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A water pump powered by hybrid solar and wind energy

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Abstract. There is enough wind and solar energy around the world to meet all of humanity's energy needs. Vertical Axis wind turbines (VAWT) can be as efficient as the current horizontal axis system, cheaper to build and maintain than horizontal axis wind turbines (HAWT). They have other unique advantages, such as the fact that they are always dependent on wind, which makes them important in everyday life for inexpensive, clean, renewable energy sources. Many rural areas do not have access to electricity, which makes it difficult to water and irrigate livestock. VAWT can even play a key role in solving the problems of stability and reliability of network connections pumped from power producers and suppliers. In addition, inexpensive VAWT can become an alternative to the destruction of tropical forests for growing crops using biofuels. In this project, we will try to design and build a Savonius wind turbine with a vertical water pumping axis. We also produce a hybrid model of water pump driven by solar and wind turbines. The solar energy from the solar panel converts this electrical energy into mechanical energy, which converts the shaft connected to the crankshaft. Using a crank mechanism rotating in an up and down motion, and we use this to lift the water.

Keywords: *pump, water, wind turbine, air, solar energy.*

1. Introduction

With the technological developments, the drive for renewable energy has intensified the use of renewable energy sources (RES), particularly wind and solar photovoltaic (PV) generation. The use of renewable energy and hybridization is taking new shapes, but PV and wind energy tend to be the center point of renewable energy hybridization. This is mainly due to the aim of the reduction of greenhouse gas emissions, but the increased penetration of RES is also due to the dropping prices of the renewable energy sources. The technological advancements in the PV and wind generation systems have been formidable. The global cumulative installed capacity of all solar PV (utility scale and rooftop) increased from 42 GW in 2010 to 714 GW in 2020.

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. 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. Groundwater has often been relied upon to meet water needs, but declining water tables pose significant challenges. As the water table level drops, accessing groundwater through traditional pumping methods becomes increasingly challenging. This situation leads to the necessity for more innovative and sustainable approaches to water It's crucial to employ a multi-faceted approach involving sustainable practices, technological innovation, and water resource management strategies to mitigate the impacts of decreasing water tables and ensure access to this vital resource for communities in arid regions.

Some of the land used for agriculture in the world and also in Kazakhstan has no access to an electricity grid. Therefore, mechanical power from tractors or Diesel generators facilitate 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 and by using solar energy for the last half century.

For different regions and locations, climatic conditions including solar radiation and wind speed are always changing. 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 photovoltaic (PV) technologies advance, the hybrid systems are becoming more promising, more reliable and cheaper than stand-alone wind or PV systems. Hybrid systems improve load factors and save maintenance and replacement costs, as the renewable resource components complement each other. Renewable hybrid systems can provide a reliable power source for many applications including water pumping.

Water pumping one of the first and most important uses of windmills, the pump works by pushing up and down through reverse motion and drawing water from the piston. It is also important to use energy to rotate the mill to grind the grain. A solar panel installed next to wind turbines generates electricity

in the form of direct current and sends it to an inverter. An inverter is an electronic device that converts direct current to alternating current. The inverter supplies current to the battery and DC motor through power transmission lines. A DC motor converts electrical energy into mechanical (Rotary) energy and transmits it to the main shaft connected to the crank mechanism. Currently, windmills are mainly used to generate electricity, grind grain or pump water. In addition, there is a one-way valve that prevents water from entering the well again when the pump makes a backlash [1].

The windmill makes a circular motion by rotating the shaft. The rotation speed can be adjusted using Gears of different sizes. A crank-sliding mechanism is used to rotate the rotational movement of the shaft back and forth. The puller is attached perpendicular to the rotating shaft, and the other rod is attached vertically from the edge of the wheel to the pump at the bottom. As the center of the wheel does not move and the edge rotates in a circle, the bar is pulled up. Nowadays, it is possible to generate electricity using wind turbines and a solar battery and connect them to an electric water pump.

