UACEE International Journal of Advancements in Electronics and Electrical Engineering
Volume 1: Issue 1

Analysis Of Dc Solar Water Pump and Generalized Photovoltaic Model Using Matlab/Simulink

B.Naresh [1] **P.Madhu** [2] **K.R.K.Prasad** [3]
[1, 2 ,3] Asst.Prof Dept of EEE
Sai Spurthi Institute Of Technology
B.Gangaram, sathupally, A.P,India.
[1]e-mail:nareshbangari@gmail.com,

***Abstract*—This paper presents the implementation of a simple but efficient photovoltaic water Pumping system by generalized photovoltaic model using Matlab/Simulink software package, which can be representative of PV cell,module, and array for easy use on simulation platform. It provides theoretical studies of photovoltaics and modeling techniques using equivalent electric circuits. The system employs the maximum power point tracker (MPPT).In this paper, a PV-powered water pump using Permanent Magnet DC Motor (PMDC) is taken into account. The modeling of PV cell, Boost converter and PMDC motor has been studied and developed. The overall PMDC pumping system fed by solar cell is simulated and its results are obtained.**

Key words: array, generalized, mppt, PMDC Motor.

I. Introduction

Pumping water is a universal need around the world and the use of photovoltaic power is increasing for this application. A solar powered pump is a pump running on the power of the sun. A solar powered pump can be very environmentally friendly and economical in its operation. The system operates on power generated using solar PV (photovoltaic) system. The photovoltaic array converts the solar energy into electricity, which is used for running the motor pump set.

In this paper, a simple but efficient photovoltaic water pumping system is presented. It provides theoretical studies of photovoltaics (PV) and its modeling techniques. It also investigates in detail the maximum power point tracker (MPPT), a power electronic device that significantly increases the system efficiency. At last, it presents MATLAB simulations of the system and makes comparisons with a system without MPPT.

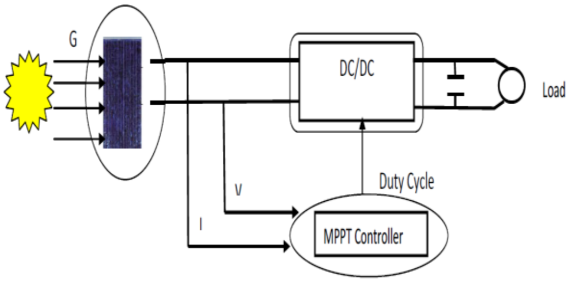


Fig. 1 Block diagram of proposed PV pumping system

II. Photovoltaic Models

Solar cell is basically a p-n junction fabricated in a thin wafer or layer of semiconductor. The electromagnetic radiation of solar energy can be directly converted electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater then the band-gap energy of the semiconductor are absorbed and create some electron-hole pairs proportional to the incident irradiation. Under the influence of the internal electric fields of the p-n junction, these carriers are swept apart and create a photocurrent which is directly proportional to solar insolation. PV system naturally exhibits a nonlinear I-V and P-V characteristics which vary with the radiant intensity and cell temperature.

A. *Solar Cell Model*

A general mathematical description of I-V output characteristics for a PV cell has been studied for over the pass four decades [1]-[3]. Such an equivalent circuit-based model is mainly used for the MPPT technologies. The equivalent circuit of the general model which consists of a photo current, a diode, a parallel resistor expressing a leakage current, and a series resistor describing an internal resistance to the current flow, is shown in Fig. 2(a).

The voltage-current characteristic equation of a solar cell is given as

$$I = I_{ph} - I_s[\exp(q(V + IR_s)/KT_cA) - 1] - (V + IR_s)/R_{sh} \qquad (1)$$

where I_{PH} is a light-generated current or photocurrent, I_S is the cell saturation of dark current, q (= 1.6 $^{x10-19}$ c) is an electron charge, k (= 1.38 $\times$ 10^{-23} J/K) is a Boltzmann’s constant, T_C is the cell’s working temperature, A is an ideal factor, R_{SH} is a shunt resistance, and R_S is a series resistance. The photocurrent mainly depends on the solar insolation and cell’s working temperature, which is described as

