PHOTOVOLTAIC WATER PUMPING SYSTEM FOR IRRIGATION.

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Abstract The economy of Bangladesh is predominately agrian. It is not possible to produce sufficient food for a large number of population with monsoon based agriculture. Modern irrigation methods are needed to fulfil the food demands. Although in Bangladesh, there are many diesel engine operated water pumps for irrigation; but these are not adequate. On the other hand, Bangladesh has no sufficient fossil fuel source. Every year Bangladesh has to import more than 144000 billion litres of oil from foreign countries. The price of diesel is increasing day by day due to increasing the oil price in international market which impacts Bangladesh agriculture. If the oil crisis in Bangladesh becomes more severe, sufficient food can not be produced and many men will die due to want of food. So alternative methods must be seeked. Photovoltaic water pumping system is one of the best alternative method for irrigation. Average availability of solar energy in Bangladesh on horigontal surface is more than 17.40 MJ/m^2 per day and on tilted surface is more than 21.50 MJ/m^2 per day. These are enough for photovoltaic water pumping system for irrigation. The components of pv-array which converts solar energy to d.c. current, the motor and pump subsystem comprising compents which converts the electrical output of the pv –array into hydraulic energy. The storage and distribution system which supply the water to its point of use. The design procedure of photovoltaic water pumping system for irrigation consists of assessing water requirements, calculation of hydraulic energy for the system, determination of available solar energy at that place, sizing the solar pump, selection of a suitable system configuration, specifying solar pump performance and construction. In economic view point, the cost of pv- water pumping system for one season irrigation is higher than diesel engine pumping system due to high cost of pv- modules and their components; but for two or three seasons irrigation, the cost of pv- water pumping system is less than diesel engine pumping system.

INTRODUCTION

Bangladesh is an agriculture-based country. The economy of Bangladesh is predominantly agrian . Its agriculture sector contributes nearly thirty five per cent of GDP, the crop sub-sector contributes 71 percent of them. To meet the growing demand of food grains for increased population, introduction of modern technology at farm level is must. Therefore, efforts to reduce dependence on monsoon based agriculture and to popularise the irrigation technology have been given importance since long. The present day world , especially the developing countries , is experiencing a rapid growth in demand of energy use in order to improve the standard of living . For sustaining this growth, the fossil energy sources are not considered adequate . Realisation of this situation has led the whole world to harness energy from other sources especially new and Renewable sources of energy.

In Bangladesh adaptation of irrigation techniques is reported to play a vital role in the improvement in the yield of food grain . In this regard the government has a plan to install a huge number of pumps in rural areas of the country for irrigation purposes. These pumps are diesel engine operated where electricity from the national grid is not available. It is worthwhile to note that the demand of diesel for irrigation has caused a miss - match in the demand for petroleum products. Ii is not possible to connect all the irrigation pumps to the national grid . On the other hand , there is a great problem for grid connected irrigation pumps . Because , supply of electricity in Bangladesh is not regular due to deficiency of electrical energy (Load shedding) . Supply of electricity to grid connected irrigation pumps remain stop for one , two days , even two weeks also . Want of sufficient water, crops will die. So, photovoltaic pumping system is very essential for irrigation in Bangladesh.

The conventional irrigation methods in Bangladesh, in most cases, is to lift ground water and used to supply this water directly to the crop fields. Sometimes surface water is also used for irrigation. In both the cases , diesel engines are used to power the pumps .

In Bangladesh, there are 68,000 villages and , each village has at least 10 irrigation farms . It is roughly estimated that the number of diesel engines in Bangladesh is more than 700000 which are used for irrigation and consumed a lot of diesel fuel. Every year Bangladesh imports more than 146000 billion litres of oil from other countries, which impacts the Bangladesh economy. On the other hand, it makes highly air pollution and also sound pollution.

