Developing a Hybrid Solar/Wind Powered Drip Irrigation System for Dragon Fruit Yield

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Abstract. Irrigation operations take a large amount of water and energy which impact to total costs of crop production. Development of an efficient irrigation supplying precise amount of water and conserving the use of energy can have benefits not only by reducing the operating costs but also by enhancing the farmland productivity. This article presents an irrigation method that promotes sustainable use of water and energy appropriate for a developing tropical country. It proposes a drip irrigation system supported by a combined solar-wind electric power generation system for efficient use of water in dragon fruit cultivation. The electric power generated is used to drive a water pump filling a storage tank for irrigating a 3000 m² dragon fruit yield in Nguntoronadi, Wonogiri, Indonesia. In designing the irrigation system, the plant’s water requirement was identified based on the value of reference evapotranspiration of the area. A cost/benefit analysis was performed to evaluate the economic feasibility of the proposed scheme. The installation of this solar and wind drip irrigation helps provide sufficient quantity of water to each plant using renewable energy sources which reduce dependence on fossil fuel.

1. Introduction

Agricultural activities drive the world’s water as they consume for 70% total global freshwater with more than 50% of global irrigated land requires energy and that number is growing with significant carbon emissions. This situation is expected to exacerbate in the future as increasing 60% of food production to satisfy the requirement for increasing the world population [1]. Availability of efficient energy required for irrigation is a key to farmers as it utilizes about 20% of all the energy used for direct production operations in agriculture.

Renewable energy options offer promising and reliable solutions for sustainable agriculture as they eliminates the needs of petrochemical, provides economic benefit by saving maintenance cost and more environmental friendly. Solar energy is the source of all other energy types on earth, which can be used in any application with no pollution resulted [2, 3]. The wind power resulted from conversion of kinetic energy in the wind is another renewable energy resource that currently under steady development worldwide. As well as the solar power, it is also said to be an absolutely clean source of energy since produces no emissions or direct influence on the environment [4]. Those renewable
energy sources have been implemented well for powering the irrigation system in several areas [2, 5-9].

The amount of water used for irrigation purpose is not only controlled by a crop’s consumptive water used, but also by irrigation practices which include unnecessarily deep percolation of water into soil. It has been estimated that in surface irrigation, one to three times the amount of water actually needed to satisfy the crop’s requirement may be lost during the process of applying water to the land [10]. In the irrigation system, the most significant advantage is that when proper amount of water gets by roots of the plant. Therefore, it is required to improve the irrigation practices which directly save energy and make more efficient use of water.

Drip irrigation applies low-pressure water to soil and plants, enabling precise water uptake directly to the plant’s roots thereby improving soil moisture conditions [6, 8, 11]. This system has reported resulting yield gain of up to 100%, water savings of up to 40-80% and associated fertilizer, pesticide and labour saving over conventional irrigation system [7]. It is developed based on plastic tubing system with embedded water emitters, allowing for the application of fertilizers and nutrients directly to roots of the plant. Precise planning of irrigation schedule may achieved using this technology, utilising information of crop needs, soil type and weather conditions.

Beji District of Nguntoronadi is a dry region in the southern part of Java island, Indonesia. As in most rural districts, the economy is mainly based on agriculture with more than 80% of the population involved with farming. Crop production in Beji is influenced by natural conditions and depended on rainfall. An intensive irrigation will enables the local to grow vegetables and fruits during dry session, improving food security as well as increasing the income from selling excess crops in the market. This project aims to evaluate the installation of an efficient irrigation practice by replacing the fossil fuels for irrigation power with renewable sources of energy in a dragon fruit farmland in Beji.

2. Methodology
This work provides a general approach for developing a suitable technology for irrigation purposes. The first part of the article focuses on the general system design of the drip irrigation. For the system design, the FAO Penman-Monteith equation was used as an approach to identify the water requirement of irrigation system. The second part deals with the design analysis of the hybrid wind solar powered drip irrigation for a specific case study for dragon fruit cultivation in a dry area of Wonogiri, Indonesia. Using the parameter of the system design, an economic analysis was presented in the last section of the article.

2.1. Design of drip irrigation
The first step in the design of the system is to determine the drip irrigation subsystem by identifying the water and power required. The amount of water needed for irrigation is determined on the basis of weather as the rate of evapotranspiration is directly affected by temperature, solar radiation, wind speed, relative humidity, crop type and stage [9]. Calculation of crop evapotranspiration needs was performed following the Food and Agriculture Organization (FAO) using CROPWAT® software [12]. The required climate data consisting of daily temperature, humidity level, solar radiation level and wind speed was derived from Stasiun Puslitbang FP UNS Jumantono, Karanganyar [13].

