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A Low Cost Multiple Motor Switched PV Powered Irrigation System

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***Abstract*— Conventional solar photo voltaic (PV) systems for pumping are designed with panel over-capacity of 30 to 40 percent so that pumping can be continued during low insolation. This adds much to the cost of such a system. In this paper a new concept for optimum utilization of photovoltaic output for irrigation is presented. The designed system eliminates over-capacity requirement of PV modules by using a combination of pumps where load become variable with the change of PV power output. The developed system can continue pumping even during low solar insolation. Directly fed DC motors used to drive the pumps avoid design complexity and eliminate battery and its maintenance cost. The designed system is superior to existing systems, increasing the water output for the same installed PV module capacity. A practical irrigation system based on the concept is implemented in the field. Field testing shows that the system improves the total output of water over conventional PV powered irrigation system by maximum utilization of available photovoltaic output and maximum utilization of the duration for which solar power is available.**

Keywords*— Solar pumping, multiple pump controllers, rule based algorithm, intelligent switching.

I. INTRODUCTION

Photovoltaic (PV) powered pumping systems are being used at different parts of the world since the 1970s [1]. They are highly reliable systems that inherently require low maintenance. But high investment cost and low energy conversion efficiency makes the cost for irrigating per acre of land still very high [2]. Therefore, there is a large scope and need for research in the area of lowering the investment cost and improving the system design of PV pumping. Agricultural land requiring irrigation in Bangladesh is about 5.0 million hectors. Pumps run by electricity needs 700 to 800 MW of power and cover 30% of total irrigated land. Since Bangladesh faces severe electricity crisis, energy sources for irrigation pumping, such as fossil fuels, are subsidized by the government. Renewable energy presents a better alternative to fossil fuels with greener impact on environment.

The application of solar energy for irrigation is of much interest for researchers around the world. Use of solar energy for irrigation in Bangladesh is suggested in [3]. In [4] authors proposed a solar powered automatic irrigation system for Turkey. Solar powered drip irrigation scheme that enhances food security is presented in [5]. An optimal design of solar powered fuzzy control irrigation system is proposed in [6].

This paper presents a new solar PV irrigation system that ensures maximum utilization of available solar energy. Moreover, the system is designed so that it requires minimum maintenance so that it can be easily maintained by the farmers. A practical irrigation system based on the concept is implemented in the field. Field testing shows that the system improves the total output of water over conventional PV powered irrigation system. It is achieved by maximum utilization of available photovoltaic output and maximum utilization of the duration for which solar power is available.

II. CONVENTIONAL SOLAR IRRIGATION SYSTEM

Solar PV modules produce direct current (DC) power. But alternating current (AC) motor-pumps are generally used for pumping purposes, therefore, an inverter is needed to convert power of solar panel from DC to AC. PV power output is non-linear and time-dependent that changes with change in solar irradiance throughout a day, as well as solar cell temperature [2]. The pump runs only when the available photovoltaic power is sufficient to drive the motor and compensate for inverter losses. If, for a low light condition, the PV power output falls short of the power requirement by the motor, the motor stalls. Since the optimal performance of a pump driven by a motor depends on the PV panel configuration [7], a 30 to 40 percent overcapacity of solar panels is generally maintained so that pumping can be continued during low insolation, even though it is by far the most expensive component in a PV pumping system.

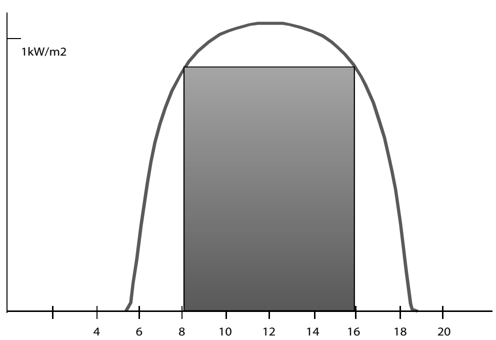
In such a system design, the excess solar power available at times can only be utilized by storing the energy in a battery and using the stored energy when there is lack of available solar power. Addition of batteries increase investment cost and adds to maintenance cost.

