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Theoretical simulation and testing of a solar photovoltaic pump

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Abstract

In this paper, a solar photovoltaic pump is investigated theoretically and experimentally. Matlab/Simulink is used as the simulation tool and a test bed is developed to compare the simulation results with the experimental ones. Data required for the simulation are determined both from the manufacturer data and laboratory experiments. Flow and volume of water delivered during three time periods are compared with the experimental results. The comparison shows that the simulation results are in good agreement with the experimental ones. The model can be used for further investigation of the effect of parameters which change the performance of the system.

Keywords: solar pump, photovoltaic pump, Simulink, solar energy

1. Introduction

Use of solar energy in water pumping has many applications, especially in rural areas. The system can pump water to an elevated tank whenever there is appropriate sunshine and use the stored water volume when needed. While there is a benefit from renewable energy application, there are also some advantages like the avoidance of noise and land pollution from common diesel motors which are conventionally used as the motive power for pumps (Parajuli, R., et al., 2013).

There are some examples of application of solar water pumps which are reviewed previously (Al Smairan, M., 2012; Chandel, S. S., et al., 2015; Fedrizzi, M.C., et al. 2009; Munir, A., et al., 2007; Omer, A.M., 2001).

Among other previous researches in the field one can mention the investigation of parameters which affect system performance (Bucher, W., 1996; Chandel, S.S., et al., 2015; Gouws, R. and Lukhwareni, T., 2012; Moussi, A., et al., 2003), feasibility and economic studies (Cloutier, M., Rowley, P., 2011; Raturi, A., 2011; Kelley, L. C., et al., 2010; Mahjoubi, A., et al., 2010; Sahin, A. and Rehman, S., 2012), effect of PV array configuration (Boutelhig, A., et al., 2012), sizing guides and methods (Aligah, M.A., 2011; Ataei, A., et al., 2015; Bouzidi, B., 2013; Roy, R.B., et al., 2012) and experimental tests of a specific system (Kaldellis, J.K., 2011; Mokeddem, A., et al., 2011)

As far as the authors are aware, there has been few research on the application of Matlab/Simulink for the simulation of solar water pump and comparing the simulation model with the experimental results. Most of the previous works focused on using different simulation tools like Matlab/Simulink for photovoltaic panel modeling (Altas, I.H. and Sharaf, A.M., 2007; Erdem, Z. and Erdem, M.B., 2013; Qi, C., Ming, Z., 2012).

(Flores, C., et al., 2012) developed a proprietary tool to model the photovoltaic pump and compared their simulation results with the experimental ones. (Hamrouni, N., et al., 2008; Hamrouni, N., et al., 2009) simulated a photovoltaic pump in Matlab/Simulink and determined effect of solar radiation and ambient temperature on system performance. (Naresh, B., et al., 2012 described briefly how Matlab/Simulink can be used to model a solar photovoltaic pump. (Fam, W.Z. and Goswami, P., 1992) made a very noticeable work in this regard. They made a comparison between experimental values of the water volume pumped with the theoretical simulation.
Due to lack of applied analysis in this area, a model for solar photovoltaic pump including photovoltaic panel, motor, pump and piping elements is developed in Matlab/Simulink. The model's accuracy is assessed by experimental tests. Using this model, one can analyze a solar photovoltaic pump, easily.

2. System description

Among different combinations, solar photovoltaic pumps can be divided based on the type of photovoltaic panels, motor type, pump type and system configuration. A complete review of possible configurations is reported in (Chandel,S.S., 2015).
A schematic of the system configuration used in this research is shown in Figure 1. The system comprises two 80W mono-crystalline panels, electrical measurement devices for panel voltage, ampere and power measurement, a dc motor, centrifugal pump, water meter for total volume and a flow meter for flow rate measurement, storage tank, pressure measurement devices and required piping arrangements.

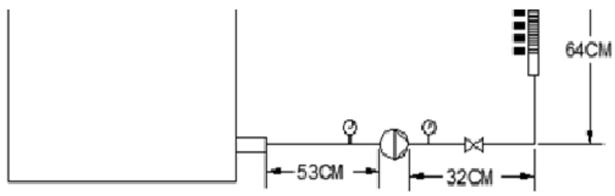

Figure 1: A schematic diagram of experimental setup

Also there is a weather station for measurement of solar radiation on horizontal and tilted plane, wind velocity and ambient temperature measurement as shown in Figure 2.

