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Mini Review

Solar energy groundwater pumping: A sustainable solution to energy squeeze in smallholders' Irrigation in India

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ABSTRACT

India's smallholder agriculture boomed with supplemental irrigation made possible by diesel and electric pumps. Nevertheless, the smallholders' irrigation is under siege from an energy squeeze with deteriorating farm power supply and manifold increase in diesel prices. This energy squeeze undermines the adoption of broad range precision irrigation technologies and profitable productivity of small holdings. However, the use of solar energy particularly in groundwater pumping and use of pressured irrigation could improve energy access, reduce fossil fuels consumptions, as average incident solar radiation over India's geographical area is of 4-7 kWh/m^2/day with 250-300 clear sunshine days/year. To promote solar energy use under the prevailing solar radiation conditions and depth to water level scenario of groundwater a suitable groundwater pumping system model is required to fulfil the irrigation needs. This paper describes a solar photovoltaic groundwater pumping model suitable for small farm irrigation ether by traditional methods of irrigations or by pressured method, as it generates pressure heads of 98 -147kPa when incident solar radiation ranged from 400- 800W/m^2, the solar radiation condition which prevails over its geographical area between 9.00-14.00 hrs round the year.

Keywords: Energy, smallholders, irrigation, photovoltaic, groundwater, India

INTRODUCTION

India's landscape is dominated by smallholders who cultivate a piece of land of an area less than 2 ha. They draw their subsistence from the output of this small piece of land. Out of 450 million small farms worldwide India alone possesses 117 million i.e. 84.8% of total holdings of the country (Nagayets, 2005; Agriculture Census, 2011). Smallholders are mostly concentrated in Assam, Bihar, Chhattisgarh, Jharkhand, Odessa, Uttar Pradesh and West Bengal, theregioninhabited by about 520 million peoples. These smallholders are highly susceptible to poverty and hunger because neither they get sufficient food production nor income to ensure household food security, though; from the efficiency point of view, smallholdings are equal or better than large holdings due to theadoption of high yielding modern varieties of dominant food staples (NCEUS, 2008).

Typically, smallholders' staple production systems in India are often both risky and relatively of low return, as the low commercial value of staple crops is exacerbated by poor yields and erratic rainfall—the two problems that are expected to worsen in the next few decades under climate change (Lobell, 2008; Held *et al.*,2005). With the advance of globalization and greater integration of global market, raising agricultural productivity and output provides an opportunity to increase their income and broad-based food security. Smallholders can play a major role in increasing food production, generating additional income and employment if they had the access to key ingredients in crop production system (Lipton, 2006).

The scarcity of water is one of the main hurdles in crop production. The secured water supply provides an opportunity to the farmers to invest in high yielding seeds, grow higher valued crops and harvest additional crops through ample opportunity for crop diversification. This will lead to generate employment even to landless people since more people are required to be involved in harvesting, processing and marketing the farm inputs and outputs as promotion of irrigation is frequently cited as a strategy for poverty reduction, climate adaptation, and promotion of food security (WDR, 2008; Polak and Yoder, 2006).

Hence, the future of sustainable agriculture growth and food security in India is depending on the performance of smallholders particularly in eastern states where severe poverty prevails despite being rich in all kinds of natural resources.

India is the biggest user of groundwater for agriculture in the world. As per MIC (2001), there were 18.5 million groundwater irrigation structures (wells and tube wells) in India of which tubewells accounted for 50%. In all likelihood, the number of groundwater irrigation structures is now around 27 million with every fourth rural household owning at least one such irrigation structure (Shah, 2009). These structures are operated by diesel, kerosene or electricity. Interestingly, more than 68% of the households owning tubewells are of small and marginal farmers. This indicated the growing dependence of these households on tube wells as a source of livelihoods.

The distribution of electric and diesel pump sets in South Asia is shown in Fig.1.Spatial distribution of pumps in India shows that most of the diesel-operated pumps are located in Eastern region. India's smallholder agriculture boomed with supplemental irrigation made possible by diesel and electric pumps. However, smallholders' irrigation in India is under siege from an energy squeeze with three sides: (a) deteriorating farm power supply; (b) embargo on new

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electricity connections; and (c) many-fold increase in diesel prices. Energy squeeze undermines the adoption of broad range precision irrigation technologies and stable and profitable productivity. India faces a formidable challenge in providing adequate energy to all its users as 84 million households do not have access to electricity (Kuppam, 2012).