WATER REQUIREMENTS FOR IRRIGATION

The quantity of water needed to irrigation a given particular land area depends on types of crops, cropping calendar, crop growth cycle, types and conditions of soil, annual rainfall, climate conditions, humidity, average wind velocity, land topography, methods of water distribution, field application efficiency, water quality, field configuration, temperature etc. Many of these very with seasons, drought, rainfall and the quantity of water -is not constant. The design of an irrigation pump installation will need to the above factors in to account.

Table 1: Typical Irrigation Water Requirements for Bangladesh and Thailand. in m^3 / day / hectare

Month	Bangladesh	Thailand
January	7.1	1.3
February	17.5	27.0
March	28.4	
April	85.0	42.0
May	-	42.0
June	-	31.0
Jully	-	28.0
August	-	22.0
September	-	12.0
October	-	-
November	15.0	-
December	16.5	21.0

Table 2: Typical Daily Water Requirements for Livestock.

Animal	Water requirements in litres per day.
Horse	50
Dairy cattle	40
Steers	20
Pig	20
Sheep	5
Goat	5
Poultry	0.1

The name and description of the farm which will be designed on the basis of use photovoltaic water pumping system for irrigation.

Name of farm:Kuchiamura Krishi Khamer.
Location: Village Kuchiamura, Thana- Ataikula, District- Pabna, Bangladesh, Latitude23.78^0 north, longitude 90.37^0 east, Time zone 18 (Considering greenwich as 0)

Table 3 : Source of water and water distribution method.

Source of water	Under ground water lifted by shallow tube well pump.
Static Lift	1 to 4.5 m
Water supply	Canal and drain , made of soil.
Field application	Furrow, efficiency 60%.
Water storage	In fishing Tanks.

Table 4: Use of land and water requirement/per day

Use of lands.	Amount of land.	Water requirement
Irrigated land	1.8 hectares	153 m^3
Fishing Tanks	$0.5 \times 2 = 1$ hectares	Nil
Poultry	0.20 hectares	0.10 m^3
Livestoc k	0.20 hectares	3.40 m^3
Total	3.20 hectares	156.50 m^3

Table 5: Cropping pattern of the farm

Cropping calendar	Crops	Seasons
Chaitali	Wheat , maize, beans ,pulse etc.	Poush to Falgune.
Aush	Paddy ,Sugar cane. Jute	Chattra to Ashar.
Amaun	Paddy,	Chrabann to Augrahayan

Table 6: Livestock and Poultry for the farm.

Number of Cattle	60
Number of sheeps	100
Number of goats	100
Number of hens	2000
Number of ducks	1000

Since water requirements are not constant. Water requirements depend on the crops, cropping calendar, types of soil, land topography, clouds, rains, climate conditions, method of distributions etc. This system has been designed on basis of peck water requirement. When water requirement is less than supply, then water will be stored in the fishing tanks. On the other hand, when water requirement is more than supply, then deficient water will be met up from fishing tanks.

Every fishing tank has a sluice gate. When gate is opened, then water goes to the crop field automatically due to potential difference between surface of water of the tanks and the crop field.

Delivery pipe head loss = 10%
Delivery pipe length = 20 m.
Gravitational acceleration, g = 9.81 m / s^2 .
Volume of water, V= m^3
Density of water, ω = 1000 kg /m^3
Total head = H metres.
Hydraulic Energy E_h=VωgH Jule.

Table 7: Format sheet for hydraulic energy requirement.

Month	Water require-ments(Q)	Static Head in metre (m)	Dynamic head loss in meters (m)	Total head in meters (m)	Hydraulic energy (MJ/day)
Jan	16.28	2.0	0.20	2.20	0.097
Feb	35.00	2.0	0.20	2.20	0.209
March	54.62	2.5	0.25	2.75	0.409
April	156.50	4.5	0.45	4.95	7.6
May	0	3.5	0.35	3.85	0
June	0	2.5	0.25	2.75	0
July	0	2.0	0.20	2.20	0
August	0	0.5	0.05	0.55	0
Sept	0	0.5	0.05	0.55	0
Oct	0	0.5	0.05	0.55	0
Nov	30.50	1.0	0.10	1.10	0.327
Dec	33.20	1.5	0.15	1.65	0.538

Required hydraulic energy for the month of April
E_h = 7.6 MJ / day.

