

Experimental Investigation of Influences of Photovoltaic Cells Configurations on a Photovoltaic Water Pumping System Performance

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ABSTRACT: The possibility of improving the performance of a photovoltaic water pumping system by using different PV cells arrangements was investigated. This is performed choosing two PV cells arrangements namely two and three parallel PV cells. In both cases the Performances of the photovoltaic water pumping system are obtained. It is then compared with each other. Experimental results show that when low heads are required the two parallel cells have higher efficiencies than three parallel cells. However, in the latter case, in spite of lower efficiencies more water is pumped during the day. Furthermore, the results show that designing photovoltaic water pumping systems have two criteria, firstly attention to maximum power of each selected head of motor pump and secondly the costumer's requirements. Considering both factors help the designer to design photovoltaic water pumping systems more economical.

Keywords: Photovoltaic cell, Pump, Configuration, Performance

NOMENCLATURE

η_{PV}	PV cell efficiency (%)
η_{MPV}	Mean PV cell efficiency (%)
η_T	Operational total Efficiency (%)
η_{MT}	Mean Operational total Efficiency (%)
G	Global Insolation(W/m ²),
Q	Flow rate (m ³ /s)
Q_M	Mean flow rate (m ³ /s)
g	Gravity acceleration(m/s ²),
V_M	Maximum PV voltage(V)
η_{Sub}	OperationalSubsystem efficiency (%)
η_{MSub}	Mean OperationalSubsystem efficiency (%)
P_{PV}	PV array power(W)
P_{MPV}	Mean PV array power(W)
A	PV array area(m ²)

P_{hyd}	Hydraulic power(W)
I_M	Maximum PV cell current(A)
ρ	Density(kg/m ³)
h	Total head(m)

1. INTRODUCTION

Introduction Photovoltaic (PV) powered water pumping systems have been one of the most popular solar energy applications in the last two decades. The use of such a system is first appropriate since there is a natural relation-ship between the availability of solar energy and the water requirement. That is; the water requirement increases with increasing solar radiation level. PV systems have some distinct advantages in

electrical power production such as, being environmentally friendly, requiring no fuel cost, operating with no noise and wear due to absence of moving parts, and also requiring little maintenance. The major barriers of using PV systems, in general, are the high installation costs and low energy conversion efficiency of PV cells available in the market. Significant cost penalties therefore result from over sizing a PV system since the cost is mostly dependent on the PV array area. The cost of photovoltaic installations is mostly dependent on the PV array area. Therefore, in order to improve the cost effectiveness of PV array powered systems, electric power generated by the PV array should be efficiently utilized. Photovoltaic (PV) water pumping is one of the most typical PV applications in developing countries and has the potential to become a major criterion for social and economic development. Photovoltaic cells are the heart of photovoltaic water pumping system so that any changes in the cells power will affect the solar water pumping system performance. Keeping PVPS at high efficiency is the most important PVPS designer's goal. Many researchers have investigated and proposed different methods for designing and optimizing the PVPS to improve the system efficiency and reduce the installation costs.

Bhat et al. [1] concluded that there is an optimum voltage–frequency (v – f) relationship that improves motor efficiency at certain pumping head. He also found that variation of pumping head has unimportant effect on the optimum v – f relationship. He proved that under variable pumping head operation, the rated motor power should correspond to the minimum pumping head value. Zaki and Eskander [2] investigated frequency control scheme to accomplish maximum motor output power. They have proposed using a maximum power point tracking (MPPT) inverter with a constant voltage frequency control of the motor. Factors that have so far inhibited the widespread implementation of PV pumping

