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Motor-Pump Subsystem's Modelling Tool for Photovoltaic Pumping System Study, Design and Analysis

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***Abstract*— the aim of this work is to present a simple and reliable software tool that was developed for motor-pump subsystem's study and modelling. This tool can be used by researchers, students and designers working on photovoltaic water pumping systems and projects. The presented tool is characterised by an easy-to-use graphical user interface which offer to its user the choice between using pre-registered model and developing new model for the studied motor-pump subsystem. For this last choice, measured electrical characteristics describing the subsystem's behaviour must be used by following a simple procedure in order to identify the model's parameters values. Thus the developed model can be saved for later use. The electrical characteristics concerned are current/voltage and flow/voltage measured for different water heads. An experimental database describing the operation of two different motor-pump subsystems, from different types and manufacturers, were used to test the simplicity and efficiency of this software application. The obtained results are fairly encouraging.**

***Keywords*— Photovoltaic energy, photovoltaic pumping systems, modelling, software tool, measured database.**

I. INTRODUCTION

The use of photovoltaic energy for water pumping is by far the most needed photovoltaic application for people living in rural and isolated areas, in order to cover both irrigation and potable water needs since water is a source of life. A considerable number of researches have been conducted in order to investigate the feasibility of such photovoltaic application, for countries endowed with a significant amount of solar energy resources. The enthusiasm for this issue can be explained and motivated by the fact that photovoltaic is a clean and renewable energy and above all abundant where natural resources as water are scarce and conventional electrification is being expensive. A 2000 World Bank/UNDP study on rural electrification programmers placed the average cost of grid extension at between $8,000 – 10,000 per km, rising to around $22,000 in difficult terrains [1], [2].

The photovoltaic water pumping application has been studied from different standpoints. As example, we can quote the analysis of the PV water pumping systems' efficiency [3], [4], their optimization and sizing [5]-[12], their modelling [13]-[16], the experimental investigation of the water pumps and actuators [17]-[21] and the economic viability of the photovoltaic water pumping projects [22]-[24] and their comparison to the fuel based ones for isolated areas.

The literature review found increases interest and use of PV water systems' device models especially the motor-pump subsystem. This can be explained by the growing need to simulate such a system for their design, analysis and troubleshooting. The aim of this work is to present a simple and reliable software tool that was developed for motor-pump subsystem's study and modelling. This tool can be used by researchers, students and designers working on photovoltaic water pumping systems and projects. The presented tool is characterised by an easy-to-use graphical user interface which offer to its user the choice between using pre-registered model and developing new model for the studied motor-pump subsystem. For this last choice, measured electrical characteristics describing the subsystem's behaviour must be used by following a simple procedure in order to identify the model's parameters values. Thus the developed model can be saved for later use. The electrical characteristics concerned are current/voltage and flow/voltage measured for different water heads. An experimental database describing the operation of four motor-pump subsystems, form different types and manufacturers, were used to demonstrate the simplicity and efficiency of this software application. The obtained results are fairly encouraging.

The paper is organized as follows. Section 2 reminds some definitions about the motor-pump subsystems properties, operating mode, mathematical models and previous modelling works. Section 3 presents the developed modelling tool. Section 4 shows results obtained with different cases of study while a summary and perspectives are presented in Section 5.

II. THE MOTOR-PUMP SUBSYSTEM

The configuration of the PV water pumping system depends on the type of the motor and the pump. Nowadays, several motors are currently available in the market, such as AC, DC, permanent magnet, brushed, brushless, synchronous and asynchronous, variable reluctance, and many more. While solar water pumps may be subdivided into three types according to their applications: submersible, surface, and floating water pumps. There are also several types of pumps according to their pumping principle: centrifugal pumps, screw pumps, piston pumps. The selection of an appropriate pump in a solar water pumping application is solely site dependent, such as water requirement, water height, and water quality [25]. The simplest configuration for PV water pumping systems, named the direct coupling configuration, can be illustrated by Fig. 1. It is composed mainly of a PV generator which converts solar energy into electrical energy, a DC motor which converts electric energy into a mechanical energy and a pump which converts the mechanical energy into an hydraulic energy. Most of the time, the motor and the pump are considered as being one subsystem in order to study the existing relationship between electrical and hydraulic variables. Therefore the characteristics of motors and pumps can be represented by current, voltage, and flow rate. Knowing that the manufacturer normally provides the head–flow–current–voltage data for the motor-pump combination, not the pump and motor individually [26].

