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DESIGN AND FABRICATION OF HYBRID DC BATTERY-SOLAR POWERED RECHARGEABLE IRRIGATION WATER PUMPING DEVICE FOR NIGERIAN SMALL-HOLDER FARMERS

РАЗРАБОТКА ГИБРИДНОГО УСТРОЙСТВА ДЛЯ ПЕРЕКАЧКИ ВОДЫ ДЛЯ ОРОШЕНИЯ С ПИТАНИЕМ ОТ БАТАРЕИ ПОСТОЯННОГО ТОКА И СОЛНЕЧНОЙ ЭНЕРГИИ ДЛЯ МЕЛКИХ ФЕРМЕРОВ НИГЕРИИ

Abstract. Irrigation is a well-established procedure on many farms and is practiced on various levels around the world. It allows diversification of crops, while increasing crop yields. Typical irrigation systems consume a great amount of conventional energy through the use of electric motors and generators powered by fuel. Nigeria faces water scarcity and high operational costs for traditional irrigation systems, hindering agricultural productivity while the price of conventional fossil fuel is skyrocketing on daily basis. However, the use of solar pumping machine for irrigation purposes in Nigeria is becoming a cost-effective and sustainable option for irrigation, particularly in remote and off-grid areas. However, these systems also have their challenges, such as high initial costs, maintenance and repairs, limited access to spare parts, lack of government policies and regulations, lack of technical expertise, lack of financing options and social acceptance. To reduce some of these challenges, a portable DC-battery or solar-powered water pumping system was designed, fabricated, and tested to evaluate its efficiency. Using the solar generation factor for Nigeria, detailed calculations were carried out to obtain the design parameters to fabricate device's components. The device was tested for performance by determining its volume flow rate. The results of two separate experiments obtained show that a flow rate of 20.44 l/min. was realised compared to conventional fuel pump of 20. 34 l/min. to irrigate a hectare of land using 0.4kW pump. Hence, the results obtained demonstrated the functionality and feasibility of the pilot system operation in the region. Consequently, the system produced is reliable, safe, and can be operated with low maintenance cost as a portable device to pump water to irrigate crops.

Keywords. Irrigation, water pumping device, hybrid, solar.

INTRODUCTION

Solar energy is the most abundant source of energy in the world. Solar power is not only an answer to today's energy crisis but also an environmental friendly form of energy. Photovoltaic (PV) generation is an efficient approach for using the solar energy. Solar panels (an array of photovoltaic cells) are now extensively used for running street lights, for powering water heaters and to meet domestic loads. The cost of solar panels has been constantly decreasing which encourages its usage in various sectors. One of the applications of this technology is used in irrigation systems for farming. Solar powered irrigation system can be a suitable alternative for farmers in the present state of energy crisis in India. This is green way for energy production which provides free energy once an initial investment is made [1].

Today the generation is heading towards ultra-technologies. Water pumping has a long history; so many methods have been developed to pump water. People have used a variety of power sources, namely human energy, animal power, hydro power, wind, solar and fuels such a diesel for small generators.

The most common pumps used in remote communities are:

i) Hand pumps;
ii) Direct drive diesel driven borehole pumps;
iii) Electric submersible pumps with diesel generator;
iv) Solar submersible pumps.

MATERIALS AND METHOD

Design Consideration and Materials Selection

Design calculations

Extra-terrestrial Radiation

The extra-terrestrial radiation (Ra) is the incident radiation outside the earth's atmosphere and it was obtained using the relation [2] as:

$$Ra = \frac{24(60)}{\pi} Gsdr[WsSin(\varphi)Sin(\delta) + Cos(\varphi)Cos(\delta)Sin(Ws)]$$

The latitude (φ) is positive for the northern hemisphere and negative for the southern hemisphere [2]. The conversion from degrees to radians was achieved using the relation [2, 3] as:

$$Latitude\ [radians] = \frac{\pi}{180}\ [decimal\ degrees]$$

The inverse relative distance earth-sun (dr) was calculated with the relation [2, 3]:

$$dr = 1 + 0.033\ cos\left[\frac{2\pi}{365} J\right]$$

J = day of the year between 1 (1st January) and 365 / 366 (31st December) as the case may be.

