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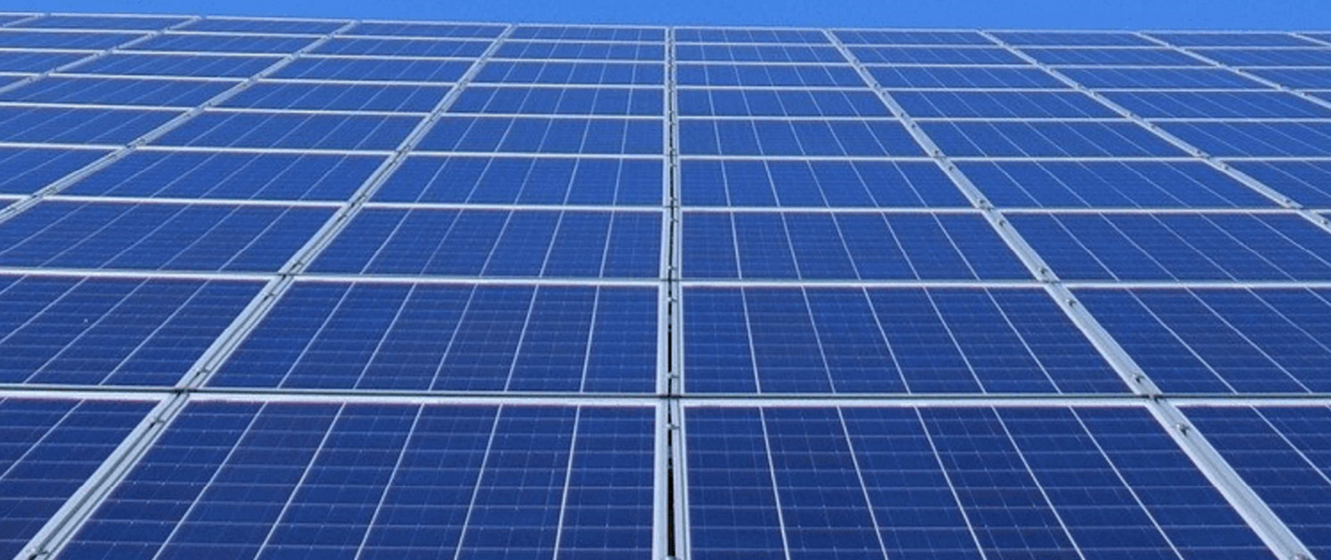

2 Design and Analysis of Solar Water Pumping System

Lakhdara Amira[a,*], Bahi Tahar[b] and Moussaoui Abdelkrim[a]

[a]Departmentof Electrical and automatic Engineering_LGEG, 8 may 1945 Guelma University, Guelma, Algeria
[b]Department of Electrical, LASA laboratory, Badji Mokhtar Mokhtar University, Annaba, Algeria

*Corresponding author: lakhdara.amira1985@gmail.com

ABSTRACT

According to the current state of the art, stand-alone photovoltaic installations are increasingly intended for water pumping, and have become a very competitive solution for remote areas. Indeed, photovoltaic pumping systems can offer the advantage of the lowest maintenance and the opportunity to save energy. Therefore, the simplest solar water pumping systems are the ones that operate directly when the sun is shining, but the performance of these systems depends on climatic conditions including solar irradiation and ambient temperature. However, in a remote area these installations do not require electrical storage systems despite the various climatic conditions. This work concerns the design, modeling and functional analysis of a photovoltaic water pumping system operating under the sun, with a view to its installation in an isolated area so that the water stored in a tank is consumed in real time or in case of need even if the pumping operation is not operational. The simulation is carried out using Matlab/Simulink environment, to evaluate the pumping installation performances. The simulation results show that the pumping system works as desired.

Keywords: Pumping system, photovoltaic, climatic conditions, solar energy

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1. INTRODUCTION

In recent years, governments around the world have insisted that part of the energy be produced from renewable sources [1,2]. Since Algeria is considered the biggest country on the African continent by its surface of 2.381741 km^2, of which 4/5 are occupied by the Sahara where the weather is generally sunny, it's around 3650 hours of sunshine / year. The photovoltaic energy is strongly applied for pumping water mainly in sunny areas, taking advantage of the free fuel source which is sunlight. The presence of a solar pumping system is a cost-effective and safe solution for supplying water using clean energy, by taking advantage of the vast Algerian Sahara, which is characterizedby its distance from the electrical distribution network, the installation of electricity production systems is a remarkable solution to meet the needs of the population[3]. This environment is therefore suitable for the installation of photovoltaic pumping systems.

