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Simulation and Experimental Performance Solar PV Water Pumping System using BI-Facial Concentrator

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Abstract*— In present scenario has water pumps in every household of a city that are driven by electric motors connected to the utility network. The use of photovoltaic as the power source for pumping water is considered as one of the most promising area of PV application but initial cost of the system was high. In this paper, viable alternative to reduce the final cost of the pumped water volume is proposed by using low concentration cavities. Bi-facial concentrators are particularly appropriate for photovoltaic applications since, for certain combinations of the concentration ratio (C) and vertex vertex angle (ψ), they provide uniform illumination on the region where the modules are located. A model of solar PV water pumping system designed for water requirement of 1500 liters/day and maximum head of 5m. This pumping system model was simulated using PVSYST software and ray tracing model of concentrator was simulated using TracePro software. Results shows that, for the climate of the city of Chennai (India), 60 % improvement in annual pumped water volume and 28% of cost reduction for concentrator system when compared to fixed SPVWP system.

***Index Terms*— Bifacial Concentrator, PVSYST, Concentrating Mirror**

I. INTRODUCTION

Solar Photovoltaic cells are capable of directly converting sunlight into electricity. Current is produced based on types of silicon used for the layers. Photovoltaic systems are eco-friendly, easy maintenance and simple. Large scale power plants, water pumping, solar home systems, satellites, Space vehicles and reverse osmosis plant are some major applications of photovoltaic. Solar photovoltaic water pumping (SPVWP) system had a many advantages over their diesel and petrol powered water pumps. For the user, the maintenance and payback period of the system is significantly lower, also it have significant environmental advantages like they are no pollutants, they are silent, does not require any fuel. At the same time SPVWP system is not popular because it includes the high initial cost, lack of awareness and lack of sufficient experts. The water volume pumped by photovoltaic pumping systems depends on solar irradiance. Large critical irradiance levels reduce the daily operational time and Consequently the water volume pumped along the day.

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Photovoltaic generators coupled to Bi-facial concentrator have been proposed in the past with the purpose of improving the cost benefit relation of the electrical energy produced by those systems. Photovoltaic pumping systems, coupled to low concentration cavities, may constitute another application of interest of those devices. Since they combine tracking and concentration, large benefits can be obtained in terms of pumped water volume, reducing, consequently, the water cost. Among the large family of concentrators available, Bi- facial concentrator are particularly adequate for photovoltaic applications since, for certain combinations of the concentration ratio (C) and vertex angle (ψ) , the illumination they provide is perfectly uniform in the region where the modules are located (absorber region). This study aims to compare the long-term behavior of a pumping system driven by the same arrangement of PV modules, but working with two different physical configurations: fixed, and concentration. The work proceeds according to the following steps. The water Pumping system model designed and simulated using PVSYST software and results compared with theoretical predictions. Then, the fixed SPVWP system analyzed experimentally. Concentrator model is developed using TracePro software and theoretical calculation. The long-term water volume pumped by the three configurations is determined with the utilizability method, using the characteristic curve to represent the system behavior. Finally a technical and cost analysis is performed, comparing the two operational modes.

II. SOLAR PV WATER PUMPING SYSTEM

Solar PV water system developed for the water requirement of 1500 liters/day with the maximum head of 5m. The system model simulated using PVSYST software.

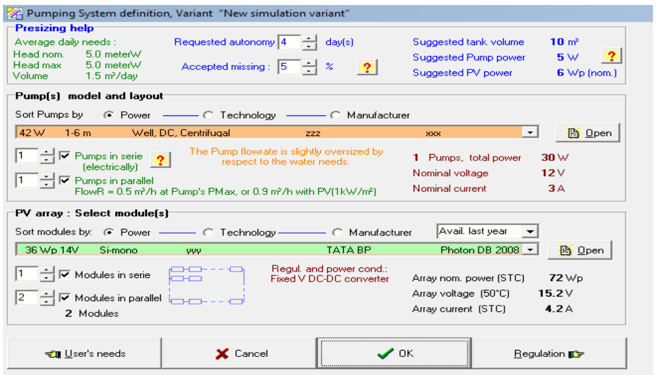

Fig. 1. PVSYST-Pumping System Definition

The results of simulation are compared with theoretical calculation. The following steps are involved in theoretical calculation.