systems include (i) high initial capital cost, (ii) lack of awareness, (iii) lack of technical installation expertise, (iv) history of failures and (v) lack of sufficient knowledge to predict accurately system daily output [3]. A typical example of the last one is some systems have experienced problems, mainly due to poor sizing and lower than expected system output [4]. It was found that there are clear problems associated with design of PV pumping systems [5]. Benlarbi et al [6] stated that MPPT control arrangement does not always lead to maximum system efficiency. Proper sizing of system components is essential for maximum utilization of PV water pumping systems [7]. An increase in total system efficiency will reduce the PV array size and thus the capital system cost which is mainly dominated by the PV array cost [8]. Betka and Moussi [9] concluded that almost an optimum constant motor efficiency can be accomplished by varying the inverter frequency and the modulation index. Improving the cost effectiveness of PV water pumping systems requires effective utilization of PV energy and thus over sizing should be avoided [10]. Yao et al. [11] have indicated a maximum power point tracking (MPPT) inverter and a variable frequency controller to improve the slip and the efficiency of the motor under low insolation conditions. They concluded that a constant optimum value of motor efficiency can be assured by adjusting the proper inverter frequency. Arab et al. [12] applied a loss of load probability method (LOLP) to estimate the optimum PV array configuration; the LOLP was defined as the ratio between the number of hours of the water deficit and the number of hours of consumption. Recently the authors showed that spraying water over the photovoltaic cells increases the system and subsystem efficiencies efficiently, since efficiencies and electrical yield decrease with increased operating temperatures and reflection loss of PV cells [13].

The goal of this work is to investigate the effects of photovoltaic cells array

configuration on increasing the photovoltaic cell efficiency. Furthermore, it has been investigated that the performance of photovoltaic water pumping system is improved as a result of choosing appropriate configuration of the cells.

2.SYSTEM CONFIGURATION AND DATA COLLECTION

The experimental facilities consist of three PV cells (45×3 W) with 13.5% power efficiency and one positive displacement surface water pump with a permanent magnet DC motor. Fig. 1 shows test setup. The PV array is polycrystalline type with 36×2 cells and fixed at 10° facing south. The power produced from the array is transmitted to the DC motor of the pump. Lorentz surface pump (Model PS150 Boost, Positive displacement, 1000L/h flow rate maximum, 45m head maximum, controller with maximum power point tracker (MPPT)) is being used to pump water from the tank. To investigate the cells configuration two arrangements are chosen namely, two and three parallel PV cells. Fig. 2 shows parallel PV cells arrangement. The measurements were recorded during clear days at Mahan Renewable Energy (MRE) lab in Mahan (Kerman) in July 2006. Irradiance was measured by a BM 6 Kip & Zonen pyranometer at the same incident plane of the modules. The Pump flow rate was measured by an Eesiflo Easz-10FP flow meter. Insolation variation and ambient temperature during the test day are shown in Fig. 3. Ambient temperature was measured in the shade. Temperature sensors (PT100) were installed on the back of the two modules where the actual temperatures are about 1.5°C below the temperatures on the front of modules. Fig.4 shows panel temperature during the test day. Data were recorded every 15min.