The photovoltaic pump system converts solar energy into electrical energy to drive a pump from an electric motor. Despite the initial investment in this system is expensive, systems can be installed as small as possible, but run as often as possible. In this case the solar pumping system cannot supply a large amount of water quickly but will be relatively inexpensive to use for many continuous hours[4]. Therefore, water storage will often be an essential element for solar pumping.
The aim of this work is the functioning of the photovoltaic pump system over the sun and to perform an indirect storage in the form of a water tank in the reason of the elimination of batteries. There are two parts: the first part is devoted to the modeling of the system (PV, Permanent Magnetic DC Motor (PMDC), Pump) and the simulation, the analysis and interpretation of simulation results are presented in the second part to validate the performance of this system under various climatic conditions.

2. MODELING OF THE SYSTEM

The performances of solar pumping depends on the characteristics of the chosen site (Irradiation, Temperature,...) and the characteristics of the chain equipment (PV, Electronics Inverters, PMDC, Pump and the Storage system) [5,6].

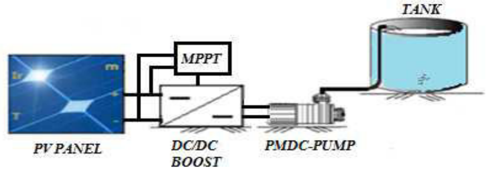


Fig. 1. Schematic bloc diagram of PV system

2.1. Photovoltaic Panel

The photovoltaic cell is also represented by the “standard” model with a diode[7].

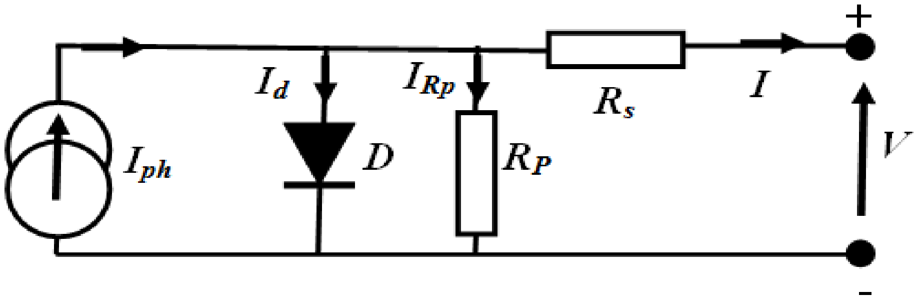


Fig. 2. Electric model equivalent to a diode of the photovoltaic cell

Where,$R_p(\Omega)$: parallel resistance which characterizes the currents of the junction; $R_s(\Omega)$: serial resistance which characterizes the various resistances of the contacts and connection; $I_{cc}(A)$: Short-circuit current (Photovoltaic) which depends on the sunshine and the temperature; I_d *(A)*: Current through the diode; $I_{Rp}(A)$: Current through the parallel resistor.
From Figure.2, we can deduce:

$$I = I_{ph} - I_d - I_{R_p} \tag{1}$$

With,

$$I_{Rp} = \frac{V + R_s \times I}{R_p} \tag{2}$$

And,

$$I_d = I_0 \times e^{\frac{V + R_s I}{V_t}} - 1 \tag{3}$$

So,

$$I_{ph} = (I_0 \times e^{\frac{V + R_s \times I}{V_t}} - 1) - (\frac{V + R_s \times I}{R_p}) \tag{4}$$

To show the influence of irradiation and temperature on behavior, characteristics *I=f(V)* and *P=f(V)* obtained by simulation are shown in the

Figure.3. Furthermore, the short circuit current and the open circuit voltage can be determined from those characteristics.

