

Optimum Design of Photovoltaic Water Pumping System Application

Sarah Abdourraziq, Rachid El Bachtiri

Abstract—The solar power source for pumping water is one of the most promising areas in photovoltaic applications. The implementation of these systems allows to protect the environment and reduce the CO₂ gas emission compared to systems trained by diesel generators. This paper presents a comparative study between the photovoltaic pumping system driven by DC motor, and AC motor to define the optimum design of this application. The studied system consists of PV array, DC-DC Boost Converter, inverter, motor-pump set and storage tank. The comparison was carried out to define the characteristics and the performance of each system. Each subsystem is modeled in order to simulate the whole system in MATLAB/Simulink. The results show the efficiency of the proposed technique.

Keywords—Photovoltaic water pumping system, DC motor-pump, AC motor-pump, DC-DC boost converter.

I. INTRODUCTION

RENEWABLE energy sources are being increasingly implemented in many applications due to the growing concern of environmental pollution. The photovoltaic pumping system has become one of the most promising areas for photovoltaic applications. To achieve the most reliable and economical operation, more attention is paid to their design and their optimal use [1], [2]. Depending on the state of the place, the pumped water can be used in many applications such as domestic use, water for irrigation and village water supplies [3], [4]. Several types of pumps and motors are available on the PV pumping market. Various studies have been done on the choice of the drive system, which suits PV source, type of pumps to use and ways to control and optimize the whole system.

The most commonly employed pump type is the centrifugal pump. Single-stage centrifugal pumps are frequently used in PV shallow water pumping for low head applications. For PV subterranean water pumping and surface water pumping with higher heads, multistage centrifugal pumps are more suitable. Other pumps types such as progressive cavity pumps [5], [19] and piston pumps [6], [20] have also been utilized.

The power conditioning has a role to optimize the transfer of the energy between the PV array and the motor -pump set. Power conditioning can be a DC/ AC inverter for an AC electric motor or a DC/DC inverter for a DC electric motor. The motor used in the PV pumping systems is one of two main types, either induction motor or DC motor [7]-[9].

Depending on the application and different water sources (wells, drilling, pump the river Etc), different types of

motor-pump sets are used. In this article, we presented modeling of two different configuration of photovoltaic pumping system (PVPS), the first one driven by DC motor, and the second entrained by an induction motor. The analysis of the performance of each system is developed. The studied systems were tested in MATLAB/Simulink environment, to define the characteristics and the efficiency of each subsystem. The block diagram of the PV pumping system studied is shown in Fig. 1.

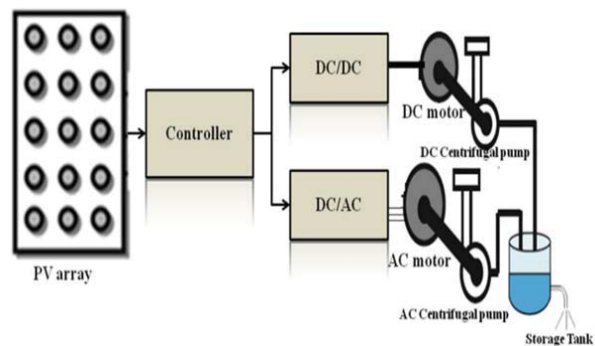


Fig. 1 General configuration of a PVPS

II. PV PANEL MODEL

PV cell is a p-n junction semiconductor, which converts light into electricity. In the literature, several mathematical models describe the I-V characteristic [9], [10], [18]. The difference between each model is the procedure of the calculation, the intervening parameters number to compute the I-V characteristic and results accuracy. The equivalent circuit of a PV cell is shown in Fig. 2.