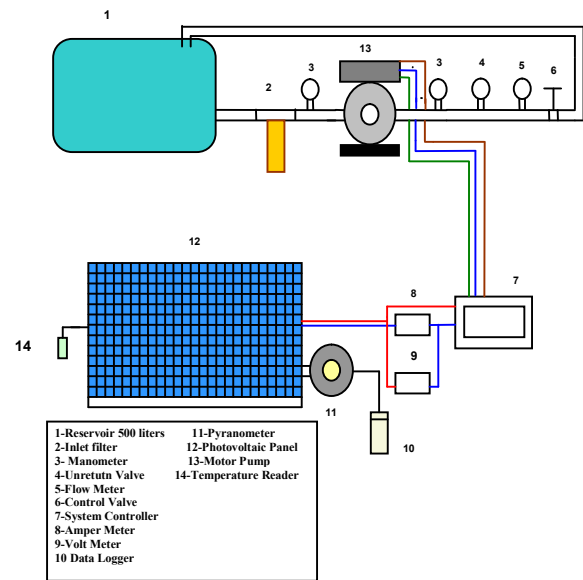


Figure.1: Layout of pumping system test stand

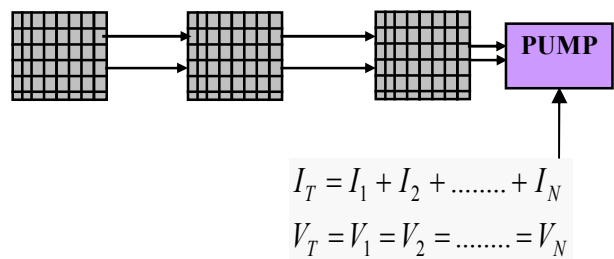


Figure. 2: Connecting PV cells in parallel

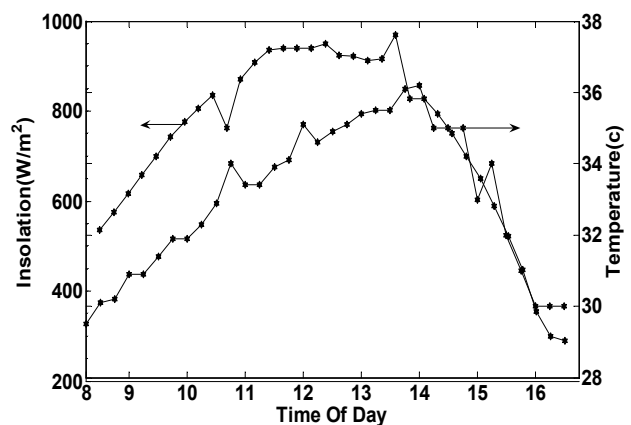


Figure.3: Variation of insolation and ambient temperature during the test day

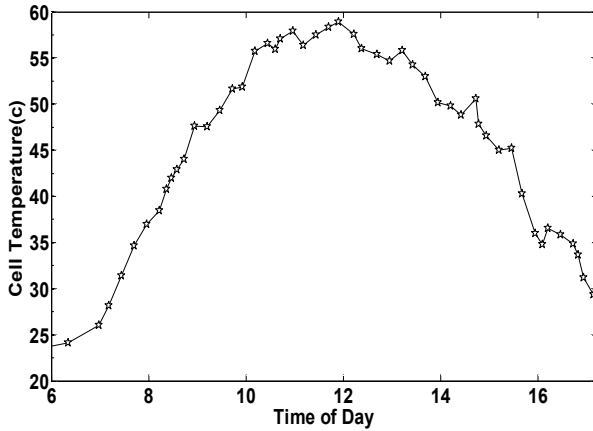


Figure. 4. Variation of PV cell temperature during the test day

1. ANALYSIS OF INFLUENCES OF PV ARRAY CONFIGURATION ON THE PHOTOVOLTAIC WATER PUMPING SYSTEM PERFORMANCE

The most critical part of the design in DC-PVPS is the PV array configuration, the number of PV modules connected in series and parallel. The main objective in searching the best configuration is, for given solar radiation, to operate the system at points as close to peak/maximum power points. In order to investigate panel configuration influences for given photovoltaic water pumping system two arrangements are considered. It is then compared with each other

4-1 Three parallel PV cells

In this part three PV cells connected in parallel are considered. Before that it is required to introduce the essential mathematical equations in order to investigate system performance. They are followed as:

$$P_{PV} = I_M V_M \quad (1)$$

$$\eta_{PV} = \frac{P_{PV}}{GA} \quad (2)$$

$$\eta_{Sub} = \frac{P_{hyd}}{P_{PV}} = \frac{\rho g h Q}{P_{PV}} \quad (3)$$

$$\eta_T = \eta_{Sub} \eta_{PV} = \frac{\rho g h Q}{GA} \quad (4)$$

Where P_{PV} is the array power, I_M the maximum PV cell current, V_M the maximum PV cell voltage, η_{PV} the PV cell efficiency, G the global solar radiation on the tilted cell, A the PV array area, η_{Sub} the operational subsystem efficiency, ρ the water density, g the gravitational acceleration, Q the pump flow rate, h the total head and η_T the total operational system efficiency.

In order to investigate the PV array configuration effects on the photovoltaic water pumping system performance four heads have been chosen, namely 6m, 10m, 16m and 20m. The PV array efficiencies of three parallel PV cells for four heads are shown in Fig. 5.