Step 1: Determine the amount of water required per day in m3.

Step 2: Determine the Total Dynamic Head (TDH) for water pumping in meter.

Step 3: Determine the hydraulic energy required per day in Whr/day Hydraulic energy

(E) = ρ*Q* G* H

Step 4: Determine the solar radiation available at given location in terms of equivalent of peak sunshine radiation (1000 W/m2) hours for which solar PV module is characterized. Topically this number is 5 to 8 varying season to season and location to location.

Step 5: Determine the size of solar PV array and motor, consider motor efficiency and other losses.

Consider system losses and efficiency of pump total wattage required from PV panel (N) was determined.

$$N = \frac{Preq}{Wp\ of\ Panel}$$

III. OPTICAL BEHAVIOR OF BI- FACIAL CONCENTRATOR

An optimization procedure to determine the cavity parameters is described by Fraidenraich (1998). Design criteria, satisfied by the concentrator cavities are: (a) light distribution on module's surface is uniform; (b) heat at the absorber region is dissipated by passive means; and (c) small deviations of tracker-sun alignment are allowed, still satisfying uniformity of illumination at the absorber. The concentration ratio (C) and vertex angle (ψ) that minimize the cost of energy are chosen as the best option in terms of cavity design. For the local climate the geometric parameters of the cavity, optimized with that procedure, C = 1.6, ψ = 200. The focal length of bi facial concentrator calculated by following formula,

$$F = \frac{D * D}{16 * d}$$

The concentrator model simulated using TracePro software. Ray tracing model of concentrator system is shown in fig 2.

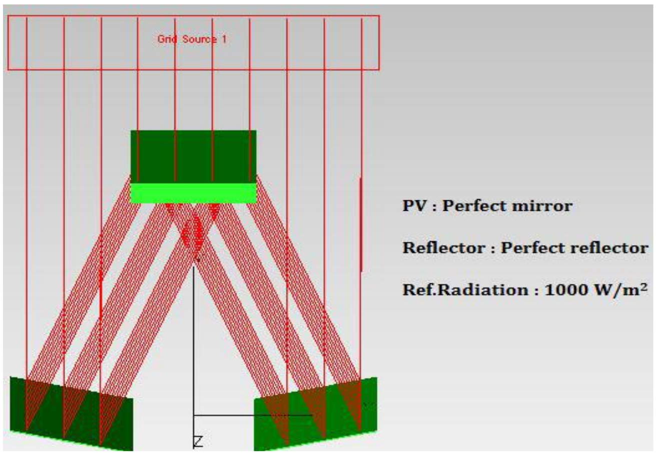

Fig. 2. Ray Tracing Model of System

A. EFFECTIVE CONCENTRATION

The relationship between irradiance at the cavity absorber (Ia) and aperture (IA) can be used as a measure of the effective concentration of the Bi facial concentrator (Ceff = Ia / IA). It can be calculated as a sum of the contributions of the direct (IbA) and diffuse (IdA) components of irradiance at the aperture, expressed as a fraction of (IA). Since (IbA) can be written as (IA- IdA), the effective concentration can be expressed in terms of the fraction of diffuse irradiation collected at the aperture plane (IdA=IA). A theoretical estimation of the relationship between (Ia=IA) and (IdA=IA) can be obtained by a detailed consideration of the optical properties of Bi facial concentrator cavities. We call P0 (0) the fraction of light rays that reaches the cavity aperture at normal incidence and propagates along the cavity reaching the absorber without reflections. Similarly, the fraction of light rays reaching the cavity aperture at normal incidence and the absorber, after making one reflection, is called P1(0) (Fraidenraich,1992). Given the beam radiation at the aperture (IbA), the light flux reaching the absorber (Iba) can be estimated as

