total system efficiency, total water discharge, and payback period of 17.30%, 41.14%, 6.40%, 38.64 m3/day, and 3.56 years, respectively.

Recommendation for using to benefit

This study showed that solar-powered drip irrigation system was very efficient and available to use throughout the daytime, water-use efficiency, contribution for carbon neutrality and less human operation. Therefore, it may be a sustainable alternative for sugarcane irrigation in Udon Thani and nearby areas.

Recommendation for future research

This study had begun to be used in sugarcane fields of farmers in Udon Thani Province, which had similar weather and soil conditions, under the flagship project, which however, the next research will compare the yield and quality of sugarcane between the irrigation obtained from this study with farmers' irrigation method. In addition, the analysis on economic aspects will be compared.

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