TECHNICAL EVALUATION OF A LOW-COST, LOW-POWER PHOTOVOLTAIC WATER PUMPING SYSTEM AND COMPARISON ASSESSMENT WITH A TYPICAL MARKETED PV PUMP

C Protogeropoulos and N Tselikis
CRES, Centre for Renewable Energy Sources
19th km Marathonos Av., 190 09 Pikermi, Athens, Greece
Tel: +30 1 6039900, FAX: +30 1 6039905, e-mail: cprotog@cres.gr

ABSTRACT: A new generation solar operated low-power and low capital cost submersible piston pump designed for high head applications is under evaluation in this paper. The comparison assessment with a typical marketed PV dedicated centrifugal pump took into consideration technical and economical factors. With the last generation pumping systems, the PV array has been minimised and adequate water is delivered for general agricultural activities at an affordable price.
Keywords: PV Pumping - 1: Water Pumping - 2: Evaluation - 3

1. INTRODUCTION

This paper reports on the experimental results obtained from testing a new generation Fluxinos Solaflux 200 piston pump and a Grundfos SP8A-5 centrifugal pump. Solar pump simulated field tests were done according to agreed procedures for instantaneous testing, [1]. The flow vs head and efficiency vs head characteristics were measured as function of the input power. The piston pump was also characterised without the controller and a comparison against the centrifugal pump was done in terms of hydraulic efficiency. Economical parameters were also taken into account and the cost of the hydraulic energy yield was estimated for both pumps.

2. THE PUMPING TEST RIG AT CRES

The solar water pumping facility was designed for evaluating the instantaneous flow rate versus equivalent head characteristics of submersible PV water pumping systems. A layout of the piping test rig is shown in Fig. 1.

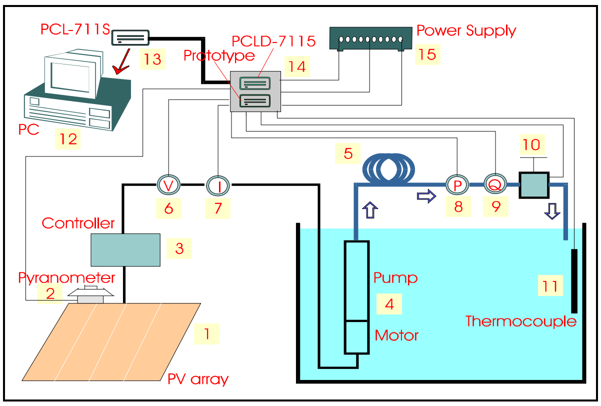

Fig. 1. Layout of the PV pumping experimental facility

In Fig. 1 numbering 6, 7, 8 and 9 refers to voltage, current, pressure and flow measurements respectively; 10 is the control valve and 12 to 15 is the PC based measuring and control system.

3. FLUXINOS SOLAFLUX 200 PV PUMP

One of the new generation low-power PV pumps is the submersible Fluxinos Solaflux 200 coaxial piston positive displacement pump, powered by a DC brushed permanent magnet motor. This pump is designed for deep well, low water demand applications. The nominal PV power is 200W and 4 modules of 55Wp each were used to power the Fluxinos motor. Any input voltage in the range 24V to 80V is suitable for pump operation and a Sunprimer DC/DC converter and controller is recommended in order to regulate the relatively high 1.5A start-up current.

The Fluxinos Solaflux pumps incorporate two pistons activated by means of cams and bearings. The test results reported herein refer to a 3.0mm standard cam size. A Turboflux inertia amplifier was used for pressure and flow stability in the system. In the experiments undertaken, a 10m length flexible hose was placed downstream the pump outlet in order to obtain realistic operating conditions (No 5 in Fig. 1).

3.1 Method of testing

The Fluxinos pumping system was evaluated at CRES under simulated field conditions. Instantaneous testing to characterise the system behaviour was undertaken. The measuring parameters were:

- water flow and pressure
- current and voltage (after the Sunprimer controller)
- solar insolation in the plane of the array

The analysed experimental data refer to:

- water flow, (Lt/s) and equivalent head, (m)
- DC motor power, (W) and voltage, (V)
- hydraulic efficiency, total system efficiency and PV efficiency (controller included), all in (%)

The pump was evaluated with the Sunprimer controller and with direct DC motor connection to the PV array.