$$I_{P\square} = [I_{sc} + K_I(T_c - T_{Ref})]\lambda \qquad (2)$$

where I_{SC} is the cell’s short-circuit current at a 25^{0}C and 1kW/m$_2$, K_I is the cell’s short-circuit current temperature coefficient, T_{Ref} is the cell’s reference temperature, and λ is the solar insolation in kW/m$_2$. On the other hand, the cell’s saturation current varies with the cell temperature, which is described as

$$I_S = I_{RS}(T_C/T_{Ref})^3 \exp[qE_G(1/T_{Ref} - 1/T_C)/kA] \qquad (3)$$

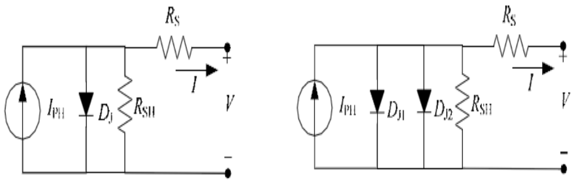
where I_{RS} is the cell’s reverse saturation current at a reference temperature and a solar radiation, E_G is the bang-gap energy of the semiconductor used in the cell. An even more exact mathematical description of a solar cell, which is called the double exponential model as shown in Fig. 2(b) [4], is derived from the physical behavior of solar cell constructed from polycrystalline silicon. The shunt resistance R_{SH} is inversely related with shunt leakage current to the ground. In general, the PV efficiency is insensitive to variation in R_{SH} and the shunt-leakage resistance can be assumed to approach infinity without leakage current to ground. On the other hand, a small variation in R_S will significantly affect the PV output power.

The appropriate model of PV solar cell with suitable complexity is shown in Fig. 1(c) . Equation (1) can be rewritten to be

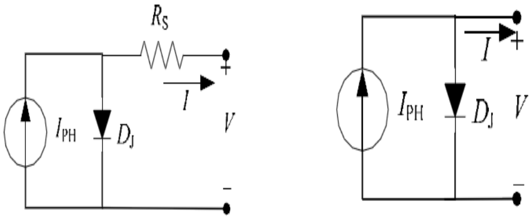
$$I = I_{ph} - I_s[\exp(q(V + IR_s)/KT_cA) - 1] \qquad (4)$$

For an ideal PV cell, there is no series loss and no leakage. to ground, i.e., R_S = 0 and R_{SH} = ∞ . The above equivalent circuit of PV solar cell can be simplified as shown in Fig. 1(d) [1],[5]-[6]. The (1) can be rewritten to be

$$I = I_{ph} - I_s[\exp(qV/KT_cA) - 1] \qquad (5)$$



(a) General model (b)Double exponential model



(c) Appropriate model (d) Simplified model

Fig.2 Equivalent circuit models of PV cell.

B. Solar Module and Array Model

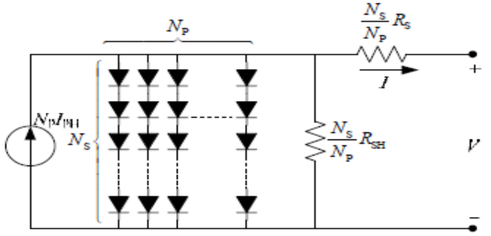
Since a typical PV cell produces less than 2W at 0.5V approximately, the cells must be connected in series-parallel configuration on a module to produce enough high power. A PV array is a group of several PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage. The equivalent circuit for the solar module arranged in N_P parallel and N_S series is shown in Fig. 3(a). The terminal equation for the current and voltage of the array becomes as follows

$$I = N_P I_{PH} - N_P I_S[\exp(q(V/N_S + IR_S/N_P)/kT_C A) - 1] - (N_P V/N_S + IR_S)/R_{SH} \qquad (6)$$

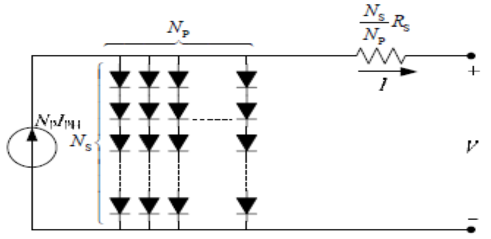
In most commercial PV products, PV cells are generally connected in series configuration to form a PV module in order to obtain adequate working voltage. PV modules are then arranged in series-parallel structure to achieve desired power output. An appropriate equivalent circuit for all PV cell, module, and array is generalized and expressed in Fig. 3(b).