Figure 2: Data logger and, ambient temperature, wind velocity and radiation sensors

3. System simulation

Matlab/Simulink is used for simulating different parts of the system. The system comprises two photovoltaic panels, a dc motor, pump and piping. A review of modeling details is given below.

3.1. Photovoltaic panel model

There are different models for photovoltaic cell/panel modeling. A review of the methods with their characteristics can be found at the work of (Tao, M., et al. 2014). The model used in this study is a one-diode four parameter model which is a simple and common method (Bikaneria, J., et al. 2013). An advantage of this model is the minimum data required which makes it simple for the users to apply it with minimum information from the panel supplier. Actually, while there are more complex models available in the literature, but one cannot find the parameters required within supplier catalogues and there is a need for the user to send the panel for more in depth analysis to a test lab. According to the above and to make the simulation tool user friendly and simply to apply, a one-diode model is used in this study. The model is shown in Figure 3.

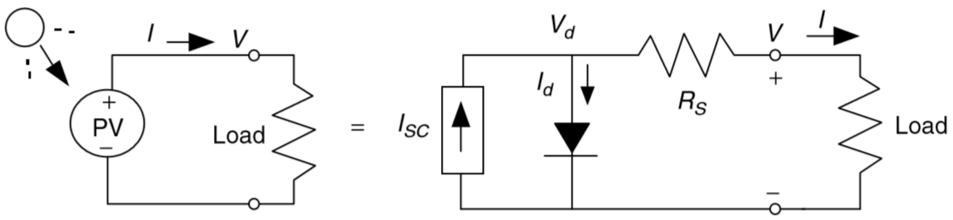

Figure 3: One-diode series resistance (4p) model of a PV panel

The relation between current and voltage is (Tao, M., et al. 2014):

$$I = I_{sc} - I_o[e^{(\frac{V+IR_S}{nKT})} - 1] \quad (1)$$

There are only five parameters required in this model including series resistance, ideality factor, short circuit current, open circuit voltage and solar irradiance. All these parameters derived from the manufacturer catalogue and are shown in Table 1.

Table 1. Photovoltaic cell parameters from manufacturer catalogue.

Parameter	Unit	Value
Irradiation	W/m2	1000
Open circuit voltage	Volt	0.9
Short circuit current	Ampere	3.84
Ideality factor	-	1.8
Series resistance	Ohm	0.0051

These parameters are used as input to the simulation model. Two parallel connected panels are used in this simulation as shown in Figure 4. Simulink modeling of two parallel panels, each consisting of 24 series connected cells is shown in Figure 5.