The reverence evapotranspiration is related to the crop evapotranspiration using a crop coefficient, which is not only different between different crops but also differs for the same crop depending on the crop stages. The value of the crop coefficient for dragon fruit is estimated from the reference on general horticulture [14]. Time of irrigation is determined from the calculation of emitting drip rate obtained by direct measurement of several samples [15]. It is calculated from the equation as follow.

$$T = \frac{ET_c}{EDR}$$

where $ET_c$ is the crop evapotranspiration [mm day$^{-1}$] and $EDR$ the emitting drip rate [mm hour$^{-1}$]
2.2. Wind power analysis
The wind turbine implemented in this project is a 6-blade 300 W with a maximum rated speed of 20m/s and a cut speed of 1.5m/s. The manufacturer stated rated power of 100 W at 12m/s. The blades are made of carbon fibre reinforced plastics with 1140 mm rotor diameter. The wind speeds were recorded in 1-minutes intervals for six consecutive days in a dry season.

The maximum available power, $P$, at any wind speed is given from following equation [9]

$$P = \frac{1}{2} \rho A U^3$$

where $\rho$ is the air density (kg m$^{-3}$), $A$ is the rotor area (m$^2$) and $U$ is the wind speed (m sec$^{-1}$)

Betz (1926) found that it is not possible to capture all the energy available from a wind turbine; therefore introduced a constant to give the maximum amount of energy that can be captured by an ideal wind turbine as follow.

$$\left(\frac{P}{A}\right)_{Betz} = \frac{1}{2} CP u^3$$

The maximum possible value of power coefficient, $C_p$ is 0.59 but in an actual wind turbine the $C_p$ value decreases even more by the effect of factors such as drag forces and turbulence.

2.3. Solar power analysis
The solar energy utilized to pump irrigation water is directly converted into electricity through a photovoltaic (PV) or solar cell. The implemented PV array consists of solar cells with an expected power at STC of 120 W. The max power voltage is 35.2 V with max power current 5.69 A. The panels face north with a tilt angle approximately 45°. Amount of electric power generated by the PV array was estimated using irradiation data and PV array area [3]. The corresponding solar radiation is obtained using the NASA atmospheric science data centre for the specified location.

2.4. Hybrid (solar/wind) powered drip irrigation

![Figure 1. Schematic of a Hybrid (Solar/Wind) Powered Drip Irrigation (SWDI) System](image)

Hybrid (solar/wind) powered drip irrigation (SWDI) systems combine the efficiency of drip irrigation with the reliability of solar and wind-powered water pump. It was reported that even the wind or solar-powered system are often dismissed out of hand due to high up-front cost, the have longer life times and cost less than liquid-fuel-based pumping system [7]. As shown in Figure 1, in a SWDI system, the hybrid of wind turbine and a PV array are utilized to generate electricity to power a pump that feed water to a reservoir. Basically, the wind turbine converts the wind energy into a
mechanical energy which then converted into an electrical energy. The reservoir then gravity-distributes the water to a low-pressure drip irrigation system. The power generated is later stored in a battery for operating the system. The size of pump and reservoir is determined based on the water availability and local evapotranspiration needed.

3. Result and Discussion

The SWDI system was installed in a dragon fruit yield of 3000 m² plot as can be seen in Figure 2.

![Figure 2. The solar array and wind turbine as energy source for water pumping](image)

3.1. Drip Irrigation Parameters

Design the proper length of lateral pipe as the pressure in the inlet for the following criteria: nominal emitter discharge \( q = 3.1 \text{ L/h} \), emitting drip rate \( \text{EDR} = 5.41 \text{ mm h}^{-1} \), emitting efficiency \( E_d = 36.86\% \) and distance between emitters on the line \( s = 2 \text{ m} \). It is found that time require to fill full capacity of 500 L is 20 minutes, therefore the water pump discharge, \( Q_{\text{pump}} \) is \( 0.000416 \text{ m}^3/\text{s} \). The pressure head at the inlet of the lateral \( H_{\text{pressure}} = 14.246 \) and the average head \( H_{\text{av}} = 16 \). It gives total head of 38.4675 m, therefore, requires 156.98 watt to power the pump.

The irrigation time is determined on the basis of crop evapotranspiration. Using CROPWAT® software from FAO, it is found that the average evapotranspiration is 7.29 mm day\(^{-1}\). As indicated by Winarno et al [16], the dragon fruit plot is located around 111°EL and 7°SL on the height of 427 m above sea level. Irrigation time will be varied among different stages of the plant growth, which the longest is the stage of fruit development for 1.02 hours. It is assumed that the frequency for irrigation is twice a week.