SOLAR ENERGY RESOURCE CALCULATION:

Unfortunately solar radiation data are not available for this farm place. For this reason solar radiation data have been calculated using world meteorological maps (world Meteorological Organization. Technical note no Geneva- 1981)

* Radiation on horizantal surface
=(extra terrestrial radiation)× (clearness index)
* Radiation on array surface
= (Radiation on horzantal surface)× (tilt factor)

Table 8: Solar energy availability for the farm place

Month	Extra-terrestrial irradiation	Clearness index	Global horizontal irradiation	Tilt factor	Global Irradiation on Array MJ/m^2 .
Jan	24	0.5	12.0	1.29	15.48
Feb	28	0.5	14.0	1.19	16.66
Mar	33	0.6	19.8	1.12	22.176
April	37	0.6	22.2	1.00	22.20
May	39	0.6	23.4	0.92	21.528
June	40	0.5	20.0	0.91	18.20
July	40	0.5	20.0	0.92	18.40
Aug	38	0.5	19.0	0.97	18.43
Sep	34	0.5	17.0	1.06	18.02
Oct	29	0.5	14.5	1.16	16.82
Nov	25	0.6	15.0	1.34	20.10
Dec	25	0.6	15.0	1.41	21.15

Solar energy, for the month of April (design month),
H = 22.20 MJ /m^2 per day .
The fraction of energy which can be converted to hydraulic energy by the pump/motor is termed as subsystem efficiency. Subsystem efficiency,$\eta_{sub}=E_h/E_e$, where E_h and E_e are hydraulic energy and energy output of PV-array respectively. Typical values of this efficiency are obtained from tests undertaken for the UNDP/World Bank Solar Water Pumping Project.

SIZE OF PV- ARRAY AND SOLAR PUMP SYSEM

A PV- array is rated by its electrical output at a temperature of 25^0C under a solar irradiance of 1000 W/m^2:

$W_p=1000\ \eta_r A$------------(1)
Where W_p= Array rating power in watts
η_r = The PV array efficiency at the reference operating Temperature (25^0C)
A= Area of the array in m^2.
The cell area required to provide a daily energy out put(E_e MJ) for a daily solar irradiation (H MJ/m^2) incident on the array is:

Area, $A = E_e/(\eta_{pv}H)$----------------(2)

Where η_{pv} is the daily array efficiency under actual operating conditions. It is generallay lower then η_r because of temperature effiects, actual irradiation less than 1000 W/m^2 due to air mass and cloud effects and the impedance mismatch between motor and array.

$\eta_{pv} = F_m\{1-\beta(T_{cell}-25)\}\ \eta_r$ ---------(3)

The first term on the right hand side of the equation (3) F_m is the match factor i,e the ratio of electrical output under actual operating conditions to the electrical output at the maximum power point. The second term is the reduction factor in efficiency due to increases in cell temperature, β is the cell temperature coefficient.

Subtracting the value of η_{pv} from the equation (3) in the equation (2) , We get

Area, A= $E_e / F_m\{1-\beta(T_{cell}-25)\ \eta_r\}H$ -------(4)

A is the cell area in m^2 required to provided a daily output of E_e MJ. To determine the required array rating, Equation (4) is substituted into equation (1)

$Wp = 1000\ E_e\ / F_m\{1-\beta(T_{cell}-25)\}H$ ---------(5)

In Equation (5), using the following parameters:
F_m =0.90 , β = 0.005 per ^{0}C and T_{cell}= 40^0C,

We get PV-array rating power in watts,

W_p=1200E_e/H-------------(6)

Where E_e= Required electrical energy,
H= Solar energy available on array surface.
The electrical energy requirements (E_e) are related to the hydraulic energy(E_h)

$\therefore\ E_e= E_h / \eta_{sub}$ ----------------(7)

