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EXPERIMENTAL INVESTIGATION OF A WATER PUMPING SYSTEM DRIVEN BY WIND AND SOLAR ENERGY FOR IRRIGATION PURPOSE

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Abstract: In this study, an experimental research for agricultural irrigation was completed for a renewable hybrid power generation system consisting of photovoltaic (PV) panels and wind turbine which can be considered as an alternative to diesel generators used for pumping applications. It was observed that the daily mean of produced electricity by the system in July was enough to pump daily average 44.1 m^3/day of water from the depth of 2.5 m and totally 1368 m3 of water during the month. It was calculated that the amount of pumped water is sufficient to meet water need of the agricultural products that were 12.4 decares (da) of sugar beet, 13.0 da of potatoes, 13.4 da of corn, 13.6 da green bean and 10.8 da of sun flower with the drip irrigation method.
Keywords: hybrid, irrigation, photovoltaic, solar energy, water pumping, wind energy

1. INTRODUCTION

Water is the primary source of life for mankind and one of the most basic necessities for development. The rural demand for water has increased six fold, at the same time the average rainfall has decreased dramatically in many arid countries in the last decade (Cosgrove, 2000). Albeit groundwater seems to be the only solution of the mentioned issue, it encounters some obstacles since the water table level is decreasing, making traditional pumping applications ever further difficult (Bakelli et al. 2011).
Some of the land used for agriculture in the world and also in Turkey has no access to an electricity grid. Therefore, mechanical power from tractors or diesel generators facilitates the irrigation from wells, streams or canals. For instance, seventy million farms in India use diesel powered irrigation systems. As a consequence, a large amount of energy is consumed during the pumping application causing an increase in the product cost.
As water pumping has a long history, many methods have been developed to pump water with a minimum effort. These methods have employed a variety of power sources, namely human energy, animal power, hydro power, wind power, solar power and fossil fuels for small generators. Water has been pumped by using mechanical power of wind energy for centuries (Kose et al, 2009, Genc 2011) and by using solar energy for the last half century (Vick, 2012).
For different regions and locations, climatic conditions including solar radiation and wind speed are always changing (Yaniktepe, 2013). Owing to that fact, the application of devices powered by PV panels or wind turbines reveals some shortcomings. Hybrid application systems are promising substitutions which diminish this unwanted instability. Renewable hybrid systems are combination of renewable technologies or supported with conventional systems. As the wind and PV technologies advance, the hybrid systems are becoming more promising, more reliable and cheaper than stand-alone wind or PV systems (Güneyand Onat, 2011). Hybrid systems improve load factors and save maintenance and replacement costs, as the renewable resource components complement each other (Bekele, 2012). Renewable hybrid systems can provide a reliable power source for many applications including water pumping.
In addition, the installed capacity of hybrid systems is not designed for the worst-case scenarios due to the fact that power does not come from a single source, fact that reduces the installation cost of the

power system. A deal of research has been carried out on wind, solar and hybrid energy systems. Some of them are related to stand alone hybrid usage of renewable energy sources (Aissou et al. 2015), size optimization (Ma et al. 2015), economics of the hybrid systems (Mohamed et al. 2015), seawater desalination (Smaouiand Krichen, 2014), size optimization (González et al. 2015), home/village/industrial usage (Bekele, 2010), and household application (Panayiotou et al. 2011).
In the literature some studies are concerned with the usage of renewables for the water pumping purpose (Tharaniand Dahiya 2016); however, it is not encountered in any study that does evaluate the adequacy of water in agricultural areas using solar/wind based hybrid power generation system.

2. MATERIAL AND METHOD

The experimental setup was established in the premises of Konya Selcuk University Technology Development Zone at 38 °00'06.80" North 32°30'31.70" East coordinates at an altitude of 1136 meters. All the components of the hybrid power station are integrated with solar and wind energy for irrigation purposes as illustrated in Figure 1. As it can be seen, the produced electricity via the PV modules with a total 480 W capacity and the wind turbine with a 1500 W capacity are regulated by their individual charge controllers and are stored in the battery bank. Four pieces of 12 V and 200 Ah batteries were wired in a serial/parallel arrangement to deliver 300 Ah at 24 V with a total capacity of 9600 Ah. Then, the electricity was transmitted to the pump in order to pump the water from a well to a storage tank. During this process the PV charge controller has a significant role and measures all electrical properties: voltage and current values of input, output and battery group; the occupancy rate of a battery group, consumption of the pump and all data stored in a data logger during the experiment. In addition to DC electricity line, the stored electricity is inverted to 220V by a 3000 W capacity inverter for AC powered systems. Generated electricity by both wind turbine and PV panels, and electricity consumption of the pump were recorded by the data loggers during the experiment. The wind speed and solar radiation were also measured by a cup anemometer at height of 10.5 m and a pyranometer in 10 minutes intervals for further process.