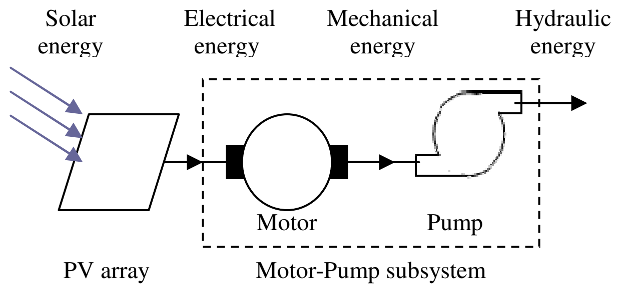


Fig. 1 A direct coupling PV water pumping system

Three main modelling approaches for the motor and the pump can be found in the literature:

A. The first approach

To describe the dynamic model of a DC motor, with constant magnetic flux, mathematical expressions of the electromagnetic developed torque (T_e), the armature voltage (e_a) and the motor sped constant (K_E) are used. The parameters of the DC motor are the torque constant (K_T), the back emf constant (K_E), the armature inductance (L_a), the armature resistance (R_a), the rotor position in mechanical degrees (θ_m) and the rotor angular speed (ω_m) as noted by Eqs 1, 2 and 3 [27]. For the solar pumps, different electrical expressions describing the flow-head characteristics which depend on the type of the used pump can be found [17], [28].

$$e_a = i_a R_a + L_a \frac{di_a}{dt} + e \quad (1)$$

$$T_e = K_T i_a \quad (2)$$

$$e = K_E \frac{d\theta_m}{dt} = K_E \omega_m \quad (3)$$

B. The second approach

This approach may be considered to be the simplest one, it is based on the energies' mathematical expressions: the daily incident energy received on the PV array area (E_i), the daily electric energy required by the pump during 12 hours of straight pumping (E_e) and the daily hydraulic energy provided by the pump (E_p) which can be expressed as follow [29]:

$$E_i = A_{PV} \int_{12h} G \cdot dt \quad (4)$$

$$E_e = \int_{12h} P \cdot dt \quad (5)$$

$$E_h = Ch \cdot H \cdot \int_{12h} Q \cdot dt \quad (6)$$

With A_{PV} is the effective area of the PV array (m^2), G is the solar intensity (W/m^2), P is the power required by the pump (W), Ch is the hydraulic constant ($Ch = 9800 Kg/(m^2 s^2)$), H is the head (m) and Q is the flow rate of the water (m^3/h).

C. The third approach

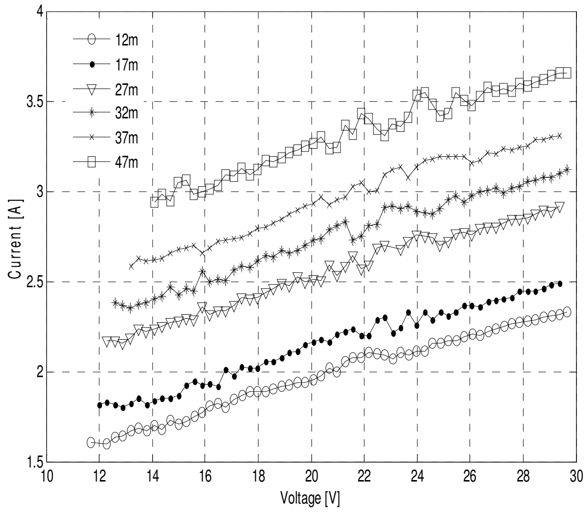
This approach considers the inputs-outputs characteristics of the motor-pump subsystem: the current-voltage and the water flow-voltage measured characteristics, in order to build a model for the studied subsystem which can be used to estimate the quantity of water that the system can pump under specific working conditions' profile (solar irradiance and ambient temperature). Many papers describe the flowchart of this modelling procedure which allows the expression of the current-voltage and flow-voltage characteristics of the motor pump subsystem by mean of the water head [13], [16].

Figure 2 illustrates some measured I-V and Q-V characteristics of a solar pump at different heads. In previous study, the authors presented a model which relates the current, voltage, the flow rate and the pump head with two polynomial equations as described by the following equations where the coefficients a_i, b_i, c_i, d_i and e_i are determined by fitting the experimental curves.