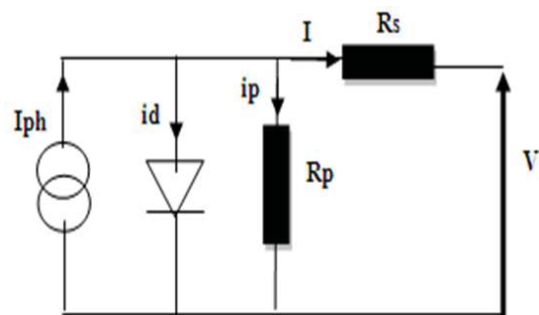


Fig. 2 Equivalent circuit of PV cell

The behavior of the PV array may be described by:

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$$I = I_{ph} - I_d - I_p \quad (1)$$

with

$$I_d = I_o \left(\exp\left(\frac{V_j \cdot q}{K_o \cdot T}\right) - 1 \right) \quad (2)$$

and

$$I_p = \frac{V + R_s \cdot I}{R_p} \quad (3)$$

$$I = I_{ph} - I_o \left(\exp\left(\frac{V_j \cdot q}{K_o \cdot T}\right) - 1 \right) - \frac{V + R_s \cdot I}{R_p} \quad (4)$$

where V is the PV output voltage, I is the PV output current, I_{ph} is the photocurrent, I_o is the saturation current, R_s is the series resistance, R_p is the shunt resistance, and q is the electronic charge, n is the diode factor, K is the Boltzmann's constant, T is the junction temperature.

The output characteristics of voltage-power and voltage-current of PV panel named SES96M, under different values of radiation at $T=25^\circ\text{C}$ are presented in Figs. 3 (a) and (b).

III. PV PUMPING SUBSYSTEMS MODELS

The PVPS entrained by a motor-pump group consists of a PV panel, a DC-DC boost converter, an inverter (for AC motor), and a motor-pump set. The modeling of each component is described in the following paragraphs.

A. PV Pumping System Used DC Motor-Pump

The overall simulation model of DC pumping system fed by solar array is shown in Fig. 6.

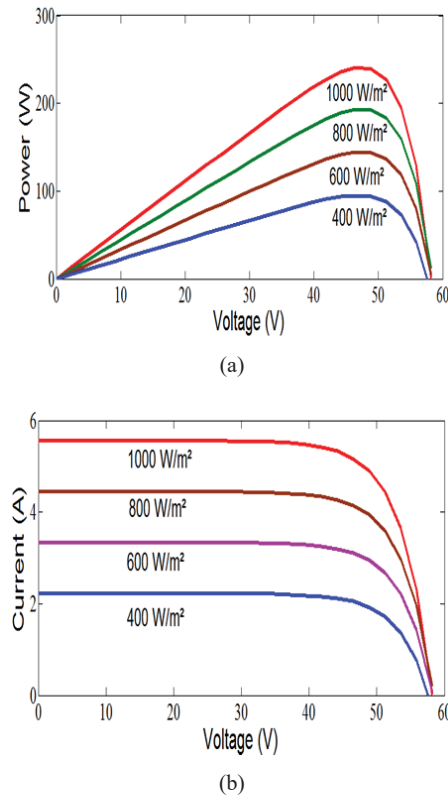


Fig. 3 Output characteristics of PV array at $T=25^\circ\text{C}$ (a) V-P, (b) V-I