Aa * Iba = AA * IbA [P0 (0) + P1(0)ρ]

or

Iba = C * IbA * ηÞ

where (Aa) and (Iba) are absorber area and instantaneous beam radiation at absorber region, (AA) and (IbA) are aperture area and instantaneous beam radiation at the cavity aperture, (q) is the mirror reflectivity and (ηb) is the beam optical efficiency, defined as

ηb = P0(0) * P1(0)ρ

The diffuse radiation reaching the absorber can be written as

Ida = C * EAa * IdA

where EAa denotes the fraction of diffuse radiation transferred from aperture to absorber (radiative exchange factor). The radiation at the absorber (Ia), due to beam and diffuse irradiance at the aperture is, then, equal to

Ia = C [IbA ηb + EAa IdA]

Substituting (IbA) for (IA - IdA),

Ia / IA = C ηb [1- (IdA / IA) [(ηb - EAa) / ηb]]

where the relationship (Ia=IA) is the effective concentration (Ceff). For the cavity tested in this work, P0(0) and P1(0) are equal to (1=C) or 0.455. Thus, the beam optical efficiency (ηb) is equal to 0.82. The interchange factor between aperture and absorber (EAa), considering reflection losses in the mirror walls, is equal to 0.43 (Fraidenraich, 1995). Introducing numerical values, we obtain

(Ia / IA) = 1.80 – 0.86 (IdA / IA).

IV. EXPERIMENTAL FACILITY

The Bi facial concentrator system, with two cavities and two PV modules, is able to track the sun path around single axis by manual tracking system. The reflective surface of the cavities are built with flat commercial mirrors, 3 mm thick and 0.96 m long, supported by a plastic sheet for environmental protection combined with an steel structure for mechanical rigidity. Dimensions of each cavity, module and PV generator characteristics follow: A schematic diagram of the Bi- facial concentrator is shown in Fig. 2. The photovoltaic generator, made up of two 35 Wp series connected modules (C-Si) (total peak power equal to 75 Wp) supplies electric energy to a submerse (50 W) motor-pump set. The motor-pump is installed in an ideal well (cistern like). The pumping head is selected by means of manual valves.

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The water circulates in a closed loop keeping the Pumping head practically unchanged, except for minor pressure losses during tests.

Table 1:

Bi- facaial Concentrator	PV modules	PV Generator
Concentration Ratio 1.6	Nominal Power : 35Wp	No of cavities =2
Vertex Angle 20º	Width . 0.44m	No Of Modules =2
Cavity Width : 0.44	Length =0.96	Width of the whole structure : 1.05m
Length =0.96	Voc= 17.2 V Isc=2,1A	Width of the whole Structure : 1.05 m
App area =0.65 m	Vmpp= 15.2 Impp= 1.75	Total area =1.2m^2

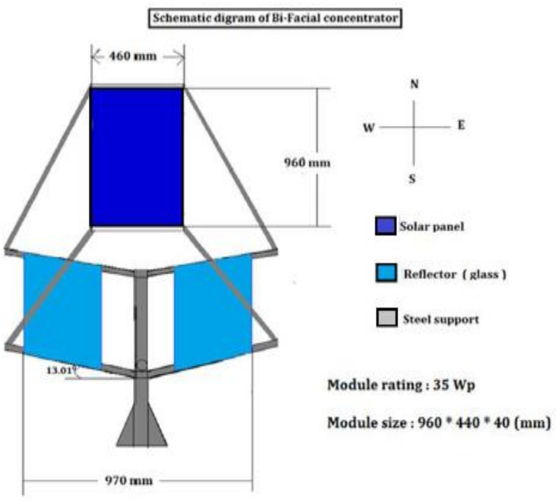

Fig 3. Bi-facial concentrator system

V. RESULT AND DISCUSSIONS

A. OPTICAL PERFORMANCE OF THE BI FACIAL CONCENTRATOR SYSTEM

Theoretical values (Eq. (10)) and results of experiment for the effective concentration of the cavities (Ceff = Ia/ IA) are represented in Fig. 3 against the fraction of diffuse irradiation collected at the aperture plane (IdA=IA). The effective concentration varies between 1.60, for a relationship [IdA / IA] = 0.15 and 1.13, for [IdA / IA] =0.80. Results obtained with Equation lie well within the set of measured values, with a slope slightly higher than the experimental trend.