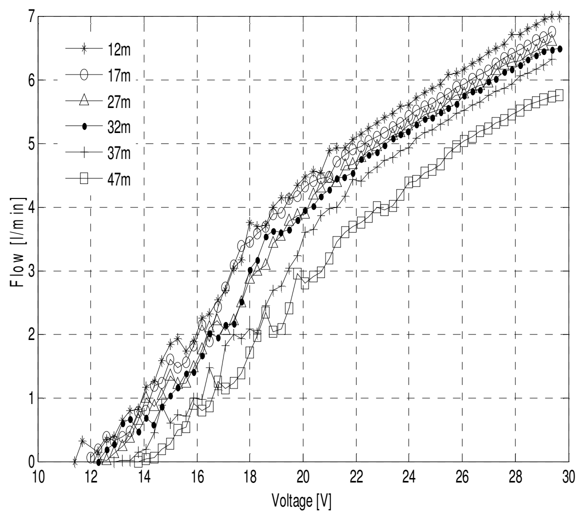
$$I(V) = aV + b \quad (7)$$

$$Q(V) = cV^2 + dV + e \quad (8)$$

$$\begin{cases} a(h) = a_0 + a_1 h + a_2 h^2 + a_3 h^3 \\ b(h) = b_0 + b_1 h + b_2 h^2 + b_3 h^3 \\ c(h) = c_0 + c_1 h + c_2 h^2 + c_3 h^3 \\ d(h) = d_0 + d_1 h + d_2 h^2 + d_3 h^3 \\ e(h) = e_0 + e_1 h + e_2 h^2 + e_3 h^3 \end{cases} \quad (9)$$



a) Current versus voltage curves for different heads.



a) Motor–pump's flow rate versus operating voltage curves for different heads.

Fig. 2 A motor-pump subsystem's output characteristics for different heads.

III. The Developed Software Tool

The developed software tool is based on the model described by Eqs. 7-9. the measured I-V and Q-V characteristics are obtained from the photovoltaic water pumping test facility located at Photovoltaic Energy Laboratory. A detailed description of this test facility can be found in [30]. Figure 3 illustrates the structure of background programmes of the developed tool while Fig. 4 illustrates its graphical user interface which permits the choice of the pump, the display of the database properties (measured characteristics), the illustration of the current-voltage and flow-voltage curves and them exploitation for the motor-pump subsystem modelling.