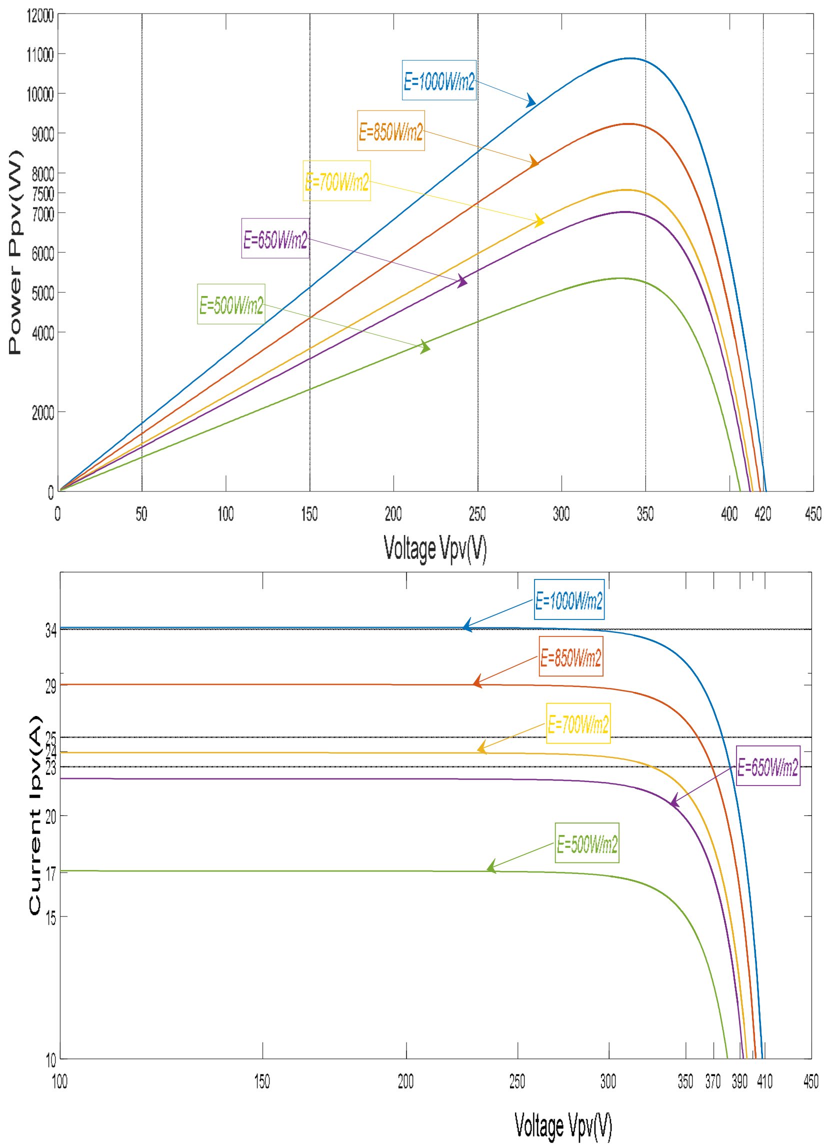


Fig. 3. Characteristics I=f(v), P=f(v) variation of E

2.2. DC-DC Boost converter

Power systems use Boost converter to increase the output voltage at the input of the inverter, its block diagram is that of Figure.4.

We notice that the semiconductor *(S)* requires a command *(D)*. However, the closing (T_f) (blocked: non-passing) and opening (T_o) (passing) periods for a period of the control cycle (T_c) defines the duty cycle *(D)*.

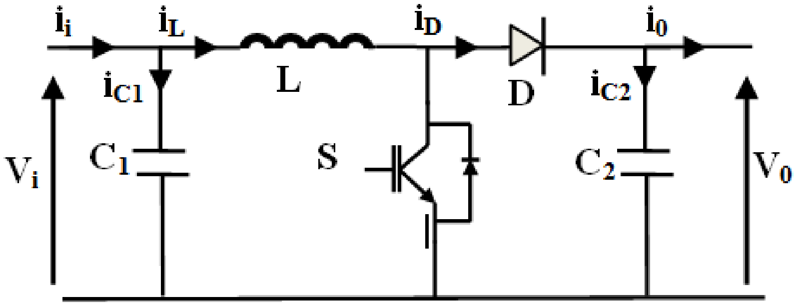


Fig. 4. Schematic diagram of a Boost converter

$$D = \frac{T_o}{T_c} = 1 - \frac{V_i}{V_o} \tag{5}$$

Where, V_i: input voltage and V_o: output voltage. The inductance and the capacitance are calculated respectively as below [8]:

$$L = \frac{D.V_i}{\delta.I_i.f)} \tag{6}$$

$$C = \frac{D.I_o}{\delta.V_o.f)} \tag{7}$$

Where, f: switching frequency, I_i: input current, I_o: output current and the ripple limit (δ = 1%).