1.1. Subsection

The goal of this project is to design and build a self-actuating vertical axis wind turbine and a solar-powered DC motor that can pump water in real conditions. Turbine design involves the study of various options for self-launch, as well as the development of model and full-scale turbines. A full-scale turbine is designed in such a way that the power produced by the engine can be connected to the pump through a crank slider mechanism that converts the high and low rotational speed of the turbine or the vertical speed of the pump. The goal of the project is to collect data on the effect of the angles of inclination of the Blades. Through the use of a vertical wind turbine and a DC motor, the pumping efficiency is increased.

2. Materials and methods

Kazakhstan has a perfect geographical location to use solar energy. According to General Directorate of Electrical Power Resources Survey and Development Administration, in Kazakhstan the average total annual sunshine duration is 2960 hours (daily average 7.4 hours) and average total radiation of 1231 kWh/m^2 per year (daily total 3.7 kWh/m^2 per day) has been identified. Although there are some statistical methods to predict solar radiation, it is necessary to measure the solar radiation locally to obtain experimental results. In this study, the solar radiation in the year 2021 was recorded by a calibrated pyranometer established to the same location on the horizontal axis.

During the observation period the average solar radiation was found to be 1766 kWh/m^2 per year and the maximum hourly average radiation has occurred as 1210 W/m^2 at 14:00 on 1th June, 2021.It can be concluded that the average solar radiation increased with sunshine and reached the maximum during noon hours. Later it was decreasing with decreasing solar sunshine during the evening hours and ends shortly before sunset. Before sunrise and after sunset the solar radiation values are zero. The solar radiation is higher in the summer months from June to July when the irrigation needs are also higher and overlaps for all crops need which affects positively the implementation of the designed hybrid system.

In order to determine the wind energy potential of the region, a wind speed measurement mast was established in accordance with the land's geographic conditions. The wind speed data were collected from in 2021. According to international standards, all the readings were repeated with 10 second intervals and on average, minimum and maximum values and their standard deviations were recorded to the datalogger at 10 minutes intervals during the measurement period. The monthly mean wind speed measured by anemometer, located at the same mast height (10.5 m) as the wind turbine hub, were found to be 5.76 m/s, 6.66 m/s, and 6.05 m/s in June, July, and August, respectively. When the water need gets its peek value for all crop types considering the worst case [2].

Solar panels absorb the sun's rays as an energy source to generate electricity. A photovoltaic module is a wrapped Connector node, usually consisting of 6*10 photovoltaic solar cells. Photovoltaic modules generate and deliver solar energy in commercial and residential premises. Each module is designed for direct current output under standard testing conditions, usually from 100 to 365 Watts. The efficiency of the module determines the area of the module with the same rated power.

Photovoltaic modules use the light energy (photons) of the sun to generate electricity through the photovoltaic effect. Many modules use plate-based crystalline silicon cells or thin film cells. The solar panel must be protected from mechanical damage and moisture. To achieve the desired output voltage, the electrical connections of the modules are performed in series.

Maintenance

The conversion efficiency of solar panels is within 20%, and the reason for the decrease in efficiency is dust, pollen formation, etc. When these substances accumulate on the panels, they obstruct sunlight from reaching the photovoltaic cells, reducing the amount of energy that can be converted into electricity. Regular cleaning and maintenance of solar panels are essential to maintain optimal efficiency and maximize their energy output.

Turbine operation

Wind energy uses the same concepts as many other energy sources, using a certain force to rotate a turbine. Then the turbine sends its energy to the pump, where water pumping is carried out. When using wind energy, the force that sets the turbine in motion comes from the wind.

Traditionally, wind energy can only be used in high-speed areas where the wind speed exceeds 13 m/s every year, but with new technologies and increased efficiency of pumps, it is possible to produce more economical wind energy, even with low wind speed [3]. Innovations such as improved turbine blade designs, better aerodynamics, and more efficient components allow wind turbines to capture energy from lower wind speeds effectively. These advancements have made it economically viable to generate wind power in areas that were previously considered less suitable for wind energy production.