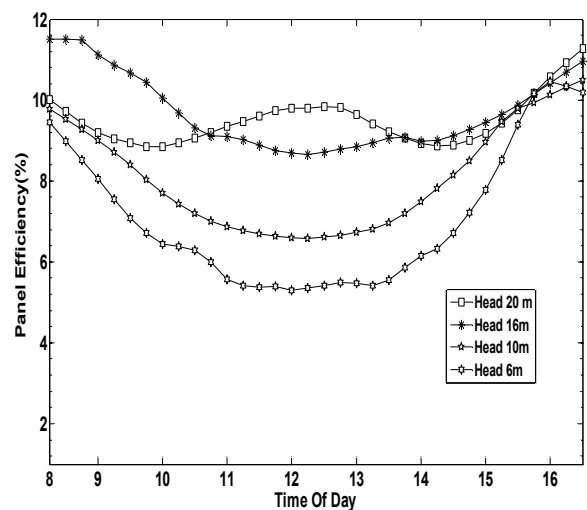


Figure. 5: Comparison of PV cell efficiency with three parallel cells in different heads

The subsystem and total efficiencies are shown in Fig.6 and 7. In these figures, in the high heads the efficiencies are higher than the low heads. To investigate the reason for decreasing efficiencies in the low heads, the plot of power against head for maximum speed of the motor pump is shown in Fig.8. As seen, each head has a maximum power point which the power more than this point can not be utilized by the motor pump.

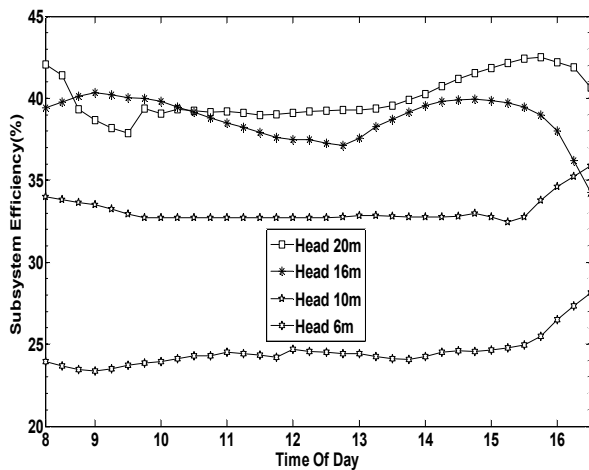


Figure6. Comparison of subsystem efficiency with three parallel cells in different heads

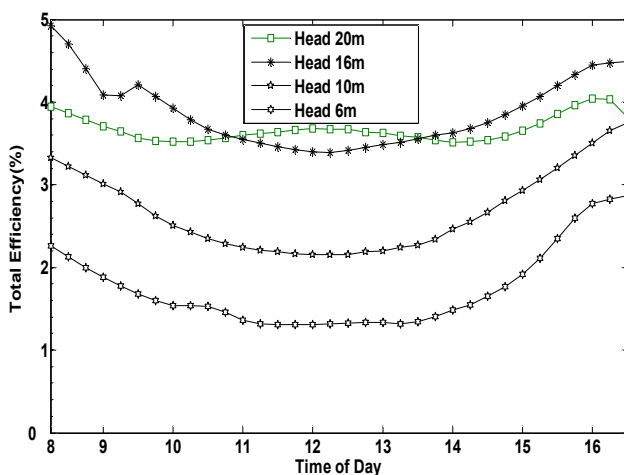


Figure.7: Comparison of total efficiency with three parallel cells in different heads

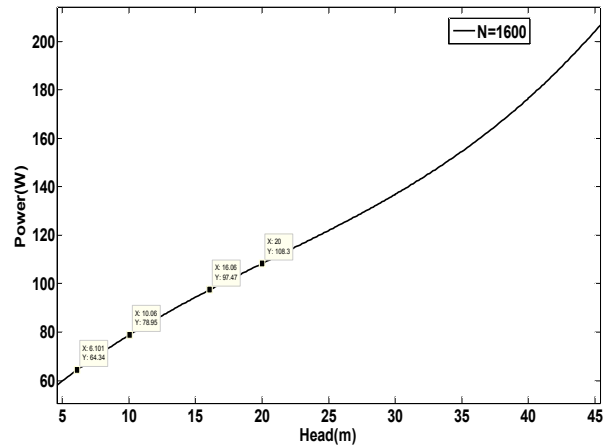


Figure. 8. Variation of motor pump power versus the pump head at maximum motor pump speed (1600 rpm)

Therefore, when the power of selecting PV cells number is more than selected head the efficiencies will dropped. In figure 9 the pump flow rates for the four heads are shown. As seen, in the low heads the pump flow rate is approximately constant and in the early morning the system can afford customer requirements. In the high heads in spite of high efficiencies the pump flow rate in the early morning dropped and if more water is required at these times the pump will not be able to afford it. However, this is a problem when the pump is not able to meet customer's requirements.

