VOL. 7, NO. 5, MAY 2012 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

# MATLAB BASED COMPARATIVE STUDY OF PHOTOVOLTAIC FED DC MOTOR AND PMDC MOTOR PUMPING SYSTEM

N. Chandrasekaran[1], B. Ganeshprabu[1] and K. Thyagarajah[2]
[1]Department of Electrical and Electronics Engineering, PSNA College of Engineering and Technology, Dindigul, India
[2]KSR College of Technology, Thiruchengode, India
E-Mail: chandrasekaran283@gmail.com

## ABSTRACT
Water pumping system has become one of the most feasible photovoltaic (PV) applications. Moreover, PV pumping is getting more attention in recent days mainly in remote areas where connection to the grid is technically not possible. Power generation by photovoltaic is reliable. The simplest PV water pumping system consists of a PV array connected to boost converter feeding power directly to a DC motor or PMDC motor and a pump. This paper deals with the simulation of PV based DC motor pumping system and PMDC motor pumping system. The comparison of the two systems has been done and proved a simple but efficient photovoltaic water pumping system among them. Motors and centrifugal pumps operate at variable speed in a photovoltaic pumping system. However, the characteristics of motors and pumps are usually only given for a single voltage and speed. To analyze operation of a pumping system, where the solar radiation causing variation in the photovoltaic power, the input/output relationship of the motor-pump assembly and motor characteristics must be determined. The results obtained from the simulation of the system are satisfactory. It is found that PMDC pumping system is better.

**Keywords:** pumping system, photovoltaic, direct current, permanent magnet direct current.

## INTRODUCTION
Water resources are essential for satisfying human needs, protecting health, and ensuring food production, energy and the restoration of ecosystems, as well as for social and economic development and for sustainable development. However, according to UN World Water Development Report in 2009, it has been estimated that two billion people are affected by water shortages in over forty countries, and 1.1 billion do not have sufficient drinking water (BetkaA, *et al*., 2010). There is a great and urgent need to supply environmentally sound technology for the provision of drinking water (Benlarbi K, *et al*., 2004). Remote water pumping systems are a key component in meeting this need. It will also be the first stage of the purification and desalination plants to produce potable water. In this paper, a simple but efficient photovoltaic water pumping system is presented. It provides theoretical studies of photovoltaics (PV) and its modeling techniques. Here, two types of PV based pumping systems are taken into account. DC motor pumping system and PMDC motor pumping system are considered and analyzed, where the solar radiation varies causing variation in the photovoltaic power. The block diagram of dc pumping system is shown in Figure-1.

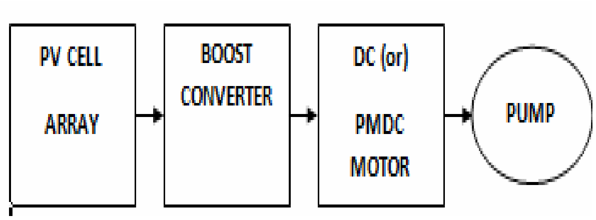


**Figure-1.** Block diagram of the photovoltaic pumping system

## PV MODULE
The module is made of 12 multi-crystalline silicon solar cells in series and provides 95W of nominal maximum power. Table-1 shows its electrical specification. The equivalent circuit of PV cell is shown in Figure-2.

**Table-1.** Electrical characteristics data of PV module taken from the datasheet.

| Electrical characteristics | Type / value |
|---|---|
| Maximum power (*Pmax*) | 95w |
| Voltage at *Pmax* (*Vmp*) | 17.2V |
| Current at *Pmax* (*Imp*) | 4.95A |
| Open-circuit voltage (*Voc*) | 22.2A |
| Short-circuit current (*Isc*) | 5.45A |

The strategy of modeling a PV module is no different from modeling a PV cell. It uses the same PV cell model (Odeh I, *et al*., 2006). The parameters are the all same, but only a voltage parameter (such as the open-circuit voltage) is different and must be divided by the number of cells. The model consists of a current source ($I_{Ph}$), a diode (D), and a series resistance ($R_{se}$). The effect of parallel resistance ($R_{Pa}$) is very small in a single module, thus the model does not include it. To make a better model, it also includes temperature effects on the short-circuit current ($I_{sc}$) and the reverse saturation current of diode (Mezghanni D, *et al*., 2007). It uses a single diode with the diode ideality factor ($n$) set to achieve the best I-V curve match.