Figure 4: Two PV panels used in experimentation

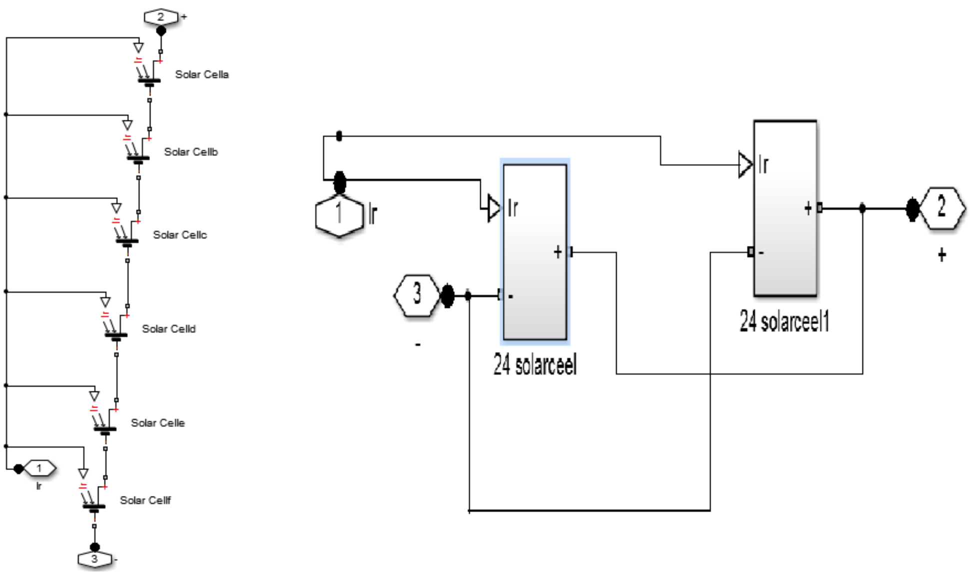

Figure 5: Modeling two parallel PV panels in Simulink

3.2. Motor model

The type of motor used in this study is a PMDC motor. These types of motors produce a high starting torque. A permanent magnet is used for excitation winding. The equivalent circuit for a PMDC motor is shown in Figure 6. The relation between voltage and torque is:

$$V_t = I_a R_a + K_m \omega_m \quad (2)$$

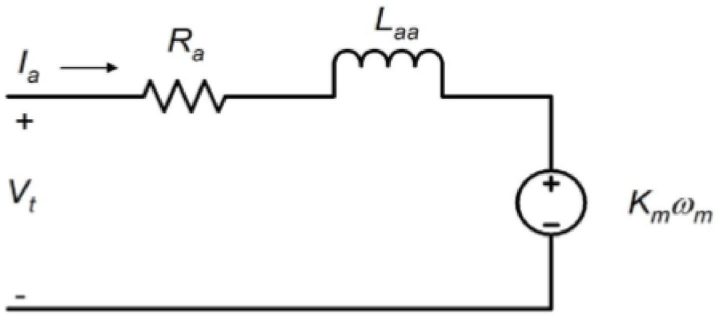

Figure 6: Equivalent circuit of PMDC motor

In order to model the PMDC motor, one needs the winding resistance and voltage constant. In case when these parameters are not available from manufacturer catalogue, they could be determined experimentally as was the case in this research.

Winding resistance was measured by a multi-meter and voltage constant was determined by measuring the rotational speed at a constant and defined voltage. Derived parameters are shown in Table 2.

Table 2. Measured parameters for the motor

Parameter	**Unit**	**Value**
Winding resistance	Ohm	0.1
Voltage constant	V/RPM	0.0028

DC motor block of Simulink is used to model the motor. This block is shown in Figure 7. The input to this block is from solar panel and its output is the pump.

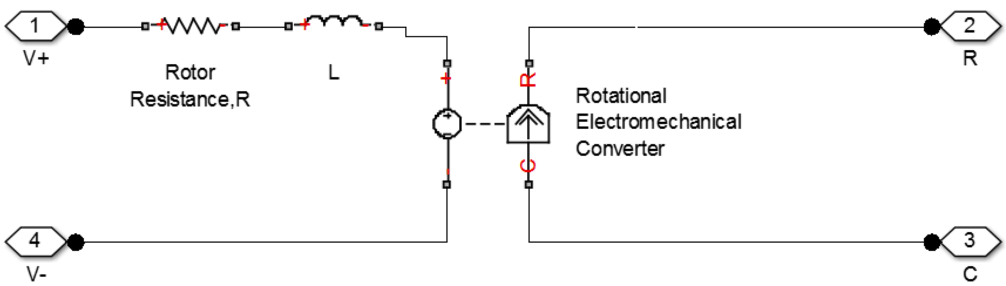

Figure 7: Equivalent circuit of PMDC motor in Simulink

3.3. Pump model

The pump parameter's block in Simulink is shown in Figure 8. A simple test facility was set up as shown in Figure 9 to measure the required pump parameters such as flow rate, head and power consumption. Measured parameters are shown in Table 3. In case, when the parameters are available from the manufacturer, the user may simply use the relevant data from manufacturer catalogues.