3.2 Fluxinos performance with a Sunprimer controller

With this configuration, 4 PV modules were connected to the controller in two pairs, each pair in series. The experimental results of a Fluxinos piston pump equipped with a 3.0mm cam are presented in Fig. 2 and Fig. 3.

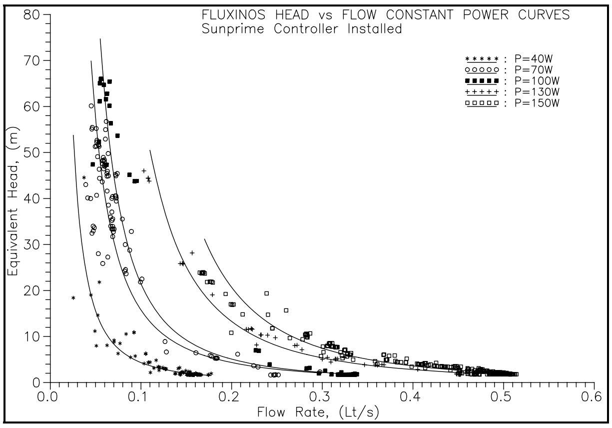

Fig. 2. Fluxinos head vs flow rate iso-power characteristics

The characteristics in Fig. 2 show that the Fluxinos pump delivers water from 70m head even with power supply as low as 70W. At half the nominal power, the pump delivers approximately 0.06Lt/s water. Assuming 6h operation during a typical summer day at 100W average input power, a total of 1.3m^3 water will be delivered.

The best fit of the experimental data was obtained by a power curve, which is in agreement to the mathematical model proposed by [2],

$$H = a\,(Q/b)^C \qquad (1)$$

In eqn. (1), H = head [m], Q = flow rate [Lt/s] and a, b and c model parameters.

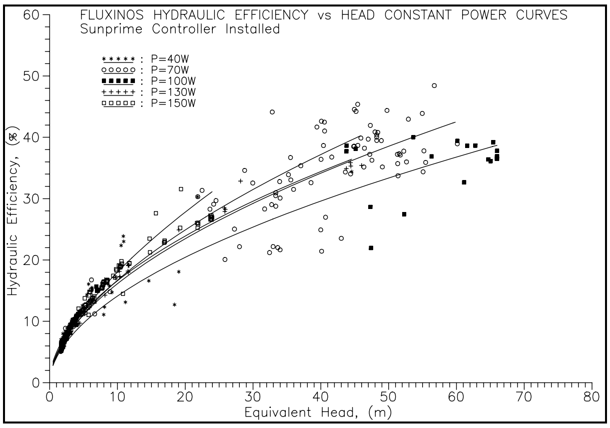

Fig. 3. Hydraulic eff. vs head iso-power characteristics

The hydraulic efficiency of the Fluxinos pump reached 45% as it is seen in Fig. 3. This value was obtained for pump operation at 60m head, indicating that this piston pump is designed to operate optimally at deep well applications. The trend of the hydraulic efficiency curves in Figure 3 indicates that efficiency would improve at higher heads. This is in agreement with the Fluxinos manufacturer suggestions, [3]. The total conversion efficiency was calculated 3.5%.

3.3 Characterisation of the Sunprimer controller

The Fluxinos pump was also characterised with direct coupling to the PV array, as suggested by [3], in order to evaluate the instantaneous efficiency of the dedicated Sunprimer controller. With this configuration, four in series PV modules were connected to the DC motor. The comparison experimental data are presented in Fig. 4.