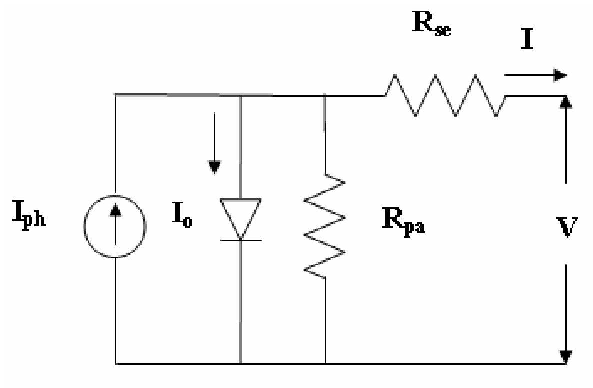


**Figure-2.** Equivalent circuit of PV cell.

$$I = I_{ph} - I_{os} \times \left( e^{\left(\frac{V+R_{se}I}{V_t a}\right)} - 1 \right) - \frac{V + R_{se}I}{R_{se}} \qquad (1)$$

The photocurrent $I_{ph}$ varies linearly with sun irradiation and depends on temperature given by

$$I_{ph} = (I_{ph} + K_i \Delta T)G / G_n \qquad (2)$$

**DC-DC BOOST CONVERTER**

The basic dc-dc boost converter circuit which can produce an output voltage greater than the source input voltage (Muhammad H. Rashid, *et al*., 2004). The circuit diagram of boost converter is given in Figure-3. The energy is stored in the inductor in the ON- period of the switch S. The current flows in the inductor, L through the switch during $t_{on}$ – period and the voltage $V_L$ across inductor is equal to $V_I$.

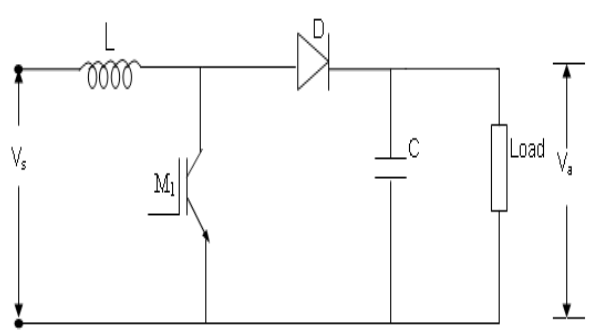


**Figure-3.** DC-DC boost converter circuit.

When switch S is opened, the stored energy in the inductance discharges in to the capacitor C and the load. During $t_{off}$ period of the static device, the inductor voltage is $V_L$ = V-$V_s$. Under steady- state operation, the voltage across the capacitor is assumed due to a large value of capacitance and also for steady operation, there must be zero average voltage across L during the time period T (T= $t_{on}$+$t_{off}$). Therefore,

$$((V_c - V_s)t_{OFF} - V_s t_{ON}) / T = 0 \qquad (3)$$

And duty cycle,

$$\delta = t_{ON} / T \qquad (4)$$

$$V_c = V_o = \frac{V_s}{1-\delta} \qquad (5)$$

Thus, theoretically the output voltage can be varied from $V_s$ to ∞ as δ is changed from 0 to 1.Generally; δ is varied from 0 to 0.8.

**PMDC MOTOR MODEL**

Many PV water pumping systems employ DC motors because they could be directly coupled with PV arrays and make a system very simple. Among different types of DC motors, a permanent magnet DC (PMDC) motor is preferred in PV systems because it can provide higher starting torque (H. Suehrke, *et al*., 1997). The PMDC motor does not require the separate dc source for the excitation of field winding. The circuit diagram of a permanent magnet DC motor is shown in Figure-4.