III. PROPOSED SYSTEM

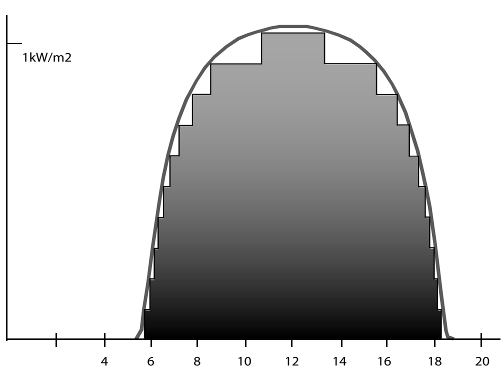
A. The Proposed System

Performance of a solar PV system is affected by availability of solar radiation. The available solar radiation is a function time of the day and the site selected. Optimal performance of a solar PV system depends upon how well these two factors are considered while designing the system. The hourly variation of irradiance at a site is represented by a bell shaped curve as shown in Fig. 1(a).

In conventional solar irrigation system the pumps are selected according to the near-to-maximum sunshine availability. Therefore, under low sun shine condition, the pumps stand as over rated, hence, can not be operated. On the other hand, during high sun shine the extra solar power is unutilized. The proposed system overcome the problem by using multiple pumps with different capacities and by switching the pumps intelligently. A simple rule based switching algorithm is developed for the purpose. Based on the availability of sunshine the pump controller decides which set of pumps to operate. The availability of sunshine is measured indirectly by measuring the terminal voltage of the PV modules. The control algorithm requires that the combined pump-motor characteristics be known beforehand.



(a)



(b)

Fig. 1 Solar energyy utilization of conventional and proposed pumping system (a) conventional, (b) proposed

The concept may be clarified more through an example. Considering a setup consisting of four pumps having rating of 1, 2, 4 and 8 hp. Depending on availability of solar power, e.g. in the early morning, only one pump with 1 hp motor may be operated. On the other hand at mid day when full sunshine may be available all four pumps having a total of 15 hp can be operated. In the intermediate conditions, the number of pumps of varying capacity may be operated depending on the solar power available at a particular time so that the photovoltaic output of solar panel is utilized to the maximum. This results in the maximum possible water being pumped. But with the conventional system, the pump can be operated only a portion of the day and if one wants to increase the duration of use, one has to increase the panel size. The solar energy utilization capability of the conventional and the proposed pumping system is shown qualitatively in Fig. 1.

For the proposed system, gain in pumped water output in a single day for the same amount of available solar power is estimated to be about 37.85%. For a cloudy day, the gain in pumped water output is expected to be much higher.

In the proposed system almost all available solar power is utilized to pump the water. Consequently, the same amount of water pumped by the conventional system can be pumped by a smaller sized proposed system. The savings in solar panel is estimated to be about 50%. Since the increase in cost due to multiple pumps and pump controller in the proposed system will not be appreciable, overall cost savings will be very attractive.

B. System Setup

The system setup of the proposed system is presented in Fig. 2. The proposed system depends for its performance on intelligent switching of multiple pumps. DC motors are used instead of ac motors as used in conventional solar irrigation system. Use of dc motors avoids system complexity by eliminating batteries and inverters. The motors are fed directly from the PV modules. The higher cost of dc motors over ac motors are more than compensated by the elimination of batteries and inverters. A microcontroller based switching circuit is used to switch the pumps on or off. With series parallel combination of solar panels, solar power at desired voltage and current is fed into the terminal of a MOSFET based switching device that switches on or off the motors.

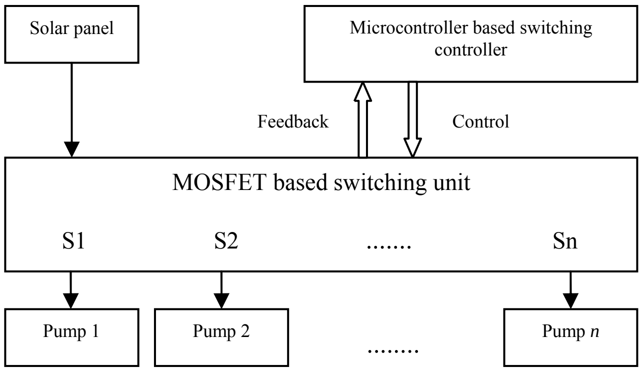


Fig. 2 System level design of the test solar pumping system

The dc motors are rated at 60V, 22A and 3600 rpm. For nonavailability of suitable motors of different rating in the local market, we had to use motors having same rating. The switches are controlled by the switching controller with a feedback system that operates based on a simple rule based algorithm. The switching controller samples voltage from the terminal and depending on the voltage level turns number of pumps on or off. An Atmega128 microcontrooler is used as the switching controller. It has 128Kbytes of in-system flash program memory, 4Kbytes EEPROM, 8-channel 10-bit ADC and 53 programmable I/O lines. The motor switching circuit is shown in Fig. 3.