B. TESTS OF BI FACIAL CONCENTRATOR SYSTEM

B.1 V-I CHARACTERISTICS OF MODULE

The test location is a dry city placed in Asia continent with Latitude 13.05 and longitude 80.27. Variation of current with respect to PV module voltage is shown in figure 4. The open circuit voltage test and short circuit current test was conducted for different solar radiation. PV module voltage is decreased if panel temperature increased but PV module current is increased.

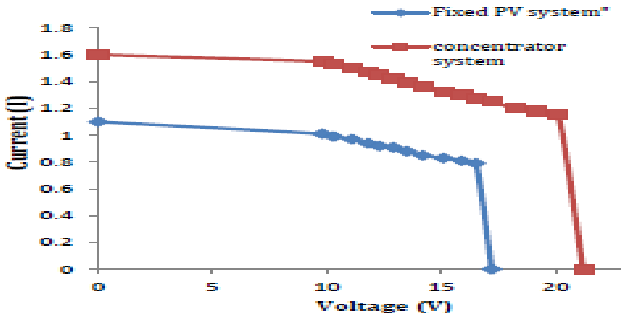

Fig 4. VI characteristics of PV Generator

B.2 MODULE TEMPERATURE VARIATION

Solar module temperature is one of the major factors of an electrical power generation of a crystalline solar cell module. The photovoltaic cell efficiency decreases with increasing temperature and also the cells will degradation if the temperature exceeds a certain limit. If the solar radiation increases, temperature of the PV module is increase. Temperature of PV module is higher in concentrator system as compared to fixed system. Fig 5 shows the PV module temperature variation with solar radiation.

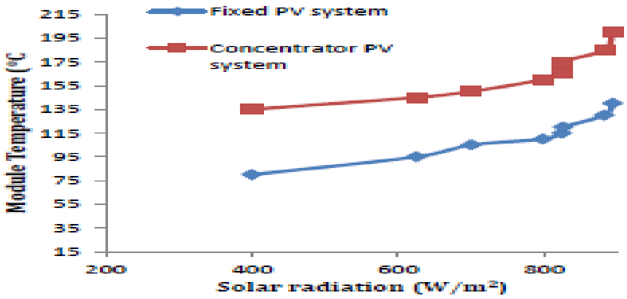

Fig. 5.2.1 Variation of Module Temperature

C. TESTS OF WATER PUMPING SYSTEM

C.1 WATER FLOW RATE CURVE AGAINST PUMP INPUT POWER

The characteristic curve of the PV V-trough system has been obtained using measurements of water flow rate and input power of pump (Pp) is shown in fig 6. Pump is directly connected to the PV generator. Pump input power is calculated by

Pp = VM * IM

Tests are made in different solar radiation data and different climate conditions

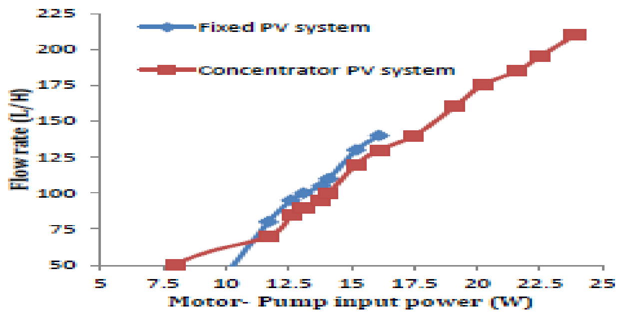

Fig. 5.2.2 Daily Characteristic Curve of the Two PV Generator Configurations

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The pumped water flow rate, for the Bi-facial concentrator system, against collected irradiation is represented in Fig. 6. Estimated values for the fixed and concentrator system as a function of collected irradiation in their respective aperture surfaces are also shown.