Thus after sizing the Boost chopper, the figure.5 shows that for an input voltage of 100 V, the output has stages corresponding to the three values of the duty cycle *(D)*.

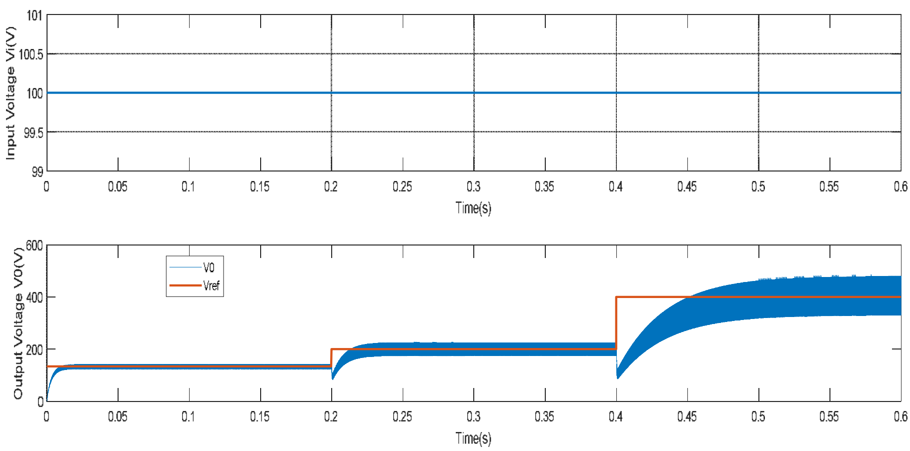


Fig. 5. Input voltage (Vi) and output voltage (Vo) of a Boost chopper with changes of (D)

2.3. Permanent Magnetic Motor

The DC motor of a photovoltaic pump converts electrical energy into mechanical energy. The PMDC motor does not need external excitation because its field winding is permanent magnetic. This type of the motor is defined by the following relationships [9,10]:
The voltage is defined by:

$$U = R_a . I_a + L_a . \frac{dI_a}{dt} + K_m . \omega_m \tag{8}$$

Where, U: DC source voltage *(V)*, I_a: armature current *(A)*, R_a: armature resistance *(Ω)*, L_a: armature inductance *(H)*, K_m: torque constant (V.s/rad) and ω_m: motor speed (rpm).

The electrical torque T_{em} *(N.m)*,

$$T_{em} = K_m . I_a \tag{9}$$

The dynamic equation is:

$$J \frac{d\omega_r}{dt} = T_{em} - T_l - B \times \omega_m \tag{10}$$

Where, J: inertia constant *(kg.m^2)* and B: constant *(N.m.s)*.
So, the PMDC equivalent circuit is shown by the Figure 6.

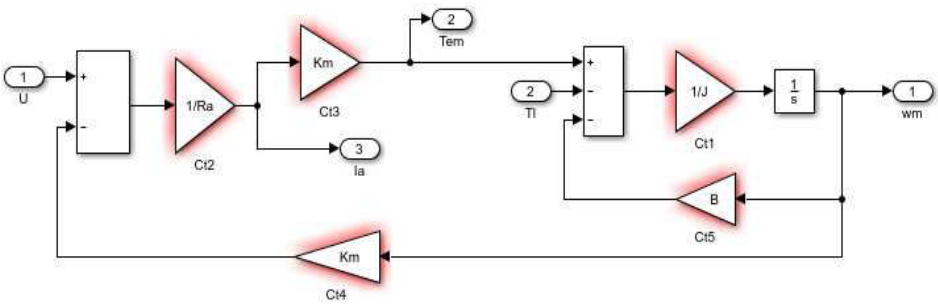


Fig. 6. Permanent magnetic DC motor model

2.4. Pump modeling

The pump is a machine that converts mechanical power into liquid power, it is directly coupled to the motor and characterized by the torque, the speed and the flow [11,12].