The solar declination (δ) is the angular distance of the sun north or south of the earth's equator. It is measured in radians and obtained from the relation [2, 4] below:

$$\delta = 0.409Sin\left[\frac{2\pi}{365}J - 1.39\right]$$

The sunset hour angle (Ws) is the angle for which the sun's rays are parallel to the horizon. It is given as [2, 5]:

$$Ws = arccos[-tan(\varphi)tan(\delta)] = arccos\left[\frac{sin(\varphi)sin(\delta)}{cos(\varphi)cos(\delta)}\right]$$

Evapotranspiration

Evapotranspiration (ET) is the sum of evaporation from the land surface plus transpiration and plant transpiration from the Earth's land and ocean surface to the atmosphere [6, 7]. Reference evapotranspiration (ET0) is the evapotranspiration rate of a short green crop (grass/alfalfa), completely shading the ground, of uniform height and with adequate water status in the soil profile [7]. Alfalfa at full cover was considered as the reference plant and its evapotranspiration was obtained using the Hargreaves method expressed as [8]:

$$ET_o = 0.0023(T_{min} + 17.8)(T_{max} - T_{min})^{0.5}Ra$$

Where: Tmean, Tmax, and Tmin are Average Mean, Maximum and Minimum temperatures respectively.

The Crop Evapotranspiration/Consumptive Water Use (ETc)

It's defined as the evapotranspiration from disease-free, well fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions [7] and it's represented as [2]:

$$ET_c = Kc * ET_o$$

Where: Kc and ETc denote crop constant and crop evapotranspirations respectively.

With Alfalfa as the reference crop, at full cover, the Kc for pepper and tomatoes are: 0.71 and 0.66 respectively [7].The obtained daily consumptive water use by the crops are as indicated in table 4.1.

The Required Flow Rate

The required flow rate (Q) was obtained using the relation [8]:

$$Q = \frac{V}{t}\ [m^3/s]$$

The Total Dynamic Head

It is the total equivalent height that a fluid is to be pumped; taking into account, friction losses in the pipe and it is expressed by the relation [9] as:

$$TDH = Static\ Height + Static\ Lift + Friction\ Loss$$

The Hydraulic Power

It's the power required for lifting a volume of water through a given head and it's given as [10]:

$$P_h = \rho gQH$$

Electrical Energy Required

This is the energy required by the motor to drive the pump. It is expressed as [11]:

$$P_e = \frac{Hydraulic\ energy}{Subsystem\ Efficiency} = \frac{Ph}{\eta}$$

η = converter (0.95) motor (0.7) x pump (0.6) x piping (0.90) [11]

Size of the Solar PV generator

The size of the PV generator is estimated from the expression [1] as:

$$PV\ wattage = \frac{Electric\ Energy\ Requirement}{PV\ Energy\ loss \times Sunshine\ hour}$$

In carrying out the design of the hybrid water pumping device factors such as cost of the materials, functionality, reliability, portability, and space, usability, maintenance cost, and safety were considered to achieve a feasible and functional device. The materials selected for the design of the device were based on their mechanical properties, physical properties, fabrication requirement, and economical requirement. The majority of the components selected are sourced locally in Nigeria which makes them accessible. The selected components and the purpose for choosing them are presented in Table 1.

Table 1 – The Materials Needed for the Project Work

S/N	Materials	Purpose
1	Pump	To pump water
2	Mild Steel Angle bar	To construct the solar panel stand
3	Mild steel sheet	To construct the device's case
4	Electrical cables	For wiring DC circuit
5	Switches	To operate and control the pumping system
6	25.4 mm pipe and coupling	To convey water in and out of the system
7	Lamp indicator	To indicate the system has been switched on
8	Timer	To control the time of operation
9	Lithium or DC Battery	To store energy and also to operate the device when solar irradiation seizes
10	Solar panel	To convert solar energy into electrical energy.
11	Compressor	To release the water
12	Wheels (optional)	To move the system from one location to another.