Additionally, there are various types of wind turbines optimized for lower wind speed conditions, such as smaller-scale turbines or designs specifically tailored to capture energy from lower wind speeds. Such innovations have contributed to broadening the geographical range where wind energy can be effectively utilized, making it a more accessible and viable renewable energy source in many regions around the world.

The wind acts on the Blades of the turbine with two driving forces: lifting and pulling. Force occurs when the aerodynamic profile must have a greater distance than the wind.

The wind blowing from the turbine must move at a higher speed than the wind. This speed difference creates a pressure difference. A zone of low pressure is created from the wind, which pulls the aerodynamic profile in this direction. This is known as the Bernoulli principle. The Bernoulli principle plays a significant role in how wind affects the turbine blades. As the wind encounters the blades, it creates two distinct forces: lift and drag. This occurs due to the difference in speed between the wind approaching and leaving the aerodynamic profile. When the angle of inclination increases, the distance traveled by the leeward air also increases, consequently raising its velocity and thus enhancing the thrust. When the angle of inclination increases, the distance traveled by the Leeward air increases, as shown in Table 2. This increases the Leeward air velocity and thus the thrust. The Bernoulli principle is shown in Figure 1 [4].

The main reason of the establishing combined solar-wind system is to support each other in case of producing insufficient energy by one of them. Solar radiation changes according to the season and it can be converted into electric energy with only the ratio of 1/3 per day on average. According to the obtained results, solar radiation and wind speed values during summer months occur in greater amounts as the irrigation needs of the crops are higher in the considered region. In addition, enough amount of energy is not obtained to produce electricity continuously due to wind variations and characterization in the locality. 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, what 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, size optimization, economics of the hybrid systems, seawater desalination, optimization, home/village/industrial usage, telecommunication power plants and lighting applications.

Figure 1. Project installation

3. Results and discussion

Table 1. Wind description

Unchanged wind speed	6-1 m/s
Air density	1.204 kg/m^3
Air viscosity	0.0000181 Ns/m^2
TSR	0.15
Solidity	4
Number of airfoils	8
Blade height	700 mm

The dimensions of the VAWT under construction for this project are listed above. The diameter of the turbine plate is 300mm, the thickness is 8mm, and the dimensions of the PVC pipe are given in the following table. This design choice provides an increase in the number of Reynolds to rotate the blades and, as a result, increases the lift. In addition, given the large traction forces involved, the short length of the aerodynamic profile is less likely to bend.

Wind Turbine/Blades Design

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

Where, P - Power of wind (W) [4]; A - Area of wind segment being considered (m^2); u - undisturbed wind speed (m/s); ρ - air density in (kg/m^3); At standard temperature/pressure (STP=273K and 101.235 KPa), equation reduces to:

Power of the wind

Area $A_s = Lw = 0.7*0.1 = 0.07m^2$

A Turbine cannot extract 100% wind energy because some of the wind energy is in because some of the wind energy is used in pressure changes across the turbine blade. This decrease in velocity causes the pressure change and their usable energy. The mechanical power that can be obtained from the wind with an ideal turbine given as.

$$P_m = 0.674*0.8428*5^3 = 7.077W$$

In equation, an area is referred as the swept area of the turbine. For VAWT this area depends on the turbine diameter and turbine blade length. For a vertical axis wind turbine equation of swept area is

$$A_s = 0.750*1.125 = 0.8375m$$

$$7.65625 = C_p*0.56$$

$$C_p = 0.56$$

Geometric definition: Between the many factors that affect the aerodynamic factor, behavior of the rotor that important role is played by its solidity, defined as Where «N» is a blade number, [-], c is a blade chord [m] and is rotor radius [m]

$$N = 0.8*0.15*0.375 = 0.45$$

According to graph TSR = 5 for 0.45 solidity

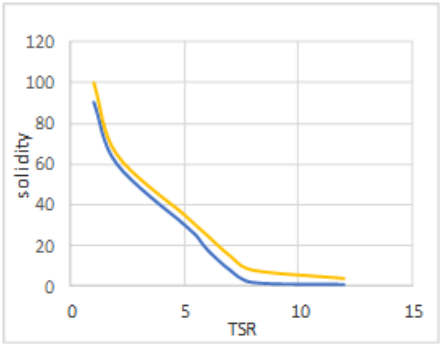

Figure 2. Rotary solidity as function of TSR

Wind-water pump operation

For different regions and locations, climatic conditions including solar radiation and wind speed are always chang-