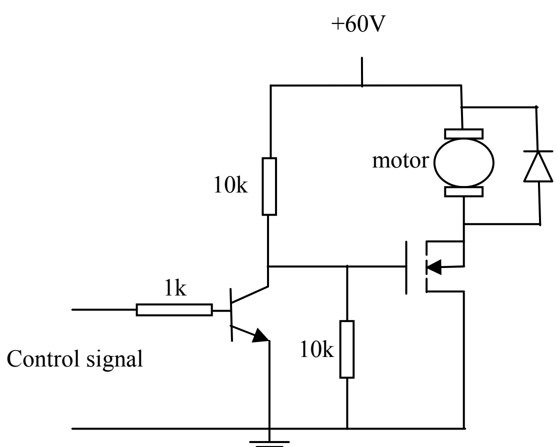


Fig. 3 The motor switching circuit

IV. FIELD TEST RESULTS AND ANALYSIS

A. Available Solar Energy at Site

The test site selected is in Keraniganj, very near to the capital Dhaka. Dhaka is situated at 23.71^0 latitude and 90.41^0 longitudes. Daily average solar insolation in Dhaka varies between 4 to 6 kWh per square meter, the average being 5.24. Maximum amount of radiation is available on the month of March-April. Solar radiation energy received on a given surface area in a given time is defined as insolation and generally expressed in kilowatt-hours per square meter per day. The monthly global insolation and daily average bright sunshine hour in and around Dhaka are presented in Tables I and II respectively [8].

Irradiance, the power incident on a surface of a site is given by the following relation.

$$Irradiance = \frac{Average\ Insolation}{Average\ daily\ bright\ sunshine\ hours}, W/m^2$$

The irradiance in Dhaka, which can be calculated using the above relation and using data from Tables I and II, is 694.04 watts per m^2.

Table I: Monthly Global Solar Insolation in Dhaka

Month	**Solar insolation kWh/m^2**	**Month**	**Solar insolation kWh/m^2**
January	5.47	July	4.18
February	5.91	August	4.60
March	6.00	September	4.94
April	5.85	October	5.44
May	5.23	November	5.34
June	4.55	December	5.38

Table II: Daily Average Bright Sunshine Hours in Dhaka

Month	**Daily mean, hr**	**Month**	**Daily mean, hr**
January	8.7	July	5.1
February	9.1	August	5.8
March	8.8	September	6.0
April	8.9	October	7.6
May	8.2	November	8.6
June	4.9	December	8.9

B. Test System at Site

The test system was set up on an agricultural field at the Purba Bamansur village in the Sakta union in Keraniganj thana in the Dhaka district. Pumps, the well and all control systems are housed in a room erected in the field. A special water delivery system is designed so that several pumps can be fed simultaneously from a single well. Each of the PV panels in the field is installed on a manually operated and easy to install three-axis movement stand. The panel stand is designed as a part of the project work. The three-axis movement helps to produce maximum power by rotating the panel to face the sun throughout the day. Flow meter is placed at the outlet of each pump. Figure 4 shows the housing in the field, PV panel installation and water discharge outlet.

(a)

(b)

(c)

Fig. 4 Test system in the field, (a) housing and PV panels, (b) PV panel installation, (c) discharge from the pumps (note that one of the pump is not discharging water meaning a less than optimum sun light)

C. Test Results

The test system consists of 2 kW of PV modules feeding directly three dc motors that drives the centrifugal pumps with a discharge diameter of 1.5, 2 and 3 inches respectively. A six inch diameter well was dug up to feed the pumps. A maximum discharge rate of 8 litres/sec with a lift of 24 feet has been achieved. The highest discharge achieved in a sunny day was 180,000 litres of water. Table 3 compares performance of the newly designed system with conventional system during a typical day in the month of April.

Table III. Comparison of Performance of the Test System with Conventional System

System type	**Discharge, liter per day**	
	Sunny day	**Cloudy day**
Test system	155,000	90,000
Conventional system	110,000	30,000
% increase	40.91	200

V. CONCLUSIONS

A new solar PV irrigation system is designed and implemented in the field. The design utilizes the principle of switching pumps from a combination of multiple units according to the availability of solar power. This maximizes the utilization of available solar power and reduces the solar panel size resulting in lower investment cost. The system has no batteries, further reducing the investment cost as well as maintenance cost. Simplified system design ensures minimum maintenance so that it can be easily maintained by the farmers. Field testing shows that the system increases the total water discharge over conventional PV powered irrigation system by more than 40%. The proposed solar irrigation system will have a great impact in tackling the prevailing energy crisis of Bangladesh.

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