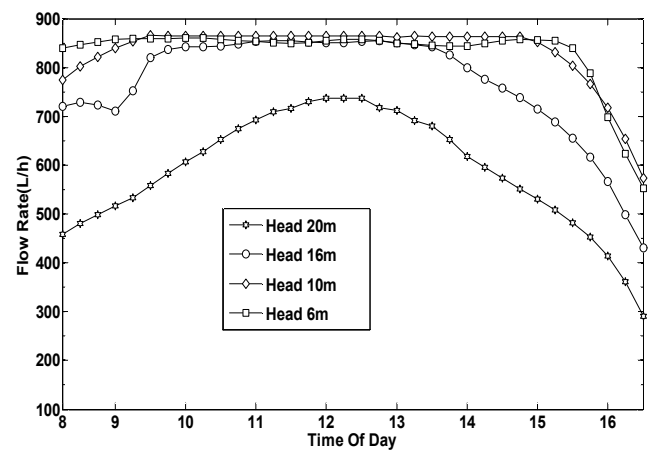


Figure. 9. Comparison of pump flow rate with three parallel cells in different heads

4-2 A Comparison between three parallel PV cells and two parallel PV cells

In the pervious part the performance of three parallel PV cells was investigated. In this part three parallel PV cells will be compared with two parallel PV cells. In Fig. 10 the PV cells efficiencies for above-mentioned arrangements in $h=6m$ are shown. In this head when the two parallel PV cells is selected the cells efficiency during the day is higher than the three parallel PV cells. The subsystem and total efficiencies are shown in figs 11 and 12. In these figures increasing efficiencies when two parallel PV cells selected are observed.

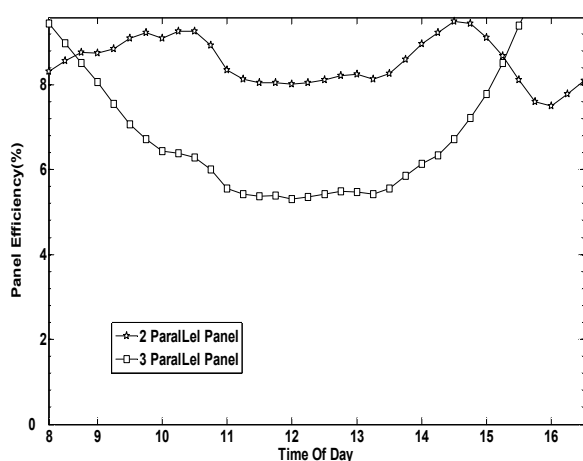


Figure10. Comparison of PV cell efficiency with two and three parallel PV cells at $h=6m$

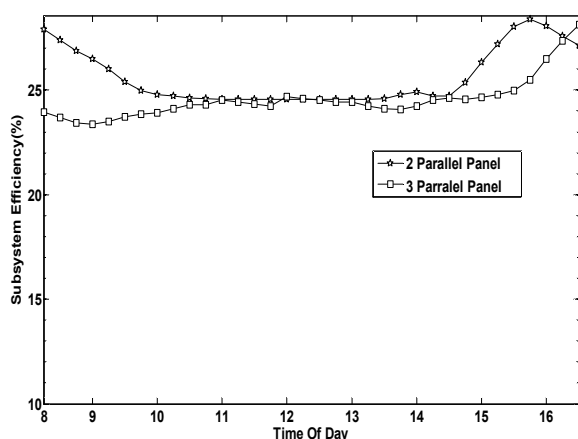


Figure. 11. Comparison of subsystem efficiency with two and three parallel PV cells at $h=6m$