ing. 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 photovoltaic (PV) technologies advance, the hybrid systems are becoming more promising, more reliable and cheaper than stand-alone wind or PV systems. Hybrid systems improve load factors and save maintenance and replacement costs, as the renewable resource components complement each other. Renewable hybrid systems can provide a reliable power source for many applications including water pumping. The water pump works by moving up and down by pushing and pulling the piston that draws water from the well. In addition, there is a one-way valve that allows water to flow back into the well.

The windmill makes a circular motion by rotating the shaft. The rotation speed can be adjusted using Gears of different sizes. A crank-sliding mechanism is used to rotate the rotational movement of the shaft back and forth. The puller is attached perpendicular to the rotating shaft, and the other rod is attached vertically from the edge of the wheel to the pump at the bottom. Since the center of the wheel is stationary and the edge rotates in a circle, the rod stretches up and down (and a little to the side and back each time, so you will need an additional hinge when connecting the rod to the piston of the water pump).

Solar panel powered DC motor

As we have seen before, the solar panel generates electricity using the sun's rays, the panel generates a direct current that is converted into a variable through an inverter. A DC motor requires constant power, which can only be achieved by installing some subsystems in the overall propulsion system. The inverter sends AC to the battery and stores it in the battery. This energy is then used to power the DC motor, which is further connected to the shaft. The shaft is connected to a crank mechanism used to pump water.

Photons create an electric current when they hit the surface of thin silicon wafers. One solar cell is about 1/2 (0.5) volts. However, a typical 12-volt panel measuring about 25*54 inches will have 36 sequential elements that deliver about 17 volts of power [5].

Table 2. Observation table for Wind turbine

Discharge, m^3	Wind speed, m/s	Time Sec
1000	8	35
1000	10	31

Table 3. Observation table for Wind turbine +Solar

Discharge, m^3	Motor Rotations RPM	Wind speed, m/s	Time Sec
1000	120	8	32
1000	120	10	28

By using this project, we can design a «Water pumping system using solar and wind power» and can be successfully developed. This project proposed the design and architecture of a new concept of electricity available. The advantage of the system lies in the fact that it helps to pump water even when there is availability of electricity.

4. Conclusions

The wind turbine generates variable output power and hence, it cannot be matched with the PV module in normal cases. But in this hybrid system this problem is overcome by connecting the solar module and the wind turbine to the utility pumping system. It only uses the renewable sources of energy, thus forming a standalone hybrid system. Even after installation of this system, if required additional sensors can also be interfaced with the Arduino controller, leading to efficient functioning of the system.

From the above data, it is clear that the rotational movement of the turbine and the rotational power transmitted by the engine are converted into the reverse movement of the one-way piston rod of the pump. With the adjustable speed gearbox, you can change the reverse speed.

It is expected that the process, efficiencies, cost and incentives of the wind and solar energy application in the World could be more attractive than the conventional system. It can be anticipated that the proposed system will be commonly used in the future since the cost of the renewable energy systems is decreasing and the government supports on them are increasing.

It was found that the hybrid system for the irrigation purposes was especially suitable in remote areas without connection to the electricity grid. Moreover, the designed off-grid hybrid water pumping system could be an alternative to diesel-operated agriculture pumps, portable pumps for drinking water/agriculture and it can be applied in farmhouses, orchards, greenhouses and livestock watering.