$$T = 4{,}8.10^{-6}. \omega^2 + 0{,}00019. \omega + 0{,}092 \tag{11}$$

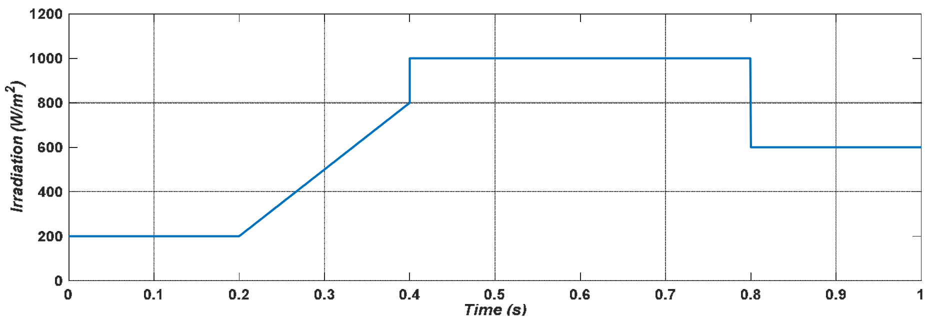
$$Q = \frac{\eta.\ P}{\rho.g.H} \tag{12}$$

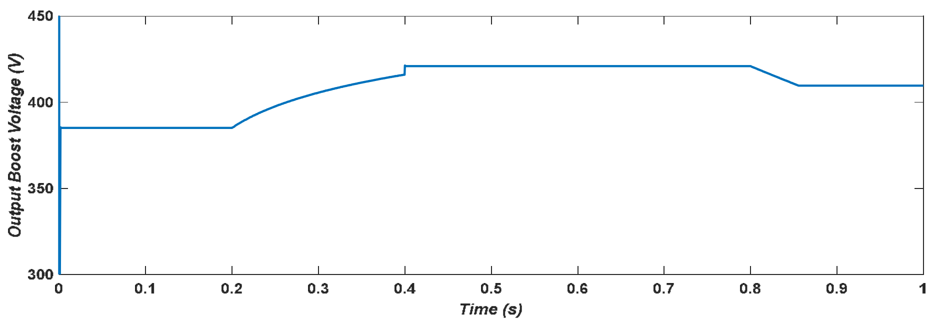
$$H = 4{,}923.10^{-3}.\ \omega^2 - 1{,}5826.10^{-5}.\ \omega.\ Q + 18144.\ Q^2 \tag{13}$$

Where, *(P)*: input power required *(ω)*, *(ρ)*: fluid density *(kg/m^3)*, *(H)*: energy head added to the flow *(m)*, *(g)*: standard acceleration of gravity *(9.81 m/s^2)*, *(Q)*: flow rate *(m^3/s)* and *(η)*: efficiency of the pump plant.

3. SIMULATION RESULTS

The operation of the system considered is analyzed taking into account a variable irradiation profile and at a temperature equal to its standard value 25°C, as shown in Figure 7.Starting with a constant irradiation level between 0s and 0.2s, the corresponding voltage as well as the other quantities represented by the same figure remain invariable.The PMDC supply voltage increases when the irradiation goes from 200W/m^2 to 1000W/m^2. This increase causes the speed of the PMDC to increase, consequently the increase in mechanical power, which results in a flow rate of the centrifugal pump proportional to the irradiation.At 0.8s there is a decrease in the irradiation from 1000W/m^2 to 600W/m^2 which causes a decrease in the speed of the PMDC which in turn causes the decrease in the pump flow.