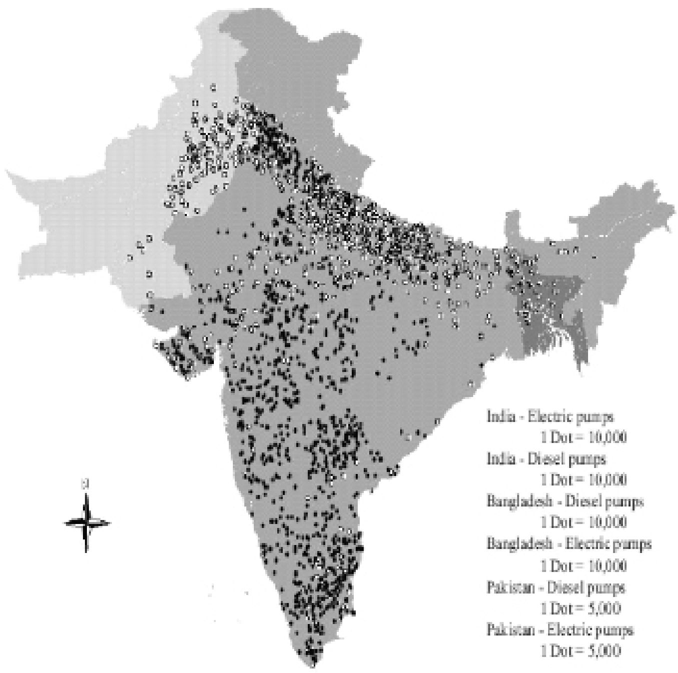

Fig 1: Distribution of electric and diesel pump sets in Indian Sub-Continent (Shah, 2009)

India is not well endowed with natural energy resources. Reserves of oil, gas and uranium are meagre. While coal is abundant, but it is regionally concentrated and is low calorie and high ash content and limited extraction technology. The hydro potential is significant, but small compared to India's needs and its contribution in terms of energy is likely to remain small. Providing energy access and energy security in agriculture in terms of electricity and fossil fuels at an affordable cost would, therefore, continue to be a major issue and problem. Solutions to this simply have to be found but which no longer appear possible from conventional sources.

Renewable energy could be a key part of the solutions and is likely to play an increasingly important role in energy access, reducing consumption of fossil fuels and helping India in pursuing its low carbon developmental pathway Rahman and Bhatt (2017). As per Rahman (2015) adoption of modern irrigation technologies are well suited when the farmers depend on groundwater. Here farmers could be stretching their scarce supply of water and enabling them to expand their cultivated area, diversified production and generate more income and employment. But despite these benefits of modern irrigation their adoption and diffusion have been far below the potential and expectations

India is located between 8°4'-37°6'Nand 68°7'-97°25'E, an equatorial region and therefore possess a very large solar energy potential. The average solar radiation incident over India varies from 4-7 kWhm^{-2} day^{-1}with 250 -300 clear sunny days gives the location for year-round reliable source of energy (Sharma *et al*., 2012). The solar radiation received over the Indian land area is estimated to be 5000 T kWhm^{-2} year^{-1}, which is equivalent to 600 TW (Muneer et *al*., 2005). Promoting renewable energy in India is essential in view of high growth rate of energy consumption and heavy dependence on imports of petroleum fuels and volatility of world oil market (Bhattacharya and Jana, 2009). Solar photovoltaic groundwater pumping coupled with modern irrigation technologies viz. drip or micro-sprinklers could be appropriate options in mitigating persistence energy crisis, overexploitation of groundwater and environmental degradation in small holders.

This paper describes a solar photovoltaic groundwater pumping model, suitable for small farm irrigation ether by traditional (flood/furrow/check basin/ border) methods of irrigations, or by using modern irrigation technologies viz. drip and micro sprinklers.

In solar photovoltaic water pumping system, main components are the solar array, power conditioning unit and solar tracking mechanism. The generated and conditioned solar power derives the groundwater lifting pump. When, there is enough sunlight, system functions well without any battery backup. However, when there is no sunlight system stops unless battery storage is available. If the water source is a deep well then a submersible DC pump is preferred. DC submersible pump can lift water that is up to 200 meter deep. However, if water source is a shallow-well the DC surface pumps can be a better option. DC surface pumps have the limitations that it can pump out water only from few meters of the depth.

AC submersible pumps can also be operated by solar photovoltaic technology by using a DC-AC inverter or variable frequency drives along with maximum power point tracker. AC submersible pumps are comparatively less efficient than the DC, but there are some advantages of AC submersible pump over DC submersible pumps. AC pumps are robust and have a longer life; however DC pumps are costly and repairing and maintenance cost is high. DC pumps can be made available of any capacity and from any local market while the DC submersible pumps are available in limited capacities.