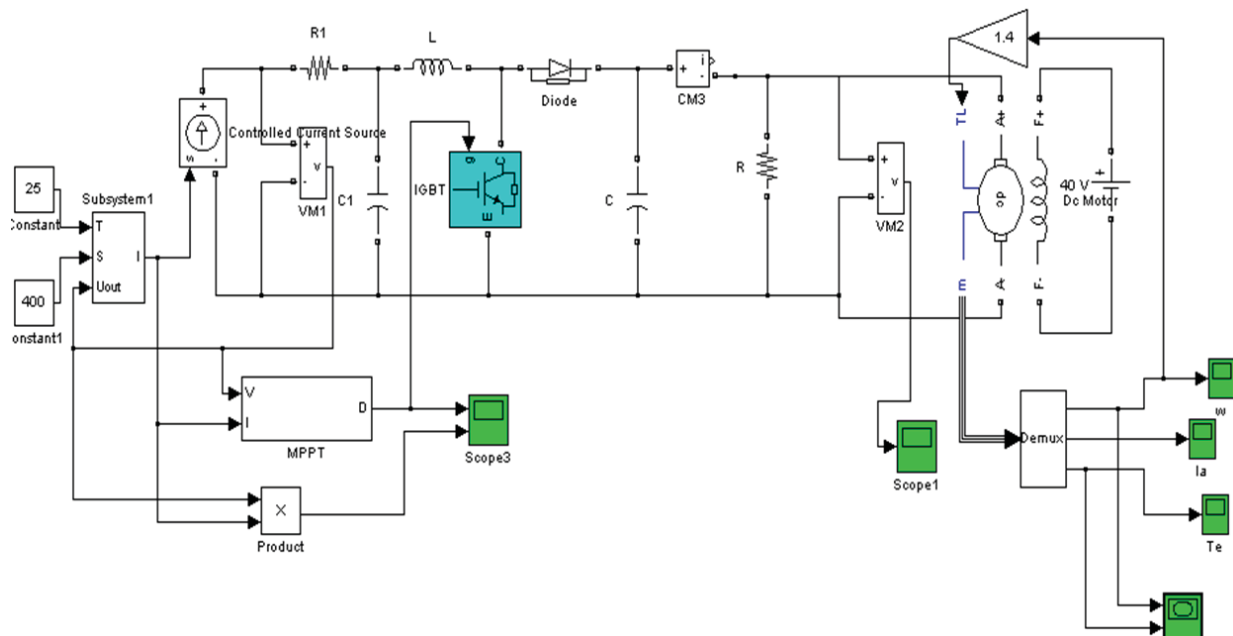


Fig. 4 Simulink diagram of PV based DC motor system

1. DC-DC Boost Converter

The dc-dc boost converter [21] is inserted between the solar generator and the motor-pump set, it is used as an adapter between the PV generator and the load. Its objective is to make the solar array operate at an operating point corresponding to the maximum output power, by adjusting the duty cycle α . The circuit diagram of boost converter is shown in Fig. 4.

The equation of the output voltage V_o depending on the input voltage V_{pv} , and the duty cycle α can be expressed as:

$$V_o = \frac{1}{1 - \alpha} V_{pv}$$

The simulation results of the characteristics of the DC Boost converter are shown in Fig. 5.

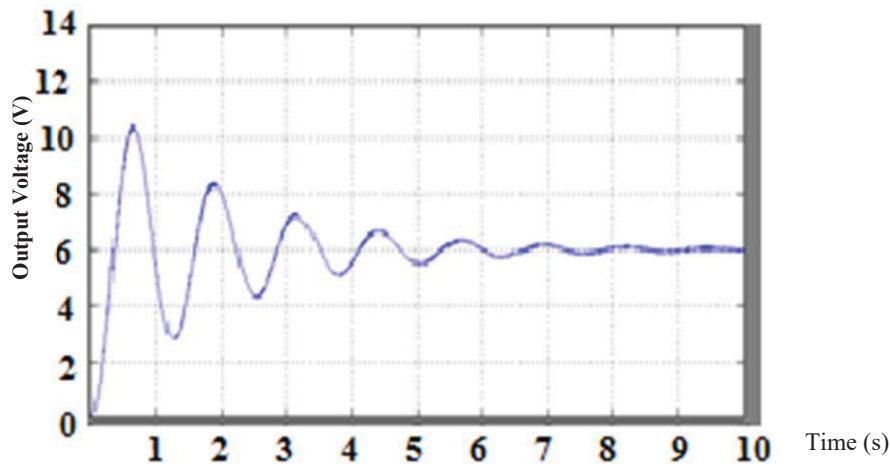


Fig. 5 (a) Output voltage of the boost converter DC-DC for $V_{pv} = 3V$ and $\alpha = 0.5$