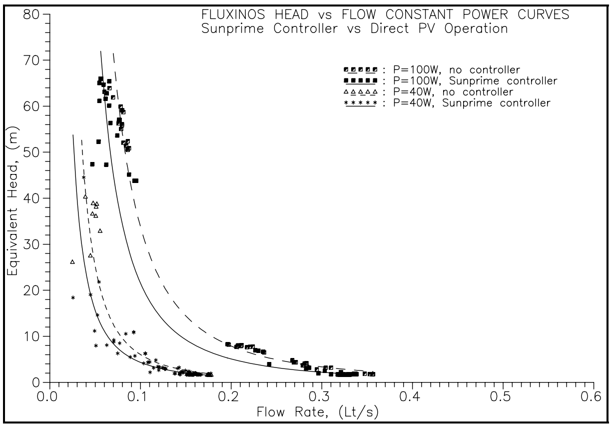

Fig. 4. Fluxinos operation with the Sunprimer controller and with direct PV coupling

The instantaneous Fluxinos performance without the dedicated controller has improved characteristics at given power levels as it is seen in Fig. 4. At constant head, the pump delivers more water in both 100W and 40W power levels. At 60m head, the hydraulic efficiency with direct coupling was measured 7% higher compared to the controller operation. In a real application, however, the Sunprimer controller guarantees start-up conditioning after an unexpected interruption or in early morning hours.

3.4 Fluxinos DC motor voltage variation

The analysis of the experimental data showed that the DC motor voltage of the Fluxinos pump varies during operation with respect to head. This is presented in Fig. 5.

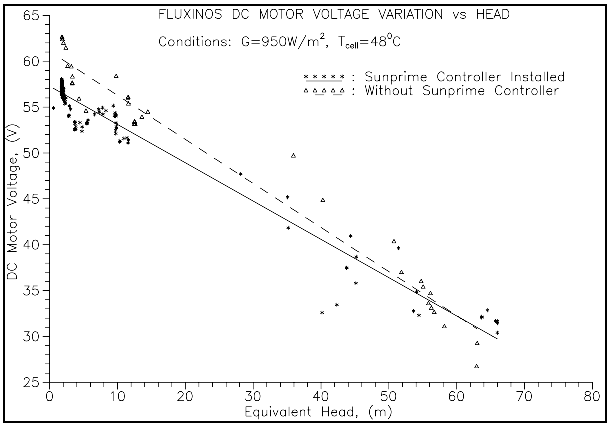

Fig. 5. Fluxinos DC motor voltage variation

The measurements in Fig. 5 show that only at equivalent heads between 2m and 10m the motor voltage corresponds to an optimal array voltage for series module connection, i.e. 60V for 4 panels. At water heads higher than 65m, the DC motor voltage (and consequently the PV array voltage), is as low as 32V. This corresponds to 8V per PV module and implies low photovoltaic efficiency. For example, at 65m equivalent head and 950W/m^2 irradiance, the solar array efficiency was calculated around 6%.

Further information provided by the manufacturer of the piston pump, [3], refer to the 24V mode operation of the Sunprimer controller at low power situations. This results in halving motor speed, thus reducing hydraulic efficiency. The present, controller based, "limitation" will be overcome soon with the Mk II series of the Sunprimer dedicated controller. This electronic unit will be designed to adapt automatically to any number of PV panels.

4. GRUNDFOS SP8A-5 CENTRIFUGAL PV PUMP

The Grundfos solar pumping system is a typical marketed product designed for water supply and irrigation in remote areas. The pump is a multistage centrifugal pump with radial impellers and incorporates an asynchronous motor. The SP8A-5 model is designed to operate between 2m and 28m head.

The 3-phase DC/AC Grundfos SA inverter is rated 1.5kW. The DC input can be connected either to a photovoltaic array or to a battery bank. For maximum water supply, the nominal PV power is 1500W.

4.1 Grundfos testing conditions and results

Three PV strings of 350Wp each were initially connected in parallel to power the Grundfos motor. Due to a malfunction at the DC side of the dedicated inverter, one string was disconnected and therefore, the experimental results presented herein refer to only 0.7kWp PV power. The testing procedure is similar to the method described previously. The results are presented in Fig. 6 and 7.