Figure 1. Schematic view of the hybrid drip irrigation system

The volume flow rate of pumped water and its outlet pressure were also measured by a turbine type flowmeter and by a pressure sensor at 1 sec. intervals. The cut-in, rated and cut-off wind speed of the wind turbine were 3.6 m/s, 12.5 m/s and 20 m/s, respectively. All measured variables and their accuracies are given in Table 1. In the experiments a DC-driven pump with head height of 5 m and volume flow rate of 5 m3 was used. PV panels were established on a designed rotating mechanism to change the PV panels' angle from 0° degrees to 80° degrees on horizontal axis. The purpose of this establishment was to adjust the mechanism to get the highest amount of solar radiation on PV surfaces. The Maximum Power Point Tracking (MPPT) was included in the charge controller of the PV system for extracting maximum available power from PV. All electronic devices and batteries were collected in a sheet metal cabinet to protect from environmental conditions.


Figure 2. PV–wind based hybrid power plant in the garden of Konya Selcuk University Technology Development Zone

Table 1. Comparison of conventional and drip irrigation systems for the total land area in Decares (1000 m^2).

	Corn	Potato	Sugar beet	Sun Flower	Green Bean
Conventional Irrigation	6.7	6.5	6.2	5.4	6.6
Drip Irrigation	13.4	13.0	12.4	10.8	13.6

The output power of the PV panels

The output power of the PV generator $\dot{P}_{pv}$ is given by the following equation (Markvart, 2000):

$$\dot{P}_{PV} = A_{PV} I_S H_{PV} \qquad (1)$$

where η_{pv} is the PV panel's total efficiency, A_{Pv} is the total area of the PV panels (m^2) and I_s represents the amount of solar radiation on tilted module plane (W/m^2). The tilt angle of the PV module is arranged according to the site latitude and

The power output of wind turbine

The fundamental equation governing the electrical power capture of the wind turbine generator is given by [38].

$$\dot{P}_w = 0.5 \rho_a A_w \eta_w V^3 \qquad (2)$$

Where ρ_a is the air density (kg/m^3), A_w is the area swept by the rotor blades, V is the average wind velocity (m/s), η_w represents overall efficiency of wind turbine and is calculated according to the power produced by the wind turbine and measured wind speed distribution of the region.

The volumetric flow rate of pumped water

The ideal hydraulic power to drive a pump depends on the mass flow rate, the liquid density and the differential height. It is explained that either it is the static lift from one height to another, or the friction head loss component of the system can be calculated as follows:

$$\dot{Q} = (\dot{P}_h \eta_p)/(\rho_w g h) \qquad (3)$$

where $\dot{P}_h$ is the power needed by the pump and it is generated by the hybrid system for this application.

$\dot{Q}$ is the volumetric flow rate (m^3/s), ρ_w is density of pumped water (kg/m^3), g is gravitational acceleration (m/s^2), h is the manometric head including all minor and major pressure losses (m) and η_p is the overall pump efficiency.

Irrigation need

There are a lot of irrigation applications such as a conventional surface, a sprinkler, a drip irrigation method etc. The methods apart from the drip irrigation one cause more evaporation of water and, thus, wasting a great amount of water. The drip irrigation requires higher costs of investment; notwithstanding, it is especially preferred to use in greenhouse and garden applications and to grow higher economic valued crops due to its less labour need. In order to determine the monthly irrigation demand it was necessary to know the average monthly rainfall of a region (Vick, 2010).

$$IN = WN - NR \qquad (4)$$

The irrigation water need of any crop (IN) in each month is the difference between the crop water need (WN) and the natural rainfall amount during the growing season (NR).

3. RESULTS

The water need of the crops reaches a peak in summer months. To consider irrigation via the solar and wind energy, the most important time interval is the summer season when the water need of the crops reaches a maximum. In this study, the daily mean total radiation (Id) was measured as 6480 W/ (m^2day), 7737 W/(m^2day) and 7100 W/(m^2day) in June, July and August respectively with a pyranometer oriented towards south and tilted at optimum angles surface such as the PV panels. It is observed that July is the month when the highest solar radiation occurred, and is the peak irrigation water needed month for many crops in Konya province.