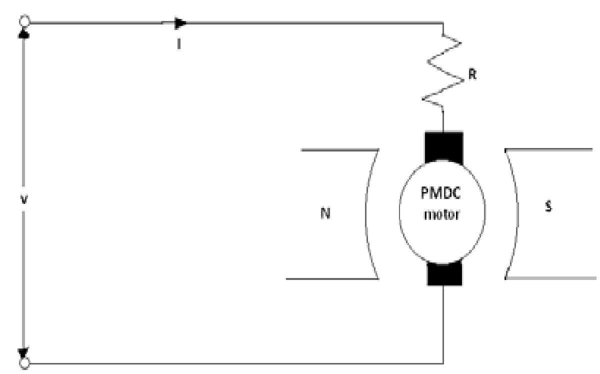


**Figure-4.** Schematic of PMDC motor.

The motor voltage equation is given by (Bhim Singh, *et al*., 1998)

$$V = E + IR + V_b \qquad (6)$$

where, V is the applied voltage, *E* is the motor e.m.f., I is the armature current, R is the armature resistance and $V_b$ is the brushes voltage drop.

The e.m.f. of a permanent magnet motor can be expressed as:

$$E = k_E \omega \qquad (7)$$

where, $k_E$ is the voltage constant and ω is angular motor speed. The motor shaft torque can be written as:

$$T = T_{em} - T_O \qquad (8)$$

where, T is the motor shaft torque, $T_{em}$ is the electromagnetic torque and $T_o$ is the torque representing the mechanical (friction and windage) and iron losses. The electromagnetic torque to the armature current is given by:

$$T_{em} = k_T I \quad (9)$$

where, $k_T$ is the torque constant.

The motor losses at load current I can be expressed as:

The motor losses = armature copper loss + brush loss + iron loss + mech. loss

For a permanent magnet motor the mechanical and iron losses are approximately independent of the armature current and may be estimated from a no-load motor test. The no load motor losses can be expressed as:

No load motor losses = no load copper loss + no load brush loss + iron loss + mech. loss

At no-load the armature losses are very small and may be neglected. As a first order approximation brush losses may also be neglected so that the motor shaft output power P = Tω, can be written as:

$$P = k_T (I - I_o)\omega \quad (10)$$

Using the fact that the $k_E = k_T$, the constants for the above model are obtained from the manufacturers rated data and $I_O$ from no load test.

## DC MOTOR MODEL

In general, DC motors are preferred because they are highly efficient and can be directly coupled with a PV module. Brushed types are less expensive and more common although brushes need to be replaced periodically (B.L. Theraja, *et al*., 2009). The speed control of a DC motor is simple. The circuit diagram of a DC motor is shown in Figure-5.

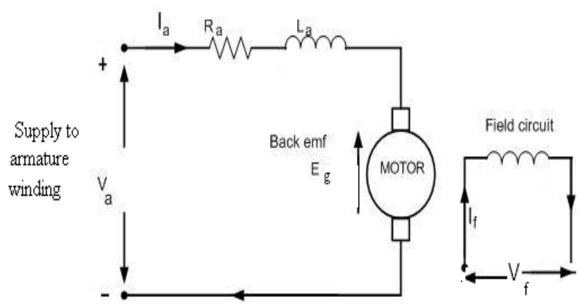


**Figure-5.** Schematic of DC motor.

The armature equation of a DC motor is shown below:

$$V_a = E_g + I_a R_a + L_a (dI_a / dt) \quad (11)$$

The description for the notations used is given below:

$V_a$ = armature voltage in volts
$E_g$ = motor back emf in volts
$I_a$ = armature current in amperes
$R_a$ = armature resistance in ohms
$L_a$ = armature inductance in Henry

The torque equation will be given by:

$$T_d = Jd\omega / dt + B\omega + T_L \quad (12)$$

where:

$T_L$ = load torque in Nm
$T_d$ = torque developed in Nm
J = moment of inertia in kg/m²
B = friction coefficient of the motor
ω = angular velocity in rad/sec