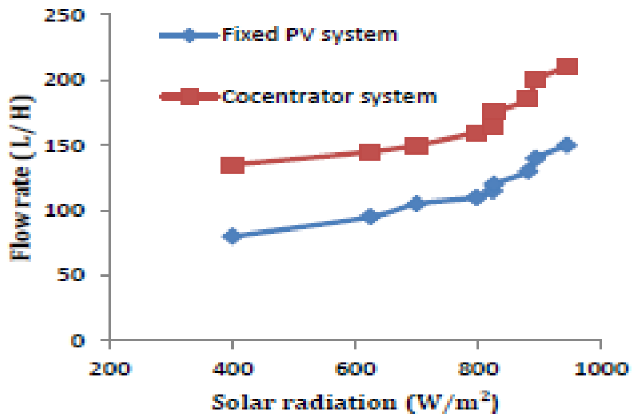

Fig. 6. Water Flow Rate Curve against Solar Radiation

As it can be verified, the linear relationship shown in Fig. 7, expressed as daily water pumped for the system.

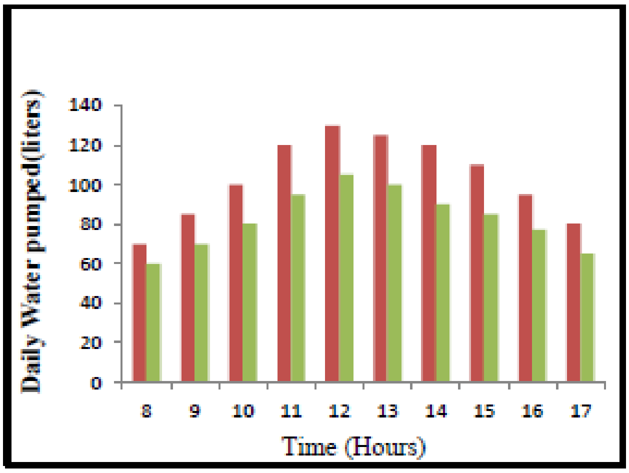

Fig. 7. Daily Water Pumped Curve

VI. COST COMPARISON

To compare the performance of the configurations studied in this work, we estimate the cost of a cubic meter of pumped water by means of the annualized cost of the system. The investment costs for the system The installation of the system has been estimated as 20% of the cost of the PV array. It has also been included a storage tank of Rs. 500. The capital recovery factor for the investment has been calculated for a discount rate of 0.06. It is assumed a useful life of 20 years for the whole system. For the Motor-pump set and mirrors. The maintenance and labor cost have been taken as 5% of the overall cost of the system. Table 2 shows, for each system, the annualized cost of a cubic meter of water components are:
Modules: Rs. 50 / Wp;
Mirrors: 400 /piece
Motor-pump: Rs. 1,500
Mounting: Rs. 1,000
pumped along one year. The cost of a cubic meter of water pumped by a concentrator system becomes then 35% lower than the one pumped by the fixed system.

VII. FINAL COMMENTS

It was determined the relationship between pumped water volume and collected irradiation for a pumping system driven by a photovoltaic generator coupled to Bi facial concentrator cavities. The procedure adopted, measuring irradiance at various planes, fixed, at the aperture and at the base of the Bi facial concentrator, enables to determine and compare the performance of the various configurations. The long-term annual benefit ratio, for collected irradiation and water pumped were estimated for the city of Chennai, India. The cost analysis shows that the concentrating system reduce of 28%, when compared to the fixed configuration. For a given PV array, the use of concentrating collectors appears as an interesting possibility to increase the volume of pumped water or to reduce its cost per cubic meter.

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