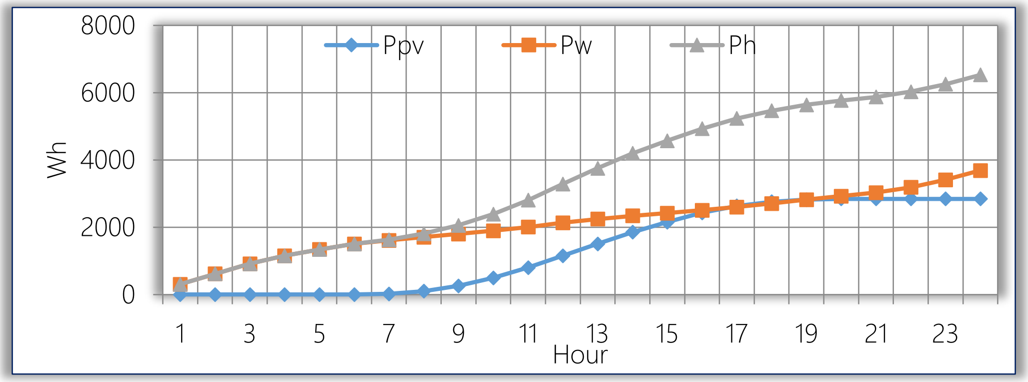

Figure 3. Cumulative variation of electric energy generation of the wind, solar and hybrid system in July

Cumulative variation of the electric energy generation by wind turbine (Pw), by PV panels (P_{PV}) and by the hybrid system consisting of a combination of the two systems (P_h) are given by in Figure 3. As it can be seen, the wind turbine produces more electricity during the night compared to the daytime hours.

Similarly, the PV panels generate energy only during daytime hours and reach its maximum value at noon hours. Wind power can be integrated with solar power successfully resulting in the better continuity of electricity generation. The daily average total energy production by the wind turbine and PV panels were determined as 3685 Wh/day and 2841 Wh/day, respectively. The hybrid system can generate electric energy during the whole day when compared with single wind and solar energy system.

It was demonstrated that the daily mean produced electricity by the system in July was enough to pump daily average 44.1 m^3/day of water from 2.5 m depth and totally 1368 m^3 during the month, which was the most irrigation needed month along a growing season of many crops in Konya. Figure 4 shows the hourly variation of average pumped water during July. It is displayed that the pumped water amount in the evening and night times were lower than the average need when just wind power was available. The pumped water amount was increased after 8:00 by the support of the solar power to the wind power. The volume flow rate of the water was over 3 m^3/h in the afternoon and it tended to decrease after 17:00. Then wind power and the stored electricity in the batteries provided energy to pump water till sunrise.