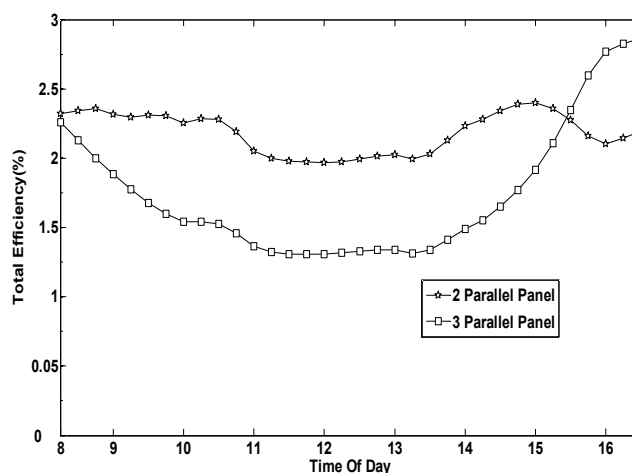


Figure12. Comparison of total efficiency with two and three parallel PV cells at $h=6m$

The efficiencies results show that if the PV cells arrangement is chosen according to the power of demanded head, which is related to maximum speed of motor pump, only extra cost of PV cells will be paid without gaining more power. How ever, in the following we will investigate volume of water is pumped in the two arrangements. Thus the pump flow rate during the test day was measured for the both arrangements, figure 13. In case of two parallel PV cells about 741L/h water is pumped and in case of three parallel PV cells it reaches to 840L/h. In spite of higher efficiencies for two parallel PV cells, the volume of pumped water is lower than three parallel PV cells. Thereby the costumer requirements may not supply when the required water is more than the maximum pumped water in case of two parallel PV cells. Furthermore, in case of two parallel PV cells the threshold radiation goes higher than three parallel PV cells, so that in the early morning lower volume of water is pumped. Since the costumer's requirement is one the most important factors of selecting the number of PV cells which the designers have to care about this important issue.

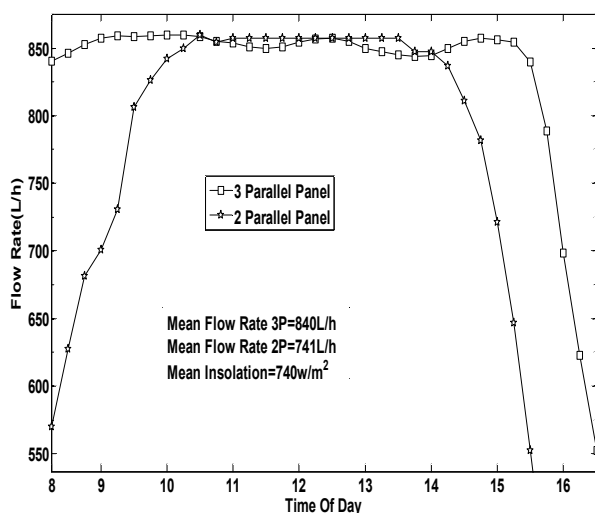


Figure. 13. Comparison of pump flow rate with two and three parallel PV cells at $h=6\text{m}$

5 CONCLUSION

The most critical part of the design in DC-PVPS is the PV array configuration, the number of PV modules connected in series and parallel. This study examines the performance of a 225W photovoltaic water pumping system with two and three parallel PV cells. The results show that in case of three parallel PV cells the cells, subsystem and total efficiencies of the photovoltaic water pumping system are low in the low heads. Since when the cells power is more than the maximum power speed of motor pump, the extra cells power is not utilized. Decreasing the efficiencies in the high heads are not observed. In this heads the cells power is close to the maximum power speed of motor pump so that most of the cells power is drawn by the pump. Also the research investigates available volume of water for two cases during the test day. It is found that when two parallel PV cells chosen less water is pumped compared with three parallel cells. Furthermore, in case of two parallel PV cells the threshold radiation goes higher than three parallel PV cells, so that in the early morning lower volume of water is supplied. Since customer

requirements is one the most important factors of selecting PV cells number. The designers have to care about this important issue. Finally the research indicates that designing photovoltaic water pumping systems have two criteria, firstly attention to maximum power of each selected head of the motor pump and secondly customer's requirements. Considering the both factors help the designer to design system more economical.

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