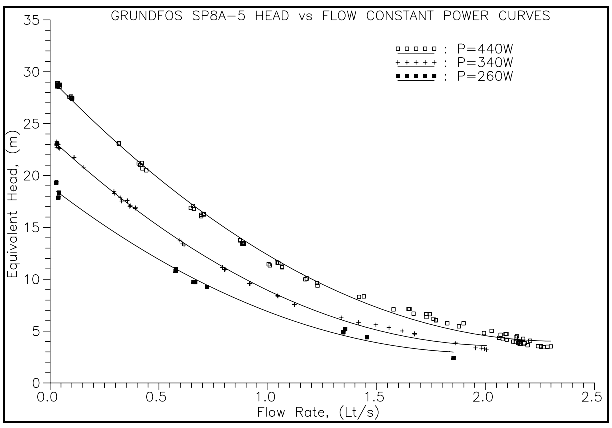

Fig. 6. Grundfos equivalent head vs flow rate iso-power characteristics

The head vs water flow rate characteristics of the Grundfos SP8A-5 pump refer to 440W, 340W and 260W DC power levels, Fig. 6. The pump delivered water from 27m head, obtaining 0.1Lt/s instantaneous water flow. At 20m head the flow was 0.5Lt/s at 440W input power, i.e. 3m^3 water supply assuming 6h daily operation in the summer period.

With the Grundfos pump, best fit of the experimental data was obtained by using a 2nd-degree polynomial curve for all iso-power characteristics.

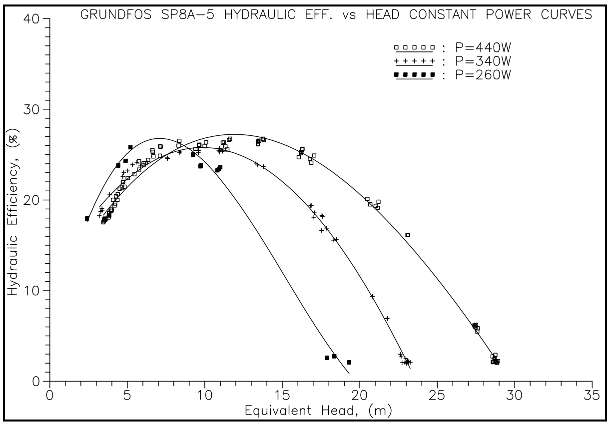

Fig. 7. Hydraulic eff. vs head iso-power characteristics

The hydraulic efficiency of the SP8A-5 pump reached 28%, for all power levels as it is seen in Fig. 7. This value was obtained for three distinctive equivalent heads which correspond to a particular input power level. Thus, for a given well depth, the PV power source should be optimised to obtain maximum hydraulic efficiency. The total system efficiency was measured less than 2.5%.

5. COMPARISON BETWEEN THE FLUXINOS AND THE GRUNDFOS PUMP

5.1 Technical appraisal

Typical hydraulic efficiency curves for both pumps are presented in Fig. 8.

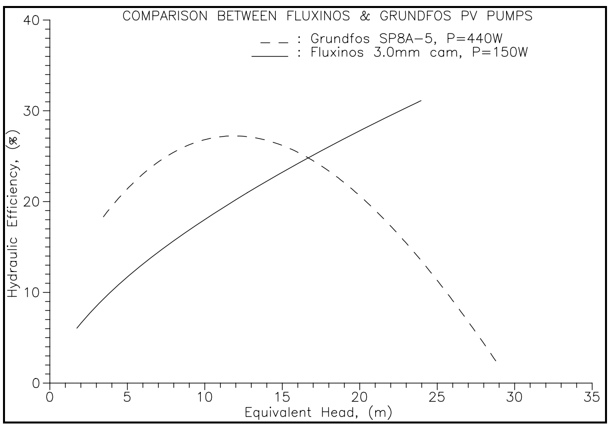

Fig. 8. Typical hydraulic efficiency curves of the piston and the centrifugal pump

As it is seen in Fig. 8, the efficiency of the piston pump increased almost proportionally with water head, reaching 33% at less than half the nominal operating head. This value is expected to increase at 150m equivalent head which is the nominal operational depth of the Fluxinos pump. The Grundfos centrifugal pump obtained a maximum hydraulic efficiency at a particular head, which is function of the DC input power. Compared to the piston pump, its maximum hydraulic efficiency was approximately 5% lower and was measured 28%.