MATERIALS AND METHODS

In solar powered groundwater pumping generally, two different type configurations are adopted. In first configuration solar photovoltaic generated electricity drives a surface or submersible pump to lift groundwater into an overhead tank. This tank serves as an energy store and supplies the pressure needed for the pressurised irrigation system.

The stored water also serves as reservoir during low insolation. In other configuration water is directly injected into the irrigation system and no storage structure is used. In proposed configuration (Fig.2), solar photovoltaic generated electricity drives a 3hpACsubmersiblepump of rating 2.2 kWused for lifting groundwater.

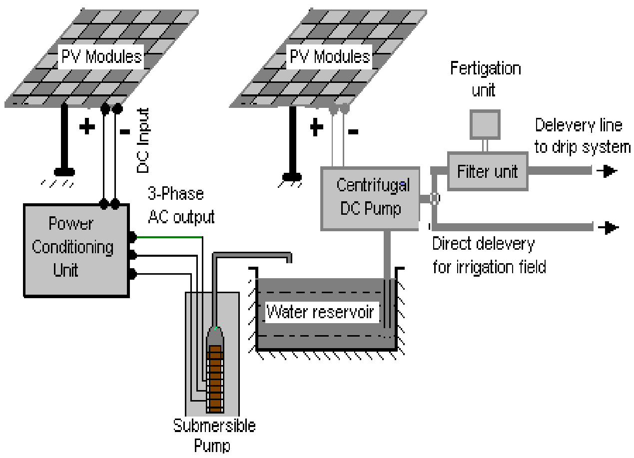

Fig 2 : The schematic of solar photovoltaic ground water pumping system

The performance curve of the pump is shown in Fig.3. In many parts of the country especially in the eastern region, the groundwater depth is ranging from 2-10 m below the ground level with annual water level fluctuations ±2 m to ±4 m in the post and pre-monsoon, respectively. The diurnal variation in the solar radiation ,on a cloud free day, for the experimental site,*i.e.* ICAR Research Complex for Eastern Region Patna, India (25.65° N)is shown in Fig.4. The maximum global solar radiation at the site was 6.4 kWh/ m^2/ day(April), while the minimum of 3.5kWh/ m^2/day was in December.

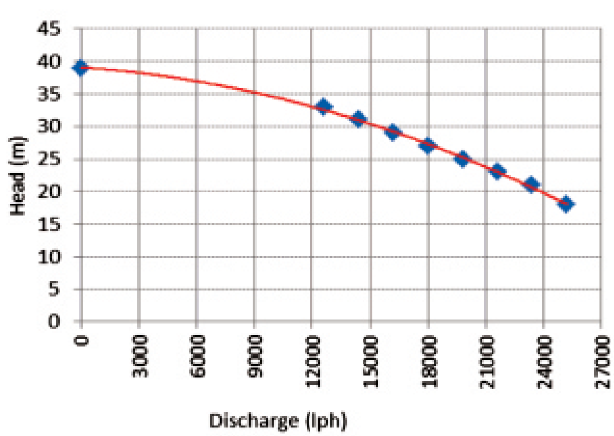

Fig.3: Performance curve of 3 HP submersible pump

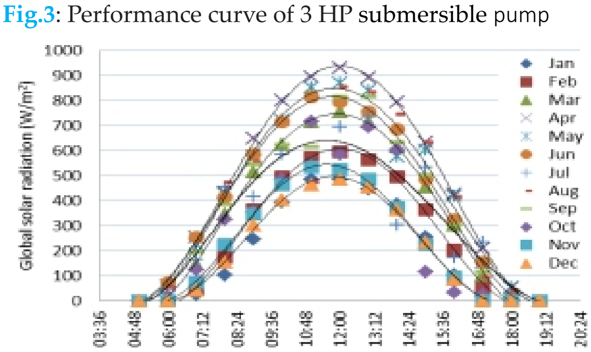

Fig 4: Diurnal variation in the solar radiation in different months with no cloud at latitude of 25.65° N (Patna).

Unlike other configurations here the water was stored in a grounded tank as raising water into the overhead tank or the direct feeding reduces the water output per day. Apart from this, a direct feeding offer low head neither facilitates satisfactory operation of pressurised irrigation systems nor covers the sizable area under pressurised irrigation. Further, the delivery of water to distant fields is difficult.