3.2. Performance Analysis of Hybrid (Solar/Wind) Power System

The recorded wind speed of six observation days is illustrated in Figure 3 as a cumulative distribution frequency. The average daily speed in day 5 was 2.46 m/s with a standard deviation 0.13 and for day 6 the average daily wind speed was 2.7 m/s with a standard deviation 0.07. Figure 4 illustrates the average daily power for 6 observation days. It can be seen from the graph that using \( C_p \) value of 0.3 the maximum daily power generated by the wind turbine is 12 kW.
Figure 3. Cumulative Distribution Frequency curve of wind speed for 6 observation days

Figure 4. Theoretical average daily power for 6 days of observation

Table 1 shows the estimated amount of electric power generated by the 28.5 m² PV panel area using conversion efficiency of 16% for a typical poly-crystalline module.

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Solar radiation (kWh/m²/day) | 2.82 | 2.94 | 3.22 | 3.93 | 4.68 | 4.8 | 5.1 | 5.22 | 4.98 | 4.35 |
| Output (kWh/day) | 9.024 | 9.408 | 10.304 | 12.576 | 14.976 | 15.36 | 16.32 | 16.704 | 15.936 | 13.92 |

From Table 1, it is clear that the PV modules power rating is adequate to generate 156.98 Wh/day for a whole year which proves the design’s utility and which is sufficient to operate the water pump.
3.3. Economic Analysis

The net present value (NPV) as shown in Figure 5 is calculated over a 15 year time span (the assumed lifetime of the PV arrays and wind turbine). The SWDI systems installed in Nguntoronadi, Wonogiri is compared with current implemented system: a surface irrigation using a liquid-fuel engine-driven pump. As shown in the Table 2, a 0.3 ha hybrid-powered drip irrigation system costs approximately 17 million rupiahs to install or 5,800 rupiahs per m² dragon fruit plot, and requires annual expenses of 414,540 rupiahs (140 rupiah per m²) in support of technical service. Using current surface irrigation method, each dragon fruit plant produces 3-4 kg per year. It is estimated that the productivity of dragon fruit will increase by 30% after drip irrigation installation. For comparison, it uses the current system implemented with liquid-fuel pump for surface irrigation performed manually. Both systems are connected to the same 500 L reservoir but with different amount of water pumped. It is assumed that drip irrigation uses 25% less of water than the surface irrigation.

Figure 5 provides the investment analysis for a liquid-fuel surface irrigation system and drip irrigation systems using various sources of pumping energy. In general, drip irrigation system provide cost-competitive benefit compared to the surface irrigations from the saving of labour cost for manual watering method and cost of diesel oil. However, due to higher-up front costs, it is recommended to form a group-based SWDI system providing the stability and institutional support necessary for the poor to invest in production of high-value crops [7].

**Table 2.** Economic analysis of 3000 m² hybrid (solar/wind) powered drip irrigation system

| Expenses                              | Total (Rupiah) | Time (yr) |
|---------------------------------------|---------------|-----------|
| **Equipment**                         |               |           |
| - PV Panels and installation          | 4,462,500     | 15        |
| - Wind turbine and installation       | 8,105,000     | 15        |
| - Hybrid inverter                     | 1,344,000     | 10        |
| - Battery                             | 725,000       | 5         |
| - Water pump                          | 750,000       | 5         |
| - Reservoir                           | 750,000       | 5         |
| - Drip irrigation lines and pipes     | 1,221,000     | 3         |
| **Operational cost**                  |               |           |
| - Technical services                  | 160,000       | 1         |
| - Water (979 L/day for 104 days)      | 254,540       | 1         |
| **Revenues**                          |               |           |
| - Dragon fruit (first year) (3.5 kg per plant) | 11,424,000  | 1         |
| - Dragon fruit (all other years) (4.5 kg per plant)* | 14,688,000  | 1         |

*) Assumption: drip irrigation increase crop productivity by 1 kg per plant

As shown in Figure 5, the hybrid powered drip irrigation system has a lower NPV at high discount rates compared to a system without drip irrigation. It can be seen that the solar powered drip irrigation system is less sensitive to changes in the discount rate. With an improve applied technology, system cost could be driven down by using local components which make it more cost competitive.
4. Conclusion
This study presents the design and installation of a hybrid (solar/wind) powered drip irrigation (SWDI) system in a dragon fruit plot in District of Beji, Nguntoronadi, Wonogiri, Indonesia. The watering method chosen is drip irrigation powered by a pump with a combination of 120 watt photovoltaic array and 5-blades wind turbine. The upper limit of the available solar and wind energy are predicted on the basis of metrological data and direct observation. It was found that for the district of Beji, the SWDI has an attractive option for irrigation method as it provides more technical and economic benefit than the current irrigation practice. Future research should include further analysis on the impact of crop productivity after the implementation of SWDI. A stand-alone solar or wind powered system may be potential for future use in the appropriate area.

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