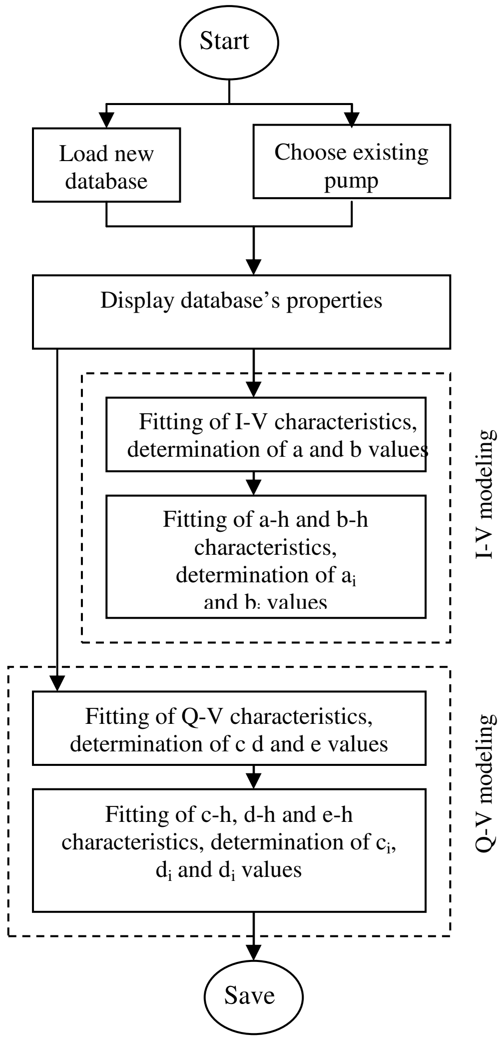


Fig. 3 Flowchart of the background programs

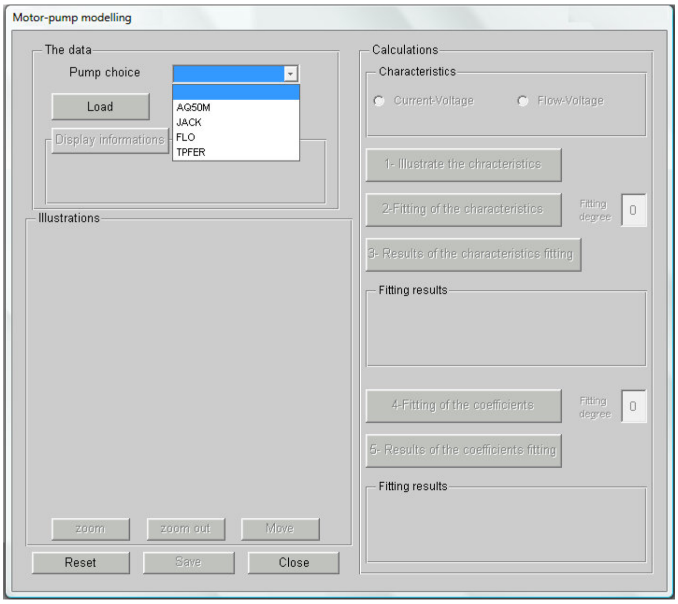


Fig. 4 Motor-pump subsystem modelling tool: graphical user interface.

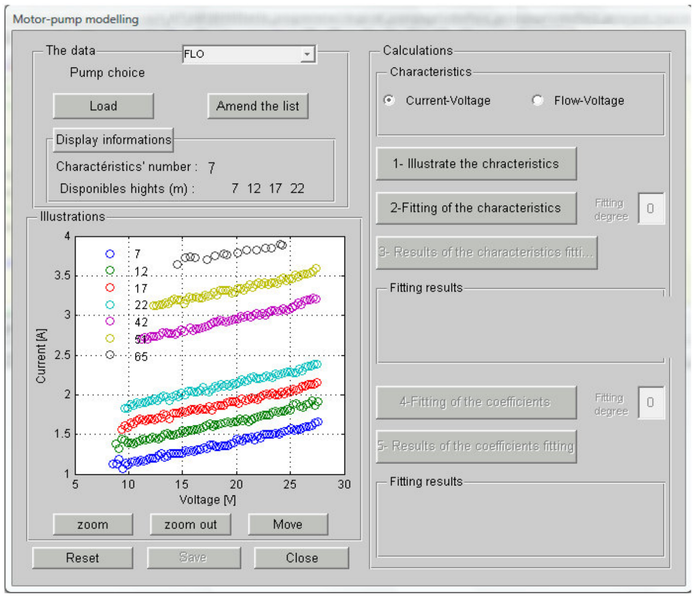


Fig. 5 Graphical user interface: I-V curves plot and database properties displaying.

IV. CASES OF STUDY

The presented examples are based on software run with data obtained from CDER's test facility. Two different pumps were tested under different water heads, a centrifugal pump and a positive displacement pump. To obtain their characteristics, we have fixed the pumping head, varying the input voltage, and we measured the input current, the input voltage and the output flow rate. The experience has been repeated for different pumping head values in order to proceed to their modelling. Table 1 summarises the electric properties of the studied pumps. Here, the results concerning only one pump is presented due to the paper's number page restriction. As we can see on the following Figs. 6, 7, 8, 9, 10, which shows the modelling results, a simple and easy use of the developed tool permits to its user to obtain the model's parameters without having to worry about the procedure's and model's equations complexity.

TABLE I
FONT SIZES FOR PAPERS

Pump	P1	P2
Type	Floating centrifugal and multistage	Positive displacement and submersible
Motor	DC	DC
Nominal power (W)	400	120
Nominal voltage (V)	0-48	24
Maximum current (A)	13	4

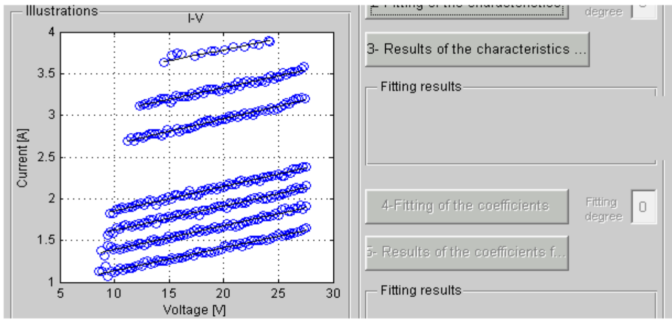


Fig. 6 Graphical user interface: I-V curves fitting.