The Portable Hybrid DC Battery-Solar Powered Rechargeable Irrigation Water Pumping Device

The major components are solar panel array, solar charge controller, battery, compressor, and main controller as shown in Figure 1. In this design, the solar PV will absorb sunlight intensity or solar irradiation, which will be converted to DC electricity. Then, the solar charge controller will regulate the voltage and current coming from the PV panel going to the battery and prevents battery overcharging, also prolonging the battery life. Furthermore, the battery stores the electrical power need especially for the no sun period. The compressor pumps the water from the water stream or river to the output pipe which is placed in farm. Apart from the solar PV panel, the other components are encased in a box for ease of mobility. Advantages of this concept are its ease of mobility, portability to overcome the challenge of poor terrain, its ability to pump water from surface sources of water to various locations of the farm, and it is not exposed to vandalization because it will be kept in a safe place after use being portable. The device can also be passworded to prevent unauthorised persons from operating without permission.

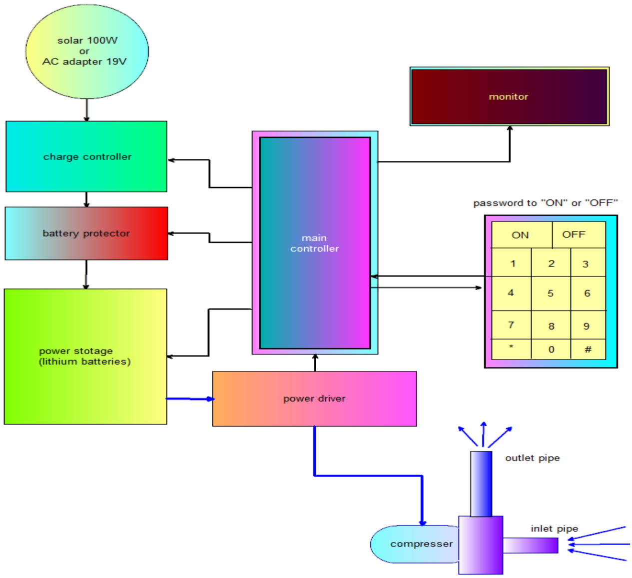

Figure 1 – The Block diagram of the Hybrid DC Battery-Solar Powered Rechargeable Irrigation Water Pumping Device

RESULTS AND DISCUSSION

Method of Data Analyses

After fabrication, the machine was test-run for proper assembly while taking note of joints for leakage. The fabricated machine was taken to field (*fadama* area) in Dundaye farmland in Sokoto State for data collection. The area with available surface water as well as shallow wells as source of water for irrigation purposes where the machine was run and compared to conventional pump using fossil fuels. The following parameters in Table 2 were calculated based on the data obtained during farm operation:

Table 2 – Device's performance results

Type pumping device	Flow rate, L/min	Water discharge, Litres	Time, min.	Irradiance, W/m^2	Pumping Efficiency, %
Fossil fuel pump	20.34	6	1.5	-	90.7
Fabricated device	20.44	6	1.4	929.8	52.5

CONCLUSION. This study designed and fabricated hybrid DC battery-solar powered rechargeable irrigation water pumping device with password pad for irrigation system. Several limitations have been considered compared to the conventional water pump which the proposed could solve such as: cost-effectiveness, saving energy, portability, and use of password to disable operation by an unauthorized person. The study determined and compared generated power from the solar panel with respect to irradiance for different time of the day as well as different flow rates of the device. The device is expected to be powered directly with PV panel of 100 W nominal power and to work for 10 hours (depending on the battery capacity) when powered by a DC deep cycle battery with a rating of 12V/200 Ah.

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РАСЧЁТ НЕКОТОРЫХ ПАРАМЕТРОВ ЖЕЛОБКА КАТУШКИ ЗЕРНОВОЙ СЕЯЛКИ

Аннотация. В статье приводится теоретические выкладки к расчёту параметров желобка катушки зерновой сеялки, а также приводятся числовые значения указанных параметров.