References

[1] Hybrid Power Plant. (2012). Enertrag. *Retrieved from:* https://www.enertrag.com/en/project-development/hybrid- power-plant.html

[2] Wilson, D.S. (2016). Milestone in solar cell efficiency achieved: New record for unfocused sunlight edges closer to theoretic limits. *Science Daily*

[3] LLC «Ecogroup». (2016). Portal on construction, engineering systems, alternative energy. *Retrieved from:* http://www.ecogroup.com.ua/spravochnik

[4] Wind power plants. (2019). Energiya-vetra-i-solnca-v-ukraine-prakticheskij. *Retrieved from:* http://viter.com.ua/energiya-vetra-i-solnca-v-ukraine-prakticheskij- primer-190.htm

[5] Ecoteco. (2012). Ecology, Technologies, Economics. *Retrieved from:* http:// www.ecoteco.ru/id311/

Күн энергиясы мен жел турбинасының гибридті су сорғыш

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Аңдатпа. Бүкіл әлемде адамзаттың барлық энергия қажеттіліктерін қанағаттандыру үшін жел мен күн энергиясы жеткілікті. Тік осьті жел турбиналары (VAWT) қазіргі көлденең осьтік жүйе сияқты тиімді болуы мүмкін, көлденең осьті жел турбиналарына (HAWT) қарағанда бастапқыда салу және техникалық қызмет көрсету арзанырақ. Олардың басқа да ерекше артықшылықтары бар, мысалы, олар әрқашан желге тәуелді, бұл оларды күнделікті өмірде арзан, таза, жаңғыртылатын энергия көздерінің маңызы зор. Көптеген ауылдық жерлер электр қуатына қол жеткізе алмайды, бұл малды суару мен суаруға қатысты қиындық тудырады. VAWT тіпті электр қуатын өндірушілер мен жеткізушілерден су айдайтын желілік қосылыстардың тұрақтылығы мен сенімділігі мәселелерін шешуде шешуші рөл атқаруы мүмкін. Сонымен қатар, арзан VAWT биоотынды пайдаланатын дақылдарды өсіру үшін жаңбыр ормандарын жоюға балама бола алады. Бұл жобада біз Savonius тік су айдау осі бар жел турбинасын жобалауға және жасауға тырысамыз. Сондай-ақ, біз күн және жел диірмендерімен басқарылатын гибридті су сорғысының моделін шығарамыз. Күн панелінен алынған күн энергиясы бұл электр энергиясын механикалық энергияға айналдырады, ол иінді тақтаға қосылған білікті айналдырады. Иінді механизм арқылы жоғары және төмен қозғалысқа айналадыра отырып, суды көтеру үшін қолданыламыз.

Негізгі сөздер: *сорғы, су, жел турбина, ауа, күн энергиясы*.

Водяной насос, работающий на основе гибридной энергии солнца и ветра

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Аннотация. Во всем мире достаточно энергии ветра и солнца, чтобы удовлетворить все потребности человечества в энергии. Ветряные турбины с вертикальной осью (VAWT) могут быть столь же эффективными, как и нынешняя система с горизонтальной осью, дешевле в строительстве и обслуживании, чем ветряные турбины с горизонтальной осью (HAWT). У них есть и другие уникальные преимущества, такие как то, что они всегда зависят от ветра, что делает их важными в повседневной жизни для недорогих, чистых, возобновляемых источников энергии. Многие сельские районы не имеют доступа к электричеству, что затрудняет полив и орошение скота. VAWT может даже сыграть ключевую роль в решении проблем стабильности и надежности сетевых подключений, перекачиваемых от производителей и поставщиков электроэнергии. Кроме того, недорогой VAWT может стать альтернативой уничтожению тропических лесов для выращивания сельскохозяйственных культур, использующих биотопливо. В этом проекте мы попытаемся спроектировать и построить ветряную турбину Savonius с вертикальной осью перекачки воды. Мы также производим гибридную модель водяного насоса, управляемую солнечными и ветряными турбинами. Солнечная энергия от солнечной панели преобразует эту электрическую энергию в механическую, которая преобразует вал, подключенный к коленчатой плате. С помощью кривошипно-шатунного механизма, вращающегося в движении вверх и вниз, и мы используем это для подъема воды.

Ключевые слова: *насос, вода, ветряная турбина, воздух, солнечная энергия*.

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