It can be shown that $N_S = N_P = 1$ for a PV cell, $N_P = 1$ and N_S : series number of cells for a PV module, and N_S and N_P : series-parallel number for a PV array. The most simplified model [6], of generalized PV module is depicted in Fig. 3(c). The equivalent circuit is described on the following equation

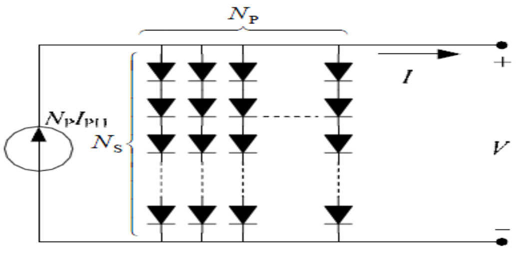
$$I = N_p I_{ph} - N_p I_s [\exp(qV/N_s K T_c A) - 1] \qquad (7)$$



(a) General model



(b) Generalized model



(c) Appropriate model

Fig.3 Equivalent circuit models generalized pv

III. Modeling of DC Water pump

Many PV water pumping systems employ DC motors (instead of AC motors) because they could be directly coupled with PV arrays and make a very simple system. Among different types of DC motors, a permanent magnet DC (PMDC) motor is preferred in PV systems because it can provide higher starting torque. Figure 4 shows an electrical model of a PMDC motor. When the motor is turning, it produces a back emf, or a counter electromotive force, described as an electric potential (*E*) proportional to the angular speed (*ω*) of the rotor. From the equivalent circuit, the DC voltage equation for the armature circuit is:

$$V = I.R_a + K.\omega \qquad (8)$$

where: R_a is the armature resistance.

The back emf is $E=K\cdot\omega$ where: *K* is the constant, and *ω* is the angular speed of rotor in *rad/sec*.

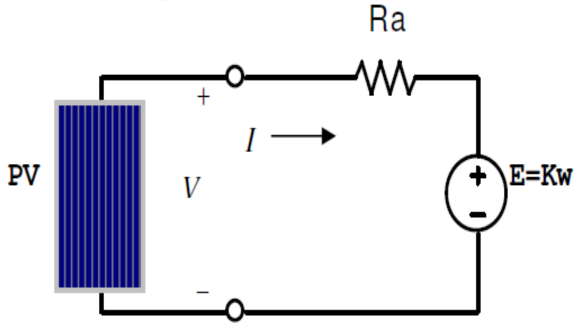


Fig.4 Electrical model of PMDC mptor

The motor shaft torque can be written as

$$T = T_{\varepsilon\mu} - T_o \qquad (9)$$

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 by

$$T = K_T I \qquad (10)$$

where, k_T is the torque constant.

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

$$P = K_T (I - I_o)\,\omega \qquad (11)$$

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. The motor efficiency can now be written as follows

$$\eta_{motor} = K_T \frac{I - I_0}{I} \frac{\omega}{V} \qquad (12)$$

The current I_o is a function of the applied voltage and rotational speed. These dependencies may be obtained from a motor no load test.

IV. Simulation Models and Results

For a PV cell with an ideal I-V characteristic, its opencircuit voltage and short-circuit current are given as V_{OC} = 0.596V and I_{SC} = 2.0A , respectively. In addition, $N_S = N_P = 1$ for a PV cell. Both I-V and P-V output characteristics of generalized PV model for a cell are shown in Figs. 6-7

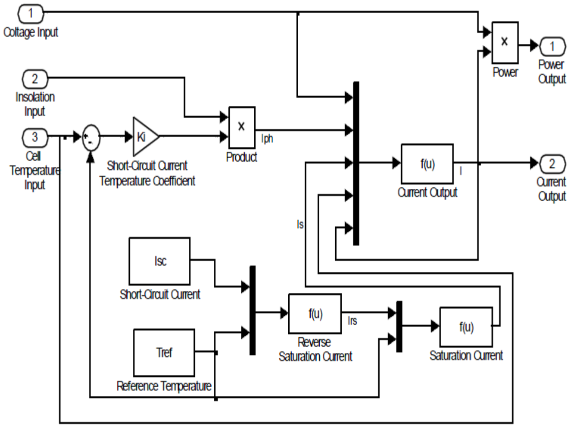


Fig.5 Simulink block of generalized PV cell.