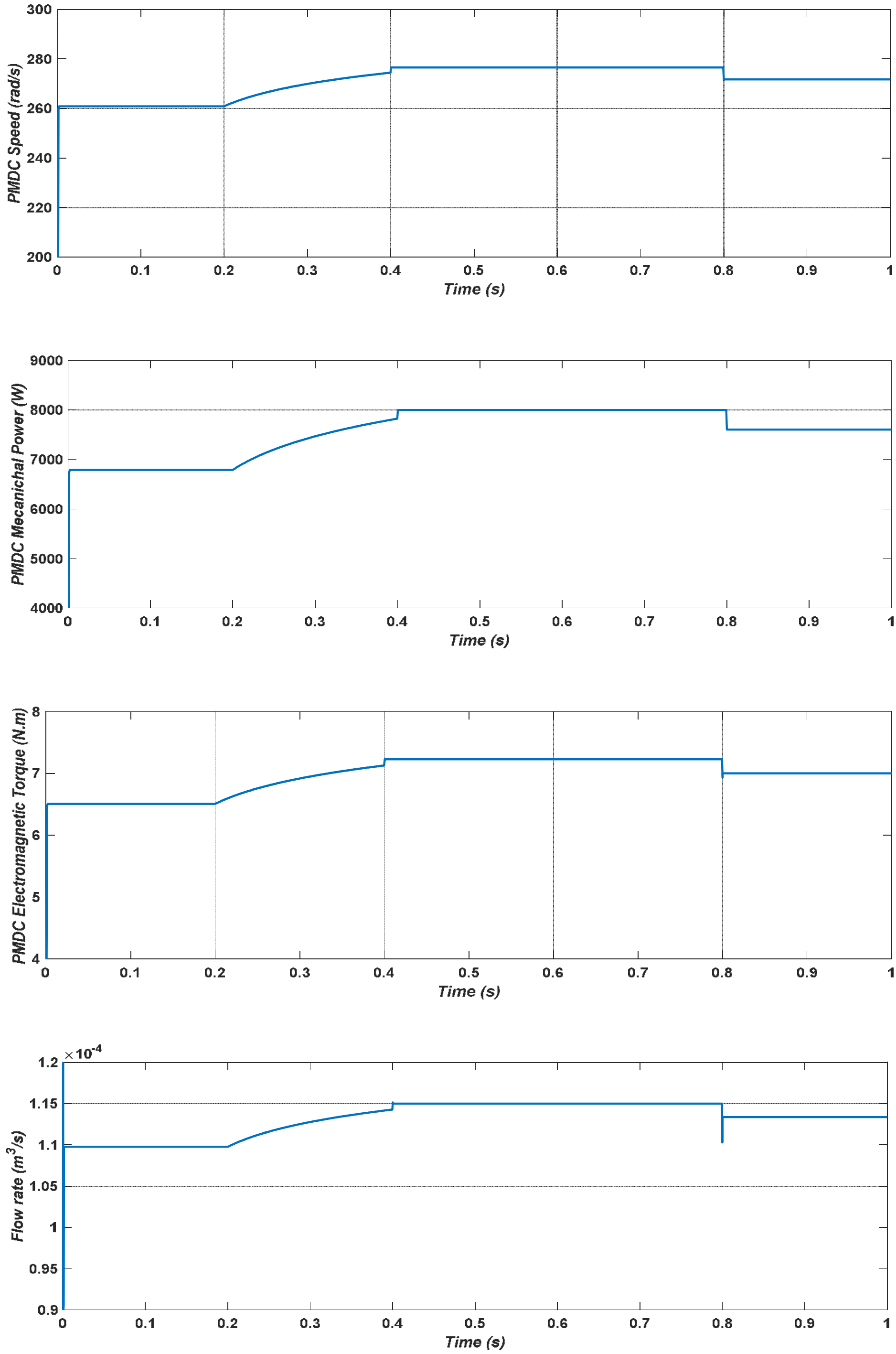


Fig. 7. Characteristics of solar water pumping system

4. CONCLUSION

This work consists of the study and operation analysis of a pumping system intended to be installed in an isolated site. Our intention waste analysis of this operation over the sun under a variable irradiation. Thus, the generalization and encouragement of such facilities for the population living in the vast Algerian Saharian areas is a promising solution to satisfy their water needs, by a simple disposal in a tank without resorting to the use of storage by battery or other alternatives , this system is less expensive and reduces the aggressiveness of the saharian climate.

NOMENCLATURE

F : Switching frequency (Hz)
I_a : Armature current (A)
I_{cc} : Short-circuit current (A)
I_d : Current through the diode (A)
I_i : Input current (A)
I_o : Output current (A)
K_m : Torque constant (V.s/rad)
L_a : Armature inductance (H)
R_a : Armature resistance (Ω)
R_p : Parallel resistance (Ω)
R_s : Serial resistance (Ω)
T_{em} Electrical torque (N.m)
U : DC source voltage (V)
V_i : Input voltage (V)
V_o : Output voltage (V)
ω_m : Motor speed (rpm)

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