## CENTRIFUGAL PUMP MODEL

In general, two types of pumps are commonly used for water-pumping applications. One is positive displacement pump and another is centrifugal pump. In displacement pumps, the water output is directly proportional to the speed of the pump, but almost independent of head. (Nejib Hamrouni, *et al*., 2009) These pumps are used for solar water pumping from deep wells or bores. Centrifugal pumps are used for low-head applications, especially if they are directly interfaced with the solar panels. (Arrouf M, Ghabrour S, *et al*., 2007) Centrifugal pumps are designed for fixed-head applications, and the pressure difference generated increases in relation to the speed of the pump. Centrifugal pumps also have relatively high efficiency and are capable of pumping a high volume of water. Due to the above mentioned advantages the centrifugal pump is chosen in this work. Any pump is characterized by its absorptive power which is obviously a mechanical power on the shaft coupled to the pump, which is given by:

$$P = \frac{\rho g H Q}{\eta} \quad (13)$$

Useful power: power consumed of the absorptive power is given by:

$$P_u = \rho g H Q \quad (14)$$

where η, the total output; *ρ*, density ($Kg/m^3$); *G*, acceleration of gravity ($m^2/S$); *H*, height of rise (m); *Q*, flow($m^3/S$).

## SIMULATION OF DC MOTOR PUMP SYSTEM

The overall simulation model of DC pumping system fed by solar array is shown in Figure-6. The output voltage from the solar array is stepped up to the required level by means of boost converter. As the number of switches in the boost converter is less, it is economical when comparing with other power converters. Here, the MOSFET based boost converter is used which is powered by PV array. The PWM technique is used to generate the triggering pulse to the MOSFET.

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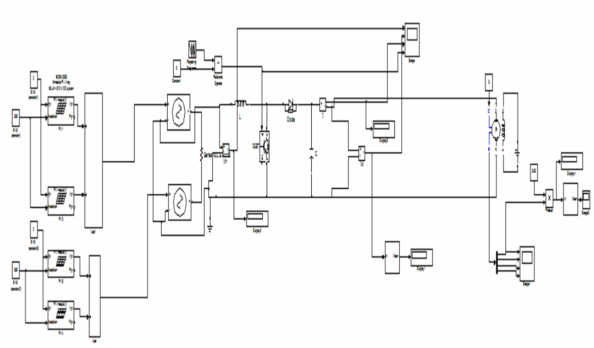

**Figure-6.** Simulink diagram of PV based DC motor system.

The simulink output for the performance characteristics of DC motor is shown in Figure-7.

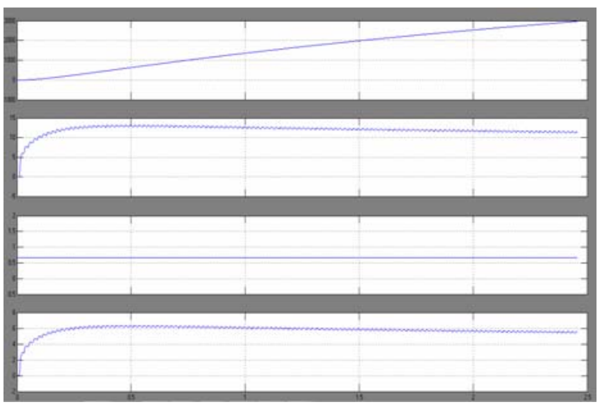

**Figure-7.** Simulation output for DC motor characteristics.

## SIMULATION OF PMDC MOTOR PUMP SYSTEM

The overall simulation model of PMDC pumping system fed by solar array is shown in Figure-8. The output voltage from the solar array is increased to required level by means of boost converter. Here also, the MOSFET based boost converter is used which is powered by PV array. The PWM technique is used to generate the triggering pulse to the MOSFET.

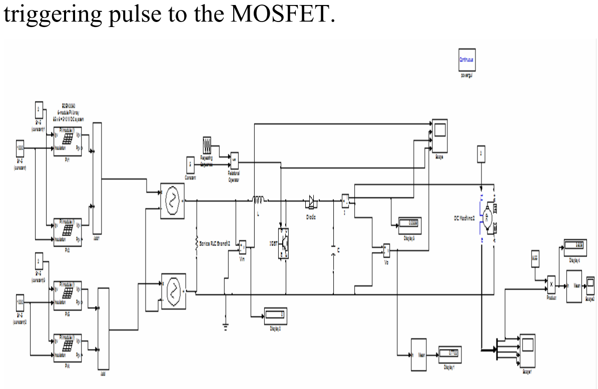

**Figure-8.** Simulink diagram of PV based PMDC motor system.

The simulink output for the performance characteristics of DC motor is shown in Figure-9. The characteristics include the speed, armature current, field current and torque of the PMDC motor, respectively.