Table 1. Electrical characteristics of PV model

Electrical characteristics	
Maximum power (P_{max})	150W
Voltage at P_{max}	34.5 V
Current at P_{max}	4.35 A
Open circuit voltage	43.5 V
Short circuit current	4.75 A
Temperature COfficient of I_{sc}	0.065±0.015%/ ^{0} c
Temperature Cofficient of V_{0c}	-160± 20 mv / ^{o} c
Temperature Cofficient of power	-0.5±0.05% / ^{o}c
NOCT	47± 2 ^{O}C

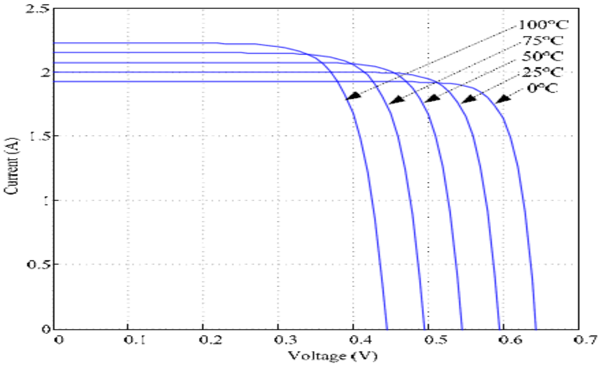


Fig.6 I-V output characteristics with different T_c

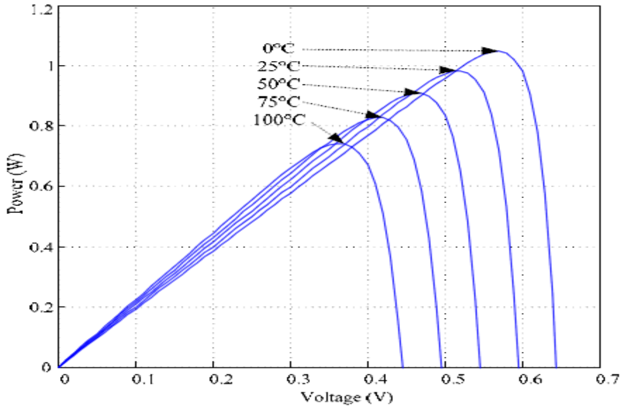
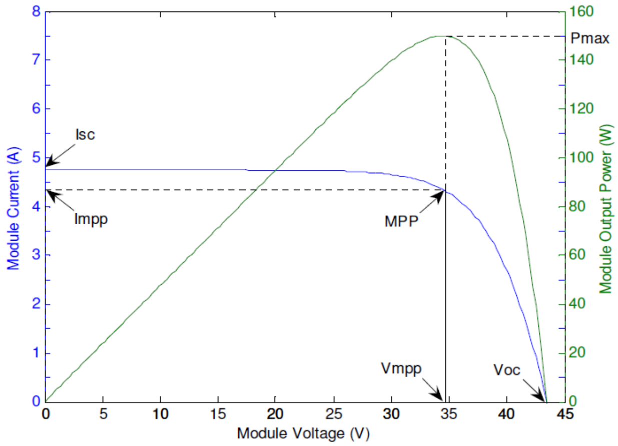


Fig.7 P-V output characteristics with different T_c



To model a permanent magnet DC motor, the SIMULINK model applies a constant field, as shown in Figure.8. Since the water pump is a positive displacement type, the load torque is also constant. The value is selected to draw the maximum power of 150W at the maximum voltage of 30V. The voltage source applies a 0-30V ramp at the rate of 1V per second. Then, the change of load resistance (*Rload*) is observed, as shown in Figure.9. [7]-[10]