The submersible pump is powered by a solar array of attributes given in Table 1. Avariable frequency drive was used for power conditioning. Solar modules were connected in parallel and series to get required voltage as per the electrical specifications of the pump. An additional pump of 2hp was installed to deliver water from the tank to the fields to irrigate crops either by traditional methods of irrigation viz. flood, furrow, check basin, border irrigation or using pressurized irrigation systems. The advantage of this configuration was lie in the fact that the water from the tank could be delivered to distant fields at comparatively higher pressure as it is completely decoupled with groundwater pumping unit with a low suction of 2.5m. This pump is powered by a solar array of attributes given in Table 1. For both the pumps, i.e.,submersible and centrifugal pumps, arrays were mounted on manually operated dual-axis sun tracking structures to maximise the power generation.

Table1: Description of attributes of submersible and centrifugal pump

Pump Type	Description	
	Submersible (AC)	**Centrifugal (DC)**
Array size	3060Wp±3%	1410Wp±3%
No. of modules	18	6
Material of cells	C-Si	C-Si
Module size	170Wp±3%	235Wp±3%
Efficiency	13.8%	14.5%
Open circuit voltage (V_{oc})	43.66V	38.10V
short circuit current (I_{sc})	5.21A	8.57A
Voltage at maximum power (V_{mp})	36V	29.58V
Current at maximum power(I_{mp})	4.82A	7.95A
Temperature coefficient W/ $_0$C	1.036W/0C	1.036W/$_0$C

RESULTS AND DISCUSSIONS

For pumping depth equal or less than 15 m the water output on a clear sunny day was ranged from 104m^3/dayto170m^3/day. During high insolation months, i.e.,April to October mean monthly daily water output was between 170m^3/day to140m^3/day while in low insolation moths, i.e., November to January it was between 120 m^3/day to 105 m^3/day. For field crops such as rice, wheat oilseed irrigation, in general, is done by flood, furrow, border or check basin methods with on an average on an average 5.0 cm to6.0 cm water depth. Therefore, as per the availability of water and seasonal status, the cropped area of 3000-2500m^2 can be irrigated per day by conventional methods. This shows that the weekly command area the system is nearly 2.0ha. Farmers can sell water to neighbouring farmers as the system can deliver water to distant fields. They can also grow aquatic crops or can culture fishes in the tank for additional income.

The performance curve of 2 hp centrifugal surface pump is shown in Fig.5 The pressure head of centrifugal surface pumpon a clear sunshine cloud day during high insolation monthsbetween9.00-14.00 hrs was in the range of 147kPato 118kPawhenradiation was800-600 W/m^2;while, during low insolation months the same was in the range of 98 kPato88 k Pawhen radiation rangedfrom550-450 W/m^2. This shows that the system is competent enough for the pressure range of 147-88kParound the year. Therefore, pressurized irrigation systems viz. drip and micro-sprinklers can be operated round the year, as this range of pressure head is sufficient for operating drip and micro sprinklers successfully. The cost of the system including all the components and accessories is approximately 4.0 lakh.

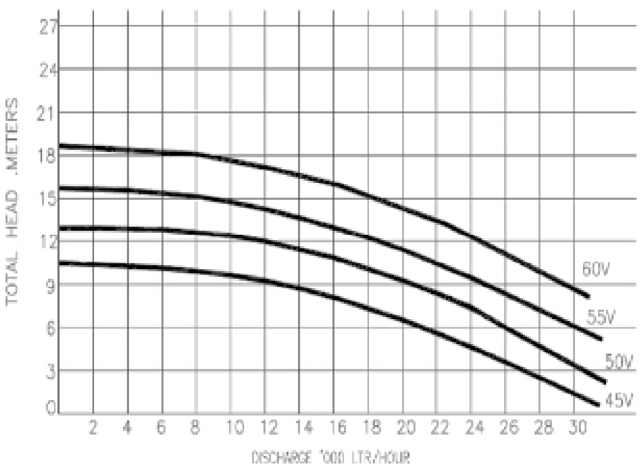

Fig 5: Performance curve of 2HP centrifugal pump

CONCLUSIONS

The proposed solar system model was found appropriate for small to medium farm irrigation and should be promoted among them as it offers well-controlled flood irrigation as well as the use of pressurized irrigation technologies. Since different crops have different water requirement, therefore, quantified water and its availability will help the farmers to plan uninterrupted crop rotation or continuous cropping systems with high value-added cash crops such as fruit, vegetables, herbs and spices etc. The initial investment on such solar system is high; therefore, the governmental agencies should promote this model among the small farmers under discount schemes till the technology is cheaper enough to encompass common farmers without any external financial helps. Once the farmers will tap its potential with high valued crops, system's payback time will be reduced and adoption rate of solar photovoltaic technologies will increase automatically.

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