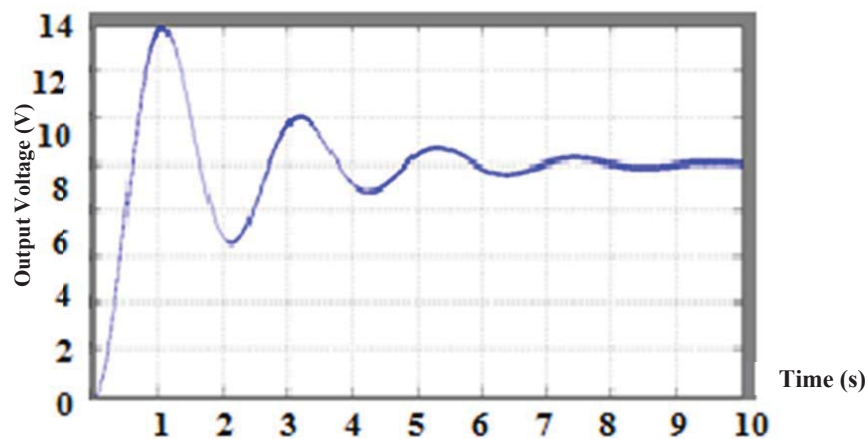


Fig. 5 (b) Output voltage of the boost converter DC-DC for $V_{pv}=3V$ and $\alpha= 0.7$

2. DC Motor-Pump Characteristics

Many PV pumping systems use the DC motors, because they can be directly coupled to the photovoltaic panels which presents a very simple system. Direct coupling of series, shunt, and separately excited DC motor PV pumping systems were studied in [2]-[17]. The permanent magnet motors (PMDC) are most commonly used in PV pumping systems.

Depending on the application, and different water sources (wells, drilling, pumping river, etc..) different types of pumps are used. In photovoltaic pump, the centrifugal and the

volumetric pumps are the most used [16].

The output characteristics of the component of the DC motor are shown in Fig. 6.