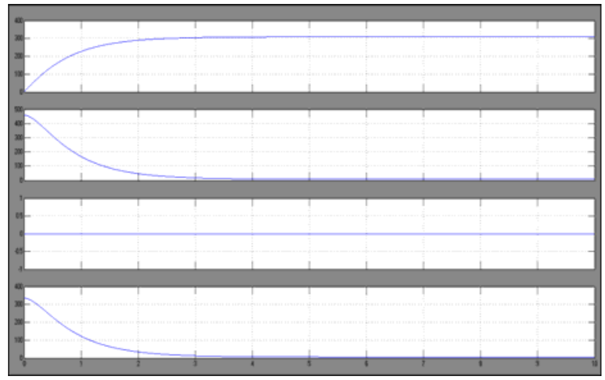

**Figure-9.** Simulink output of PMDCmotor characteristics.

## COMPARISION

The PMDC motor is small in size and rugged when compared with DC motor. The PMDC motor will not require a separate dc source for the excitation of field coils. The speed range of the PMDC motor is more. The comparision of field current and speed of two motor are shown in Figure-10 and Figure-11 respectively. From the comparison curves for the speed and field current, it is found that PMDC motor is better than the DC motor for the pumping applications.

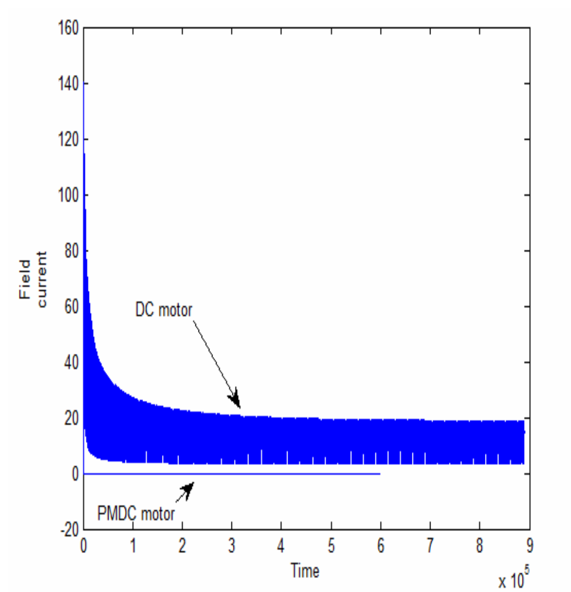


**Figure-10.** Comparision between field current of DC motor and PMDC motor.

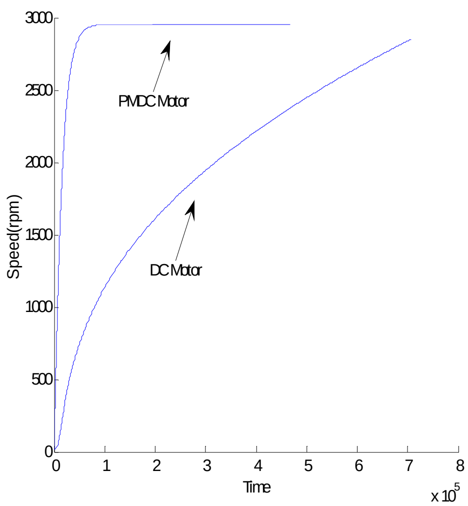


**Figure-11.** Comparision between speed of DC motor and PMDC motor.

## CONCLUSIONS

This work makes a path on the modeling and simulation of the photovoltaic drives systems using MATLAB. The various components like PV array, boost regulator and pump of Photovoltaic driving systems have been modeled with practical data and it is validated using MATLAB. The results obtained from the simulation of the system are satisfactory. It is found that PMDC pumping system is better. The experimental arrangement for the DC motor and PMDC motor pumping system fed by PV cell may be considered as future work.

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