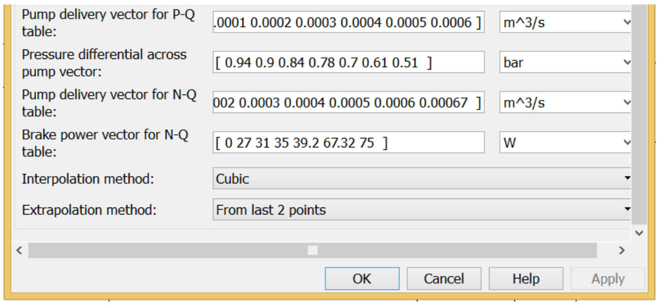

Figure 8: Pump parameter block in Simulink

Figure 9: Dc pump and pressure measurement points

3.4. Piping system model

Piping system simulation model is shown in Figure 10. The system modeled is similar to what used in the experiment. All the pipe and flow parameters are entered into the simulation model, considering the friction and minor losses.

Table 3. Pump parameters determined experimentally

Flow rate (l/h)	Pressure difference (bar)	Pump input power (w)
0	0.94	0
100	0.90	20
200	0.84	27
300	0.78	31
400	0.70	35
500	0.61	39.2
600	0.51	67.32

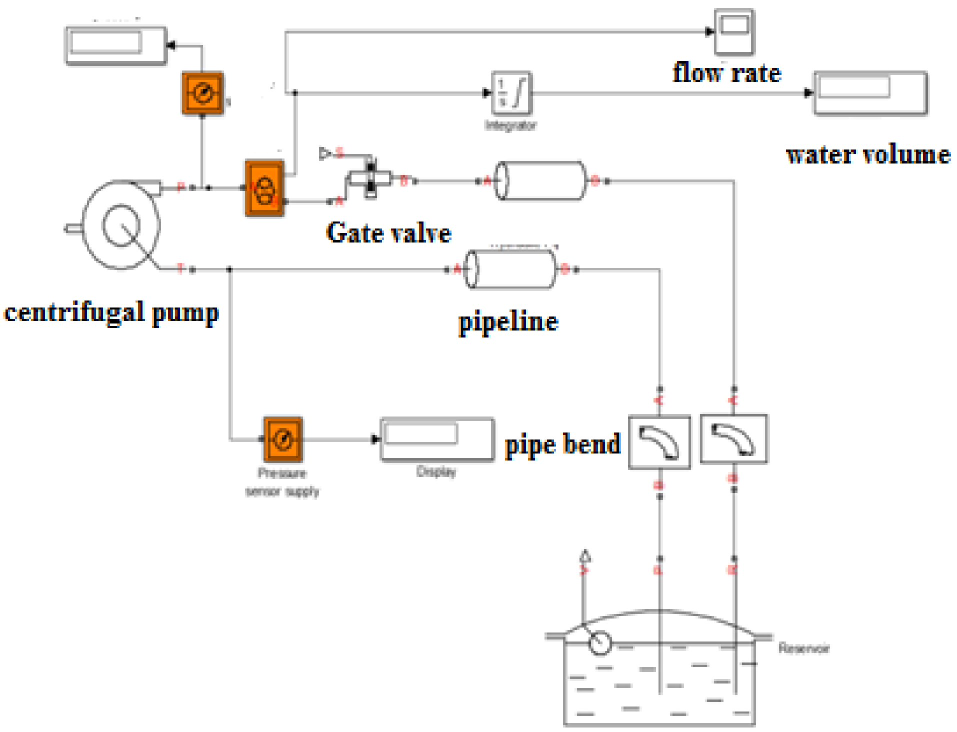

Figure 10: Piping system simulation model in Simulink

3.5. Whole system simulation

The whole system simulation diagram is shown in Figure 11. In the whole system simulation model, all the previous mentioned blocks are used together. Measured solar radiation data are given to the simulation model as input parameters.

3.6. Experimental results

An important question which is addressed in solar water pumping systems is the volume of water pumped within a specified time period, under a known solar radiation and with specific and known system parameters (including panels, motor pump and piping).

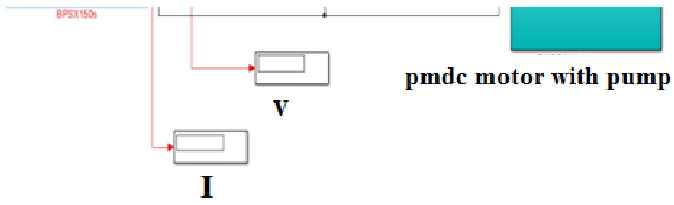

Figure 11: Complete system simulation model in Simulink

In order to check the validity of current simulation and to address the above question, an experiment has been made to compare the modeling results with the actual volume of water within a specific period of time under measured solar radiation and calculated/derived system parameters. The experimental facility is shown in Figure 12 and its specification has been described before in part 2.