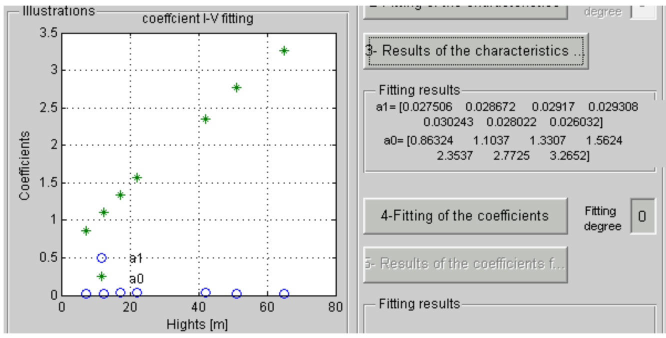


Fig. 7 Graphical user interface: I-V curves modelling

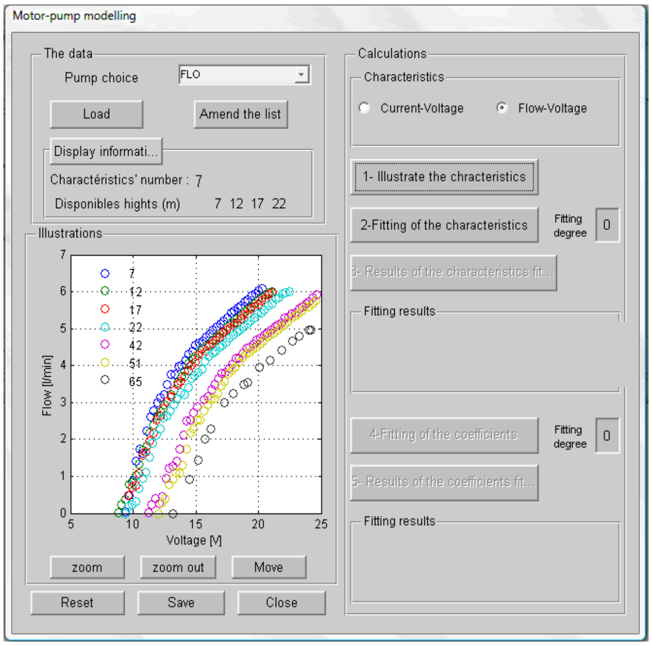


Fig. 8 Graphical user interface: Q-V curves plot.

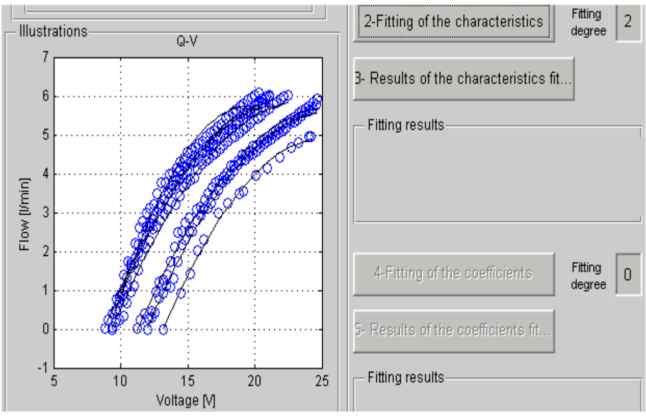


Fig. 9 Graphical user interface: Q-V curves fitting.

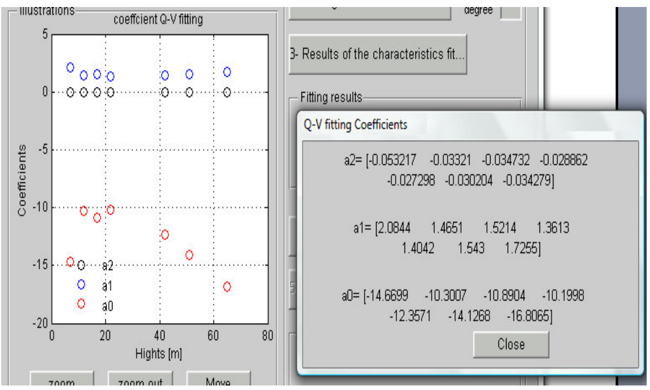


Fig. 10 Graphical user interface: Q-V curves modelling.

V. Conclusions

A software tool for photovoltaic motor-pump subsystem modelling and simulation was developed and presented. This tool can be used by researchers, students and designers working on photovoltaic water pumping systems and projects. The presented tool is characterised by an easy-to-use graphical user interface which offer to its user the choice between using pre-registered model and developing new model for the studied motor-pump subsystem. For its use, measured electrical characteristics (I-V and Q-V) for different heads must be used. An experimental database describing the operation of two different motor-pump subsystems, from different types and manufacturers, were used to demonstrate the simplicity and efficiency of this software application. The obtained results are fairly encouraging.

Further work is under way and should be continued in order to implement this modelling tool in a more complete software application which takes into account the other devices used for PV water pumping system, thus enabling the whole system study and analysis as the water need, the working conditions, the photovoltaic generator, the tank, the economic evaluation…etc.

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