Where, η_{sub} is the daily energy efficiency of the sub-system.
E_h= Required hydraulic energy for the system
Hydraulic energy Requirement for the design month, April= 156.5 m^3/day

Global irradiation on the array of the design month = 21.49MJ/m^2 per day.
Average subsystem energy efficiency =30%
Peak sub system power efficiency, n_{sub}= 40%
Inverter efficiency η_i = 90%
Using equation (7) it can be calculated the required electric energy, $E_e= E_h / n_{sub}$
= 7.6/0.30=25.33MJ/day

Using the equation (6) it can be calculated PV array size in watts. PV array size, Wp=1200E_e/H
=(1200×25.33)/21.49=1414.42W
(without inverter)

PV array size with inverter
Wp=1414.42/0.90 = 1571.57 W ≈ 1600 W

Size of the motor is 1.6 KW

Size of the pump: Peak array power × peak subsystem power efficiency = 1600×0.40 =640w.

Size of the pipe work = 150 mm ≈ 6 in.

Size of the inverter = 1500 W
Flow rate = 10 litres / s.

ECONOMIC ANALYSIS

Economic analysis is consist of the Comparing pv-pumping system with the existing diesel pumping system for irrigation.

Costs are divided in to two parts: Capital cost and recurrent cost. Recurrent cost are the following three types (1) Replacement cost (2) Maintenance and (3) Operating cost.

Payback period: The length of time required for the initial investment to be repaid by the benefits.

Rate of Return: The benefits gained are expressed as a rate of return on the initial investment.

Present Worth (PW) : The sum of all the casts and benefits associated with the pumping system over its lifetime is expressed in present day money and this is termed the present worth .

For a payment or benefit Ca occuring annually for a period of N years which is inflating at a rate i per year and discounted at a rate d , the present worth ,
PW =Ca. Pa, where

$P_a = [1-\{(1+i)/(1+d)\}^N\ ] /(d-i)$

Table 9: Costing Procedure
Input data on PV – pumping system

Size of the module	1600 (W_p)
Inverter	1500 (W_p)
Pump and motor set	1500 (W_p)
System head of the pump	4.95 meter
Annual discharge(pump used for only one crop season and one season equals to 20 days)	18780 m^3
Annual discharge(pump used for only two crop season and two seasons equal to 240 days)	37560 m^3
Cost of module per W_p	\$3 - \$5
Cost of structure and instillation	§ 550
Cost of inverter (with 30% duty and taxes)	\$1337.70
Cost of pump and motor set	\$ 1209
Cost of maintenance per year	\$20
Life of the system	20 years
Life of module	20 years
Life of the inverter	10 years

Life cycle cost (LCC) : The life cycle costs are simply the sum of the present worth of the recurrent costs and capital cost.

Annual equivalent life cycle cost (ALCC)
= LCC / P_a

Table 10: Cost estimation of PV-pumping system

Capital scost	Module ($4 per W_p)	$ 6400
	Inverter (with 30% duty and taxes)	$ 1337.70
	Pump and motor set(with 30% duty and taxes)	$ 1209
	Structure and installation Cost estimation of PV-pumping system	$ 550
	Total capital cost	$ 9496.70
Maintenance cost per year		$20
Replacement cost (inverter)		$ 1337.70
Replacement cost (pump & motor set)		$1209

Table 11: Input data on diesel pumping system

Power of the engine (horse power)	6 hp
Cost of pump	$ 114
Cost of the engine	$ 818
Accessories and installation cost	$ 550
Consumption of fuel per horse power per hour	0.21 litres
Cost of diesel per litre	$ 0.30
Consumption of lube oil (% of diesel)	1.0
Operator`s salary per month	$ 100
Number of working hours (pump used for only one crop season and one season equals to 120 days)	960
Number of working hours (pump used for only two crop seasons and two seasons equals to 240 days)	1920
Maintenance cost per year	$ 91
System head	4.95 meters
Annual discharge(pump used for only one crop season and one season equals to 120 days)	18780 m^3
Annual discharge(pump used for two crop seasons and two seasons equals to 240 days)	37560 m^3
Life time of engine	10 years
Life time of pump	10 years