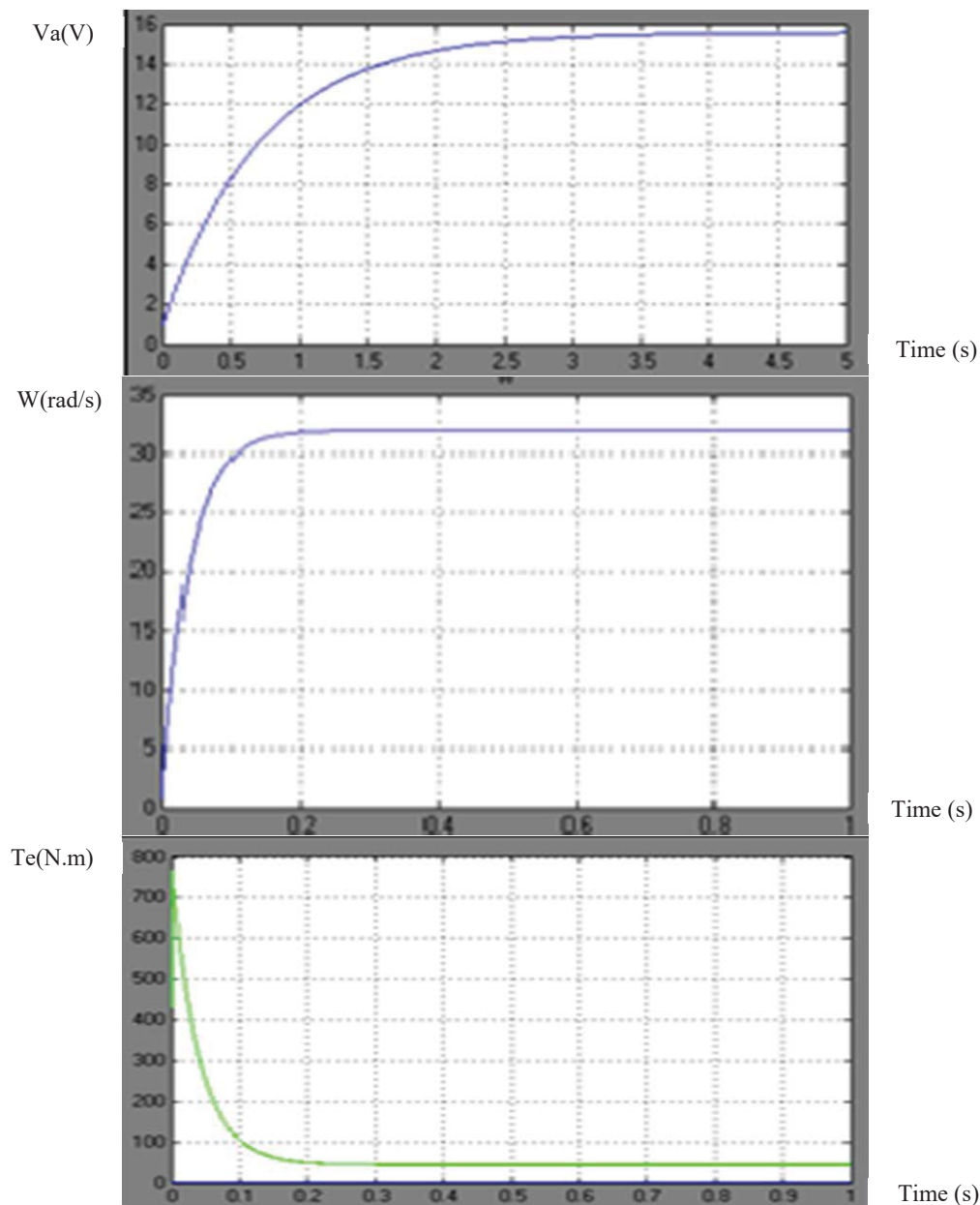


Fig. 6 Simulink output of DC motor characteristics

B. PV Pumping System Used AC Motor-Pump

The AC induction motor is used increasingly for PVPSs. The simulation results of a PVPS driven by an AC motor system are shown in Fig. 7.

1) Inverter

The dc-ac inverter provides three-phase system of voltages which is variable in amplitude and frequency according to the solar radiation. They vary from 0.1 up to 1 time the rated voltage and frequency [16]. It depends of the loads and climatic conditions. The simulation result of the inverter is presented in Fig. 8.

2) AC Motor

The AC motor is more used for PVPSs. The low cost of the engine, its low maintenance and its increased efficiency solar inverters make it particularly attractive for larger pumping systems, where the additional cost of the inverter is less significant.