In theory, a piston pump would be more efficient compared to a centrifugal of the same size. Although the Fluxinos piston pump is only one third of the size of the Grundfos centrifugal pump, the calculations indicate that the small new generation pumps are efficient units which are now produced industrially to international standards.

5.2 Economical factors and analysis

The capital investment of both pumping systems is presented in Table 1.

Table 1. PV pumping system economics

Cost, [ECU]	Fluxinos Solaflux 200 Piston Pump	Grundfos SP8A-5 1.5kW Centr. Pump
Pump & acc.	700	2900
PV Array	1400	10500
System	2100	13400

The PV array cost in Table 1 was calculated at 7ECU/Wp. The prices of each PV pumping system show clearly that the latest generation pumps offer an economically attractive solution to the end user. It is necessary, however, to mention that the Grundfos marketed PV pumping system is used for maximum water supply, while the Fluxinos system is designed for high head applications. The hydraulic energy yield over a reasonable operational period is a common criterion for the economical assessment of the two pumping systems.

The instantaneous hydraulic power is given by,

$$P_{hyd} = \rho g H Q \qquad (2)$$

In eqn.(2), ρ (water density) = 1000kg/m^3, g (gravity) = 9.81m/s^2 and, H (head) in [m], Q (water flow) in [m^3/s] and P_{hyd} (hydraulic power) in [kW].

The hydraulic energy is the product,

$$E_{hyd} = P_{hyd}\, t = \rho g H Q t \qquad (3)$$

A time period of 5 years and an annual average daily operation of 3h at nominal conditions for both pumps has been assumed. Thus, in eqn.(3), t = 5475h

The nominal operating conditions for the Fluxinos pump is H=150m and Q=0.3m^3/h, while the SP8A-5 Grundfos system delivers water from H=20m nominal with Q=10.0m^3/h. Substituting in eqn.(3), the calculated hydraulic energy yield over 5 years of operation for the Fluxinos and the Grundfos pump is 671.4kWh and 2983.9kWh respectively. Considering the costs of Table 1, the specific cost of the two pumping systems is,

Table 2. Water pumping long term cost

	Specific Cost, ECU/kWh, hydraulic
Fluxinos 200W Piston Pump	3.13
Grundfos 1.5kW System	4.49

6. CONCLUSIONS

The testing procedures and the experimental results of two different PV pumping systems were presented in this paper. The low input PV power Fluxinos piston pump operated satisfactorily during simulated field instantaneous testing and delivered water from 65m with a 3.0mm cam. Operation at higher heads was not undertaken due to the limitation of the piping material in high pressures. This piston pump exceeded 40% hydraulic efficiency and, although the exploitation of the PV power could be improved, the pump is already an economically feasible solution for little water demand, high head irrigation applications.

The SP8A-5 centrifugal Grundfos pump is designed to operate at heads up to 28m. The inverter of this pump was coupled to only 0.7kWp PV power and the system achieved 28% hydraulic efficiency. This centrifugal pump is characterised by its smooth operation and compared to the Fluxinos piston pump, the Grundfos is certainly designed for larger water demand applications. The economical assessment showed that, apart from the low capital cost, the latest generation low-power pumps have improved hydraulic energy cost compared to conventional solar pumping systems.

ACKNOWLEDGEMENTS

A subcontract to CRES was offered by IT Power, UK. We are grateful to Dr A Derrick, Mr R Barlow and Mr R Oldach for their assistance throughout the project and for donating a Fluxinos pump and a 220Wp PV array. Special thanks to Prof. J Burton and Mr T E Manning for their comments in installing and testing the Fluxinos pump.

REFERENCES

[1]. “Concerted Action for the Testing & Cost Reduction of PV Water Pumping Systems”, EU AVICENNE Programme 1995, Contract No. AVI-CT94-0004

[2]. Prof. J Burton, University of Reading,
Department of Engineering, Whiteknights,
PO Box 225, Reading, RG6, 6AY, UK
Personal communication in March 1996

[3]. T E Manning, Fluxinos Export office,
Schoener 50, 1771 ED Wieringerwerf, Holland
e-mail: manning@euronet.nl
Personal communication in October 1996
and in May 1997