Figure 12: Experimental setup

Figure 13 shows a comparison between Simulink and experimental results. As can be seen, the model can predict the flow rate of water with an acceptable accuracy.

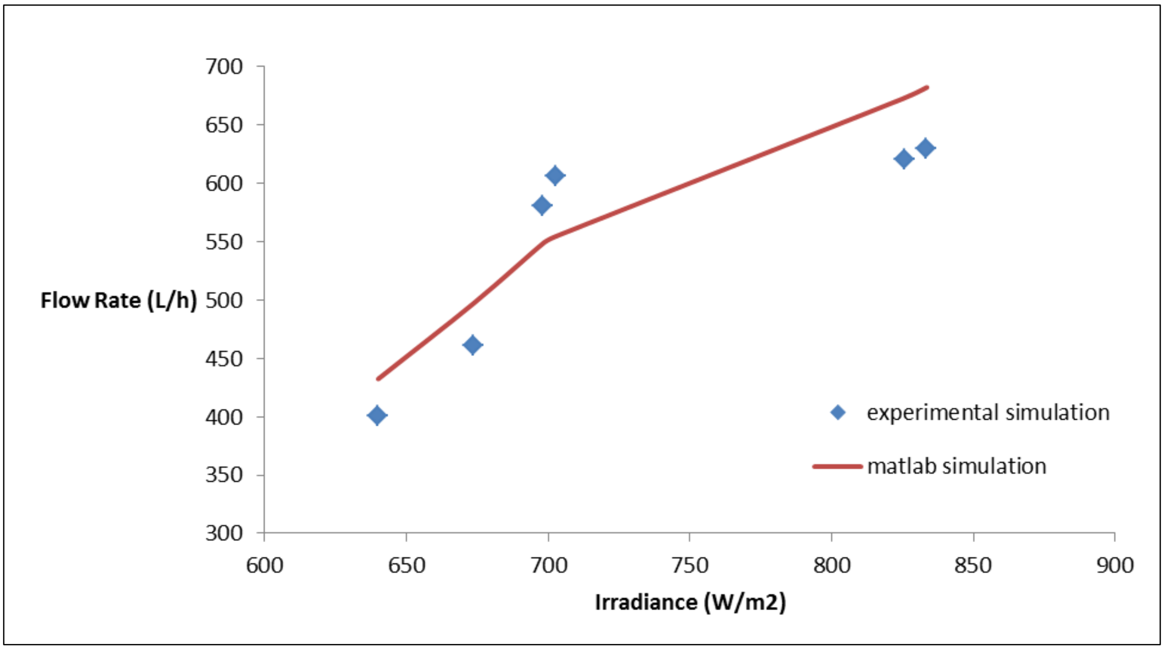

Figure 13: Comparison of modeled and simulated flow rate

A comparison is also made in Table 4 between predicted and measured total volume of water delivered within a specified time period.

Table 4. Comparison of modeled and simulated water volume

Time period	Simulated volume (L)	Measured volume (L)	Error (%)
12:10-13:10	744.5	689.9	+ 7.9 %
13:20-14:20	735	664.9	+10.5 %
15:4-16:04	592.1	563.3	+ 5.1 %

4. Conclusion

A simulation model has been introduced based on Matlab/Simulink for the modeling of solar photovoltaic pumping system. The system comprises photovoltaic panels either in series or parallel, motor model, pump model and piping model. The main motivation for this research was to introduce a tool for predicting the volume of water pumped under known or assumed radiation and with minimum data which is available for the user.

It was shown that by the model presented, the flow rate and volume of water delivered can be approximated within acceptable limits by having minimum data from the equipment manufacturer catalogue. This means that, by having the I-V curve of the panels, motor characteristics, pump H-Q curve and piping specifications, one can estimate pump output (flow rate and volume) just by assuming the radiation which is available from weather data or meteorological resources.

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