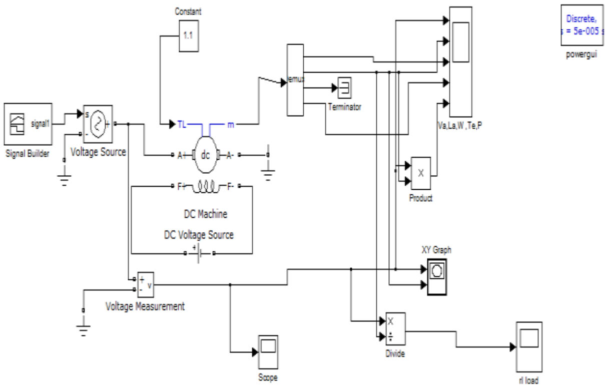


Fig.8 SIMULINK model of permanent magnet DC pump motor

Figure.9 shows an example of current-voltage relationship (*I-V* curve) of a DC motor. Applying the voltage to start the motor, the current rises rapidly with increasing voltage until the current is sufficient to create enough starting torque to break the motor loose from static friction [16]. At start-up (ω =0), there is no effect of back emf, therefore the starting current builds up linearly with a steep slope of *1/Ra* on the *I-V* plot as shown in Figure .9 Once it starts to run, the back emf takes effect and drops the current, therefore the current rises slowly with increasing voltage.

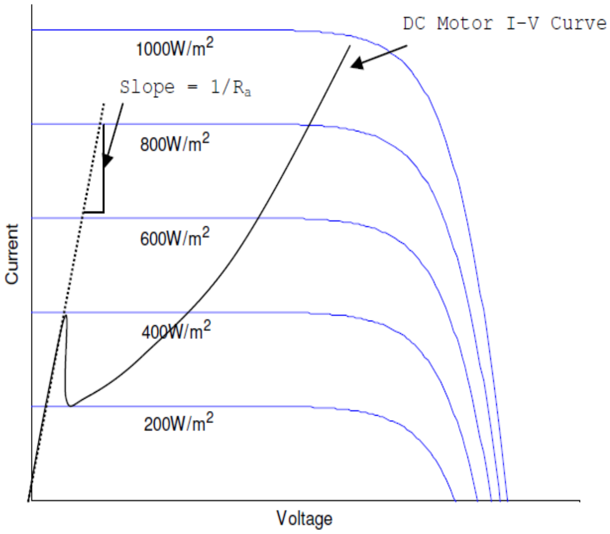


Fig .9 **P**V I-V curves with varying irradiance and a DC motor I-V curve

V.Conclusion

This paper introduces the modeling and simulation of the photovoltaic pumping systems using Matlab Simulink . The results obtained from the simulation of the system are promising and satisfactory. It is understood that PMDC pumping system is economical for low power range when comparing with the other pumping systems. The discharge rate of water and efficiency of the PMDC pumping system is better than the AC pumping system. The experimental analysis may be considered as the future scope of this work.

References

[1] S. W. Angrist, , *Direct Energy Conversion*, Allyn and Bacon, Inc., 4th edition, 1982, pp. 177-227.

[2] O. Wasynczuk, "Dynamic behavior of a class of photovoltaic Power systems," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-102, no. 9, 1983, pp. 3031-3037.

[3] J. C. H. Phang, D. S. H. Chan, and J. R. Philips, "Accurate Analytical method for the extraction of solar cell model parameters," *Electronics Letters*, vol. 20, no. 10, 1984, pp.406-408.

[4] J. A. Gow and C. D. Manning, "Development of a photovoltaic array model for use in power-electronics simulation studies," *IEEProceedings- Electric Power Applications*, vol. 146, no. 2, 1999, pp.193-199.

[5] O. Wasynczuk, "Modeling and dynamic performance of a Line commutated photovoltaic inverter system," *IEEE Transactions on Energy Conversion*, vol. 4, no. 3, 1989, pp. 337-343.

[6] R. Messenger and J. Ventre, *Photovoltaic Systems Engineering*, CRC Press, 2000, pp.41-51.

[7] Castañer, Luis & Santiago Silvestre *Modelling Photovoltaic Systems, Using PSpice* John Wiley & Sons Ltd, 2002

[8] Sharaf A. M., Abdulla Ismail, R. A. El-Khatib & S. I. Abu-Azab "A Photovoltaic Utilization System with Bang-Bang Self-Adjusting Maximum Energy Tracking Controller" *International Journal of Energy Research*,

*Volume 22, Issue 12*December 1998, page 1091 – 1098

[9] Rashid, Muhammad H. Editor-in-Chief *Power Electronics Handbook* Academic Press, 2001

[10] Kyocera Solar Inc. *Solar Water Pump Applications Guide* 2001 (downloaded from www.kyocerasolar.com)

[11] Masters, Gilbert M. *Renewable and Efficient Electric Power Systems* John Wiley & Sons Ltd, 2004.