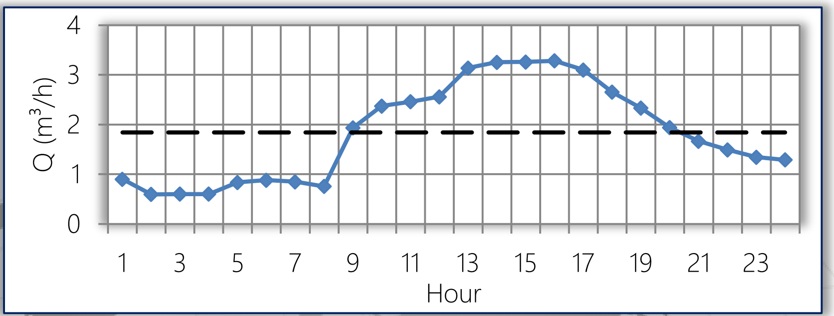

Figure 4. Hourly average variation of pumped water in July

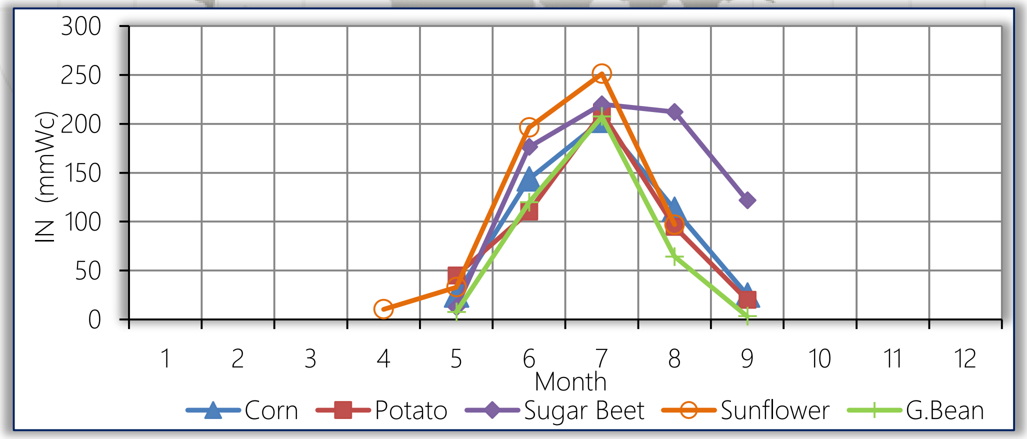

Figure 5. Average irrigation needs of different crops for Konya province along the growing season

Figure 5 presents the monthly irrigation water need that is calculated by subtracting the effective rainfall amounts from the crop water need for all crops during each month of the growing season. For instance, a sugar beet crop grown in Konya has a total growing season of 180 days and its monthly water needs from April to September vary between 30.0 mmWc in April, 53.8 mmWc in May, 197.2 mmWc in June, 227.3 mmWc in July, 217.3 mmWc in August and 132.8 mmWc in September. The cumulative water need of the sugar beet through the growing season (April-September) is 858.4 mmWc. The average rainfall data between 1970-2010 for the area where the crops considered to be grown have been obtained from the Turkish Meteorological Office as 37.5 mmWc in April, 40.5 mmWc in May, 23.2 mmWc in June, 7.8 mmWc in July, 5.6 mmWc in August and 10.6 mmWc in September with the total amount of 124.6 mmWc along the growing season. The monthly irrigation water need for a sugar beet was calculated by the difference between the crop water need and the natural rainfall. The use of irrigation in April is unnecessary owing to efficient rainfall. The monthly irrigation water needs changes 12.5 mmWc in May, 176.3 mmWc in June, 219.9 mmWc in July, 212.1 mmWc in August and 121.6 mmWc in September. The irrigation need of a sugar beet over the total growing season was 742.4 mmWc per growing season. It can be concluded that the irrigation water need reaches its peak in July for sugar beet. If the sugar beet is the only crop grown in the area, the irrigation would have to be designed in such a way that it should supply a net water layer of 219.9 mmWc to the whole covered area in July as shown in Figure 5. Total irrigation water needs for the other crops such as a corn, a potato, a sun flower and a green bean per growing season were found to be 509.3 mmWc, 480.9 mmWc 587.7 mmWc and 402.3 mmWc, respectively. The maximum irrigation needs of the all crops were 203.4 mmWc for a corn, 211.2 mmWc for a potato, 219.9 mmWc for a sugar beet, 251.2 mmWc for a sun flower in July, which was the peak irrigation water need month as seen in Figure 5.

The amount of pumping water per a growing season was converted into water requirement of the different crops per growing season by conventional and drip irrigation methods in Table 1. It can be concluded that the drip irrigation method for all considered crops can provide two times more field for the water requirement of the related crops than the conventional irrigation system. Drip irrigation systems reduce the loss of water by conveying or evaporation, and achieve the highest irrigation efficiency up to 90%.

4. CONCLUSIONS

In this work, performance characteristics of the small-scale PV/Wind based hybrid electric supply system for the water pumping application in Konya province is presented. The hybrid system consisting of a 1500 W wind turbine and 480 W PV panels were established in the open area of Selcuk University Technology Development Zone in Konya, Turkey. Generated electricity was stored in a battery group and was used to power a 300 W DC-driven submersible pump under 2.5 m depth of the ground level. It was seen that the wind power can be integrated with the solar power successfully providing constant electricity generation. It was demonstrated that totally 1368 m^3 water was pumped during July when was the highest demand for irrigation during growing season. It was calculated that the amount of pumped water was enough to meet water need of the crops that were 12.4 decares (da) of a sugar beet, 13.0 da of a potato, 13.4 da of a corn, 13.6 da of a green bean and 10.8 da of a sun flower. It was demonstrated that the drip irrigation method for all considered crops could satisfy the water requirement of two time larger field than the conventional irrigation system.

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