Table 12: Cost estimation of diesel pumping system

Capital cost	Pump	$ 114
	Engine	$ 818
	Accessories and installation	$ 550
	Total capital cost	$ 1482
Operator`s salary per season		$ 300
Fuel and lube oil cost per season		$ 392.88
Maintenance cost per season		$ 30.33
Replacement cost (for engine)		$ 818
Replacement cost (for pump)		$ 114

Unit cost of water for pumping systems:

Unit cost of water = Annual production / ALCC

1. Water requirement = 18780m^3(for 1 season)
= 37560m^3(for 2 seasons)
= 56340 m^3(for 3 seasons)

(a) Cost analysis of PV pumping system:

Period of analysis , N = 20 years.
Discount rate, d = 10 %, Inflation rate , i = 5 %
$\mathbf{P_r}$ = 0.5981041, $\mathbf{P_a}$ = 12.112084

	Annual Cost	Present Worth
Capital Cost		$ 9496.70
Replacements (Inverter)		$ 800.08
Replacements (Pump & motor)		$ 723.10
Maintenance	$ 20	$ 242.24
Operating	0	0
Total annual Cost	$ 20	
Life Cycle Cost (L O C)		$ 11262.12
Annual equivalent of LOC, ALOC		$ 929.82
Cost/ Unit	(for 1 season)= 4.95 cents / m^3 (for 2 seasons)= 2.47 cents / m^3 (for3 seasons)= 1.65 cents / m^3	

(B) Cost analysis of Diesel-Pumping system

(For one season)

	Annual Cost	Present Worth
Capital Cost		$ 1482
Replacements (Pump)		$ 68.18
Replacements (Engine)		$ 489.25
Maintenance	$ 91.00	$ 1102.20
Operator`s pay	$300	$3633.63
Operating (Fuel , Lube oil)	$392.88	$4395.23
Total annual Cost	$783.88	
Life Cycle Cost (L O C)		$ 11170.49
Annual equivalent of LOC, ALOC		$922.26
Unit Cost of water	4.91 cents / m^3	

Footnote: In the case of diesel pumping system for one, two and three seasons irrigation, the unit costs of water are more or less same.

Cost comparison "Diesel vs PV-pumping system

	PV	Diesel
Unit cost for 1 season	4.95	4.91
Unit cost for 2 seasons	2.47	4.91
Unit cost for 3 seasons	1.67	4.91

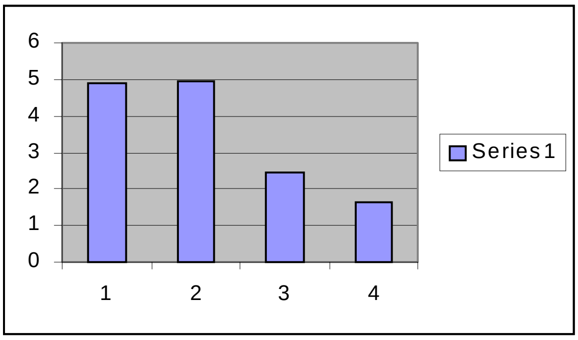

Figure: Cost comparison "Diesel vs PV-pumping system

Column1 indicates diesel pumping cost for one ,two and three seasons and columns 2,3,4 indicate pv-pumping system for one, two, and three seasons respectively.

COMMENTS:

After economic analysing , it is shown that Photovoltaic pumping system for irrigation in Bangladesh is more feasible than Diesel engine –pumping system . In economic view point , PV –pumping system for only one season irrigation is a little bit higher than the diesel engine pumping system due to high cost of PV module and its components . For two or three seasons irrigation PV- pumping system is lower than diesel pumping system . If the price of PV –module and its components will be reduced or these will be produced locally , then PV- pumping system will be more feasible . Some pilot projects of PV-pumping system for irrigation should be done by the Government of Bangladesh or NGOS for decimination .

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