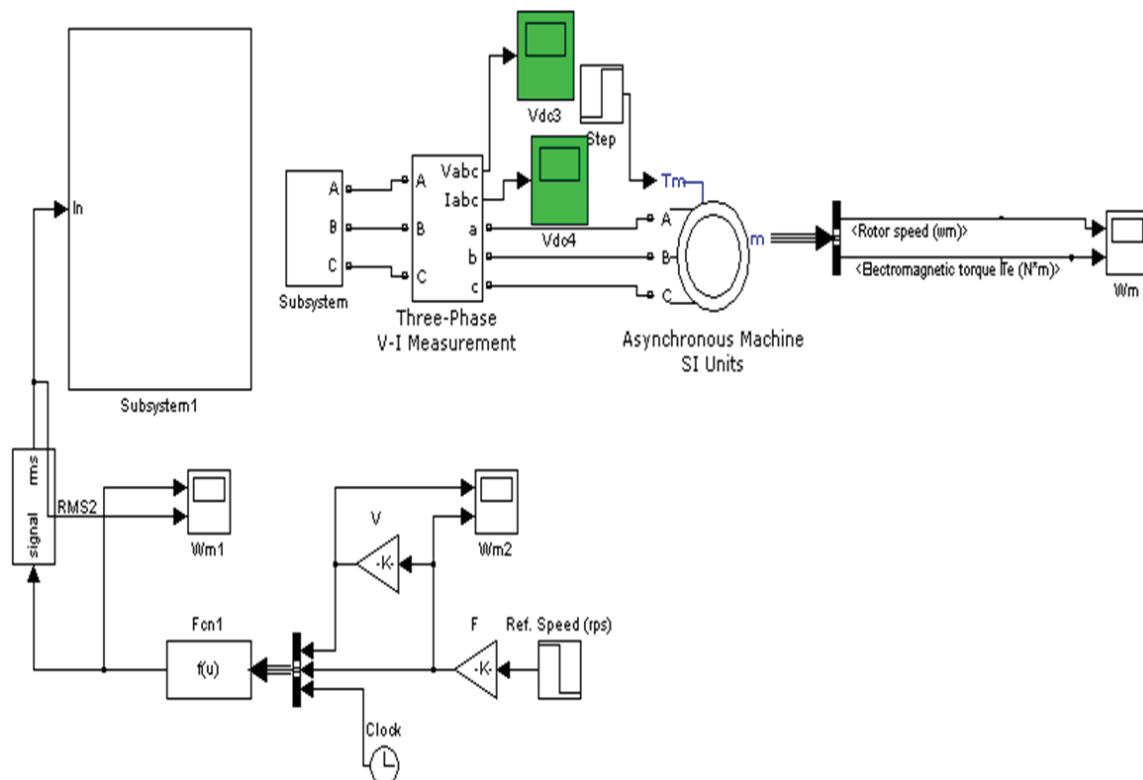


Fig. 7 Simulink diagram of PV based AC motor system

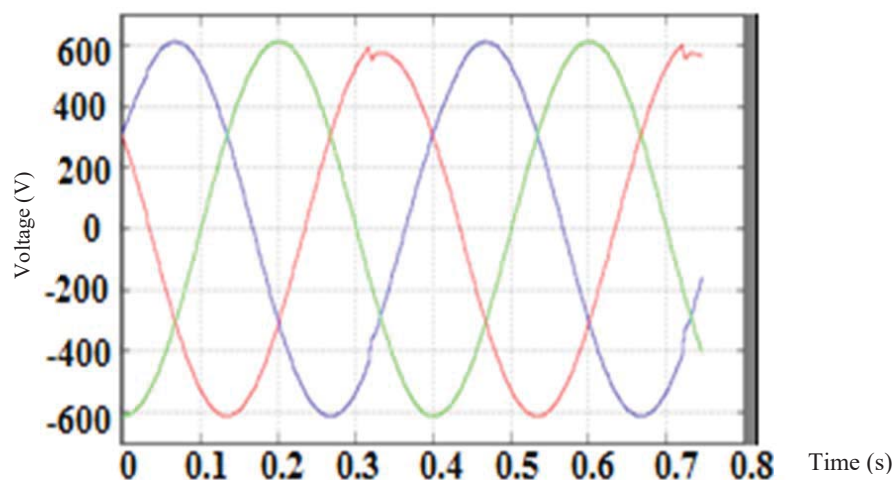


Fig. 8 Simulink result of output characteristic of the inverter

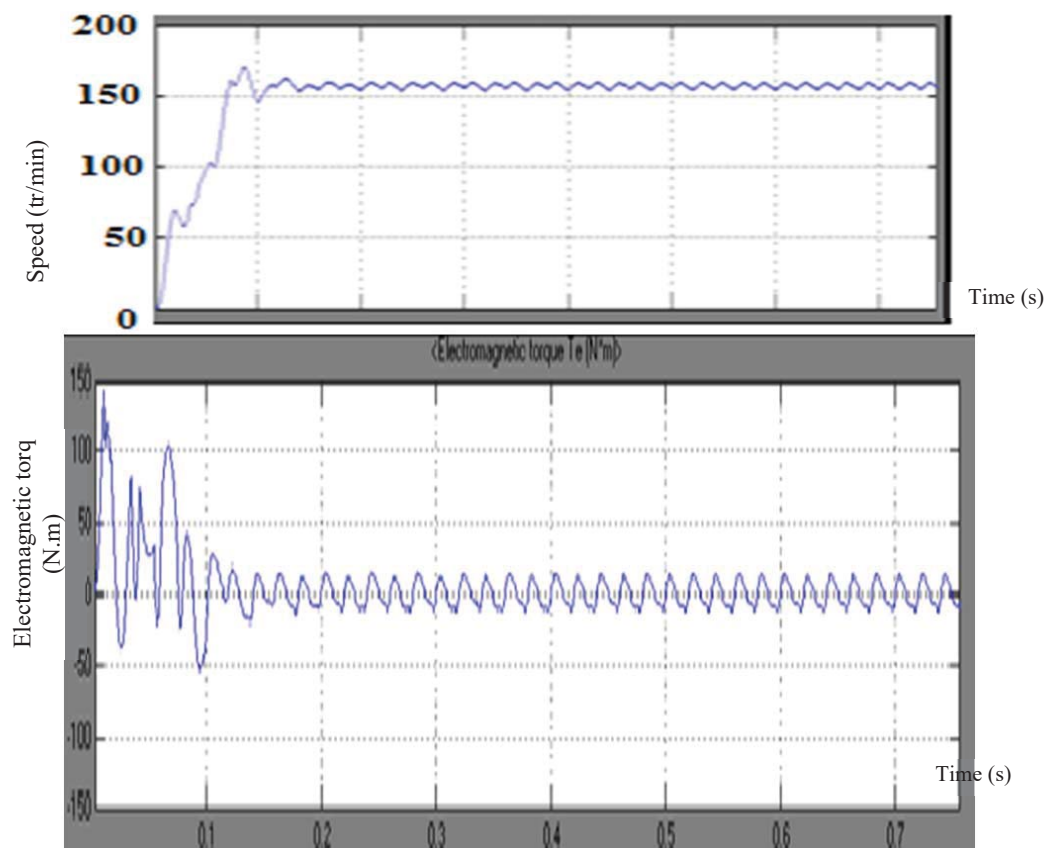


Fig. 9 Output results of induction motor characteristics

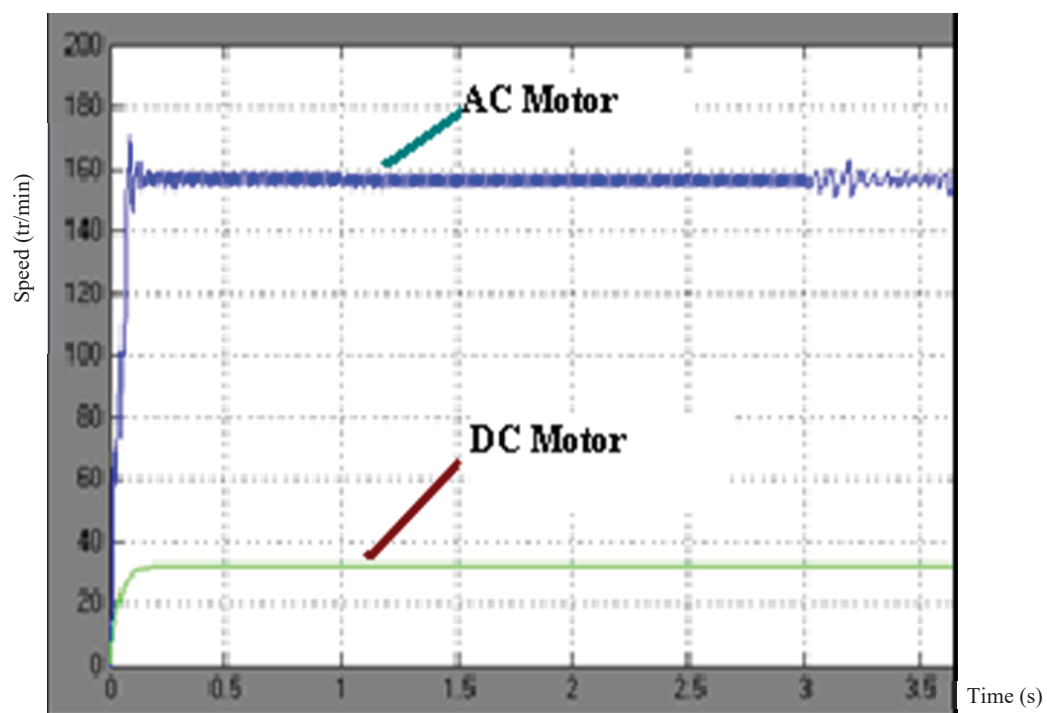


Fig. 10 Comparison between speed of PMDC motor and an induction motor

IV. CONCLUSION

This work has depicted the performance of two different configurations of PVPSSs, it makes a path on the modeling and simulation of the photovoltaic drives systems using MATLAB/Simulink. The various components like PV panel, boost regulator and motor-pump driving systems have been modeled and it is validated using MATLAB. The comparison is done to defining the advantages and drawbacks of each method, to use the efficient method. The comparison is done to defining the advantages and drawbacks of each type of motor. The results obtained from the simulation of the system are satisfactory. It allows providing a very high speed of rotation of AC motor compared to DC permanent magnet motor (Fig. 10), which provides an important power to drive the pump.

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