# SOLAR POWERED PMDC MOTOR DRIVE

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**Abstract**

In order to make solar energy competitive with the other forms of renewable energies, a better exploitation of its advantages especially environmental side, this will be possible only with the development of the less expensive and high output efficiency systems. In this paper, the modeling and simulation has been done in Simulink software available with MATLAB for a solar photovoltaic (PV) powered industrial type permanent magnet DC (PMDC) motor drive.

*Keywords:* Photovoltaic Energy, PMDC motor, Photovoltaic Module.

## 1. Introduction

Energy has become an important and one of the basic infrastructures required for the economic development of a country. Energy security is imperative for sustained growth of economy. The concern for environment, due to excessive use of fossil fuels, has led to a remarkable global effort to harness alternative energy resources. The renewable energy resources, such as, solar, wind, biomass, geothermal, etc. are environment friendly and perennial in nature.

The growing demand for electrical energy throughout the world has motivated the use of new renewable sources of energy. Among the unconventional renewable energy sources that have been studied, PV energy is now becoming a promising economical renewable/alternate energy source. Except its higher initial installation costs, the PV energy has many advantages: it is reliable and requires little maintenance. It costs little to operate and almost has no environmental impact. It's both modular and flexible in terms of economical sizes and range of applications. It is also most suited to arid and developing countries [3].

The stand-alone photovoltaic (PV) utilization system displays an inherently nonlinear current-voltage relationship, requiring a dynamic online search and identification of the optimal maximum power point (MPP). The performance of any PV system depends also on the electric load operating conditions. When designing the PV system, the combined effect of the electric load, ambient temperature and solar irradiation variations should be considered all.

The use of new efficient photovoltaic solar cells (PVSCs) has emerged as an alternative measure of

renewable green power, energy conservation and demand-side management. Owing to their initial high costs,, PVSCs have not yet been a fully attractive alternative for electricity users who are able to buy cheaper electrical energy from the utility grid. However, they have been used extensively for water pumping and air conditioning in remote and isolated areas where utility power is not available or is too expensive to transport.

Solar energy can be a major source of power. Its potential is 178 billion MW which is about 20,000 times the world's demand. So far it could not be developed on a large scale because of large space requirement, uncertainty of availability of energy at constant rate, due to clouds, winds, haze, etc. Utilization of solar energy is of great importance to India since it lies in a temperature climate of the region of the world where sun light is abundant for a major part of the year. The applications of solar energy which are enjoying most success today are solar water heating, solar cookers, food refrigeration, solar furnaces and solar photovoltaic (PV) cells. In this work, solar photovoltaic cells, which can be used for conversion of solar energy directly into electricity for water pumping in rural agricultural purposes is concentrated.

## 2. DC Motor

DC motors have lots of desirable properties. Some of them are reliability, durable, Low cost, and low operation voltages, having positive conversion coefficients between electrical and mechanical components, having size and design variation [5].

A permanent magnet dc motor (PMDC) is one of the DC motor types. PMDC system converts electrical power provided by a voltage source to mechanical power provided by a spinning rotor by means of magnetic coupling. The armature coil of the DC motor can be represented by an inductance ($L_m$) in series with resistance ($R_m$) and with a series induced voltage ($e_m$), which opposes the voltage source.

A differential equation for the equivalent circuit can be derived by using Kirchhoff's voltage law around the electrical loop.

$$V_m (k) = R_m I_a (k) + L_m d I_a (k) / dt + e_m (k) \qquad (1)$$

Where:
- $e_m (k) = K_E \ w_m (k)$
- $i_1 =$ constant; therefore $K_E = K_T$

The sum of torques of the motor must be equal zero, therefore,

$$T_e (k) - J d w_m (k) / dt - B w_m (k) - T_L (k) = 0 \qquad (2)$$

The electromagnetic torque is proportional to the current through the armature winding and can be written as $T_e = K_T i_a$

The load torque is given by

$$T_L = K_0 + K_1 w_m + K_2 w_m^2$$

Where $i_a$ and $w_m$ are motor armature current and speed.

## 3. Water Pumping Systems and Photovoltaic Power

A water pumping system needs a source of power to operate. In general, AC powered system is economic and takes minimum maintenance when AC power is available from the nearby power grid. However, in many rural areas, water sources are spread over many miles of land and power lines are scarce. Installation of a new transmission line and a transformer to the location is often prohibitively expensive. Windmills have been installed traditionally in such areas; many of them are, however, inoperative now due to lack of proper maintenance and age. Today many stand-alone type water pumping systems use internal combustion engines. These systems are portable and easy to install. However, they have some major disadvantages, such as: they require frequent site visits for refuelling and maintenance, and furthermore diesel fuel is often expensive and not readily available in rural areas of many developing countries.

PV systems are highly reliable and are often chosen because they offer the lowest life-cycle cost, especially for applications requiring less than 10KW, where grid electricity is not available and where internal-combustion engines are expensive to operate. If the water source is 1/3 mile (app. 0.53Km) or more from the power line, PV is a favourable economic choice [6].

### 3.1. *Water pump*

Two types of pumps are commonly used for PV water pumping applications: positive displacement and centrifugal. Positive displacement types are used in low-volume pumps and cost-effective. Centrifugal pumps have relatively high efficiency and are capable of pumping a high volume of water. A typical size of system with this type pump is at least 500W or larger. There is a growing trend among the pump manufacturers to use them with brushless DC motors (BDCM) for higher efficiency and low maintenance. However, the cost and complexity of these systems will be significantly higher. Water pumps are driven by

various types of motors. AC induction motors are cheaper and widely available worldwide. The system, however, needs an inverter to convert DC output power from PV to AC power, which is usually expensive, and it is also less efficient than DC motor-pump systems. In general, DC motors are preferred because they are highly efficient and can be directly coupled with a PV module or array. Brushed types are less expensive and more common although brushes need to be replaced periodically (typically every two years). There is also an aforementioned brushless type [6].

The water pump chosen here for its size and cost is submersible solar pump. It is diaphragm-type positive displacement pump equipped with a brushed permanent magnet DC motor and designed for use in standalone water delivery systems, specifically for water delivery in remote locations. The rated maximum power consumption is 150W between 2,700L and 5,000L. It operates with a low voltage (12~30V DC) and its power requirement is as little as 35W.

### 3.2. Photovoltaic cell

Photons of light with energy higher than the band-gap energy of PV material can make electrons in the material break free from atoms that hold them and create hole-electron pairs.

These electrons, however, will soon fall back into holes causing charge carriers to disappear. If a nearby electric field is provided, those in the conduction band can be continuously swept away from holes toward a metallic contact where they will emerge as an electric current. The electric field within the semiconductor itself at the junction between two regions of crystals of different type, called a p-n junction.

The PV cell has electrical contacts on its top and bottom to capture the electrons. When the PV cell delivers power to the load, the electrons flow out of the n-side into the connecting wire, through the load, and back to the p-side where they recombine with holes. Note that conventional current flows in the opposite direction from electrons [3].

### 3.3. Modelling a photovoltaic cell

The use of equivalent electric circuits makes it possible to model characteristics of a PV cell. The same modelling technique is also applicable for modelling a PV module.

The simplest model of a PV cell consists of an ideal current source in parallel with an ideal diode. The current source represents the current generated by photons (often denoted as $I_{ph}$ or $I_L$), and its output is constant under constant temperature and constant incident radiation of light.

There are two key parameters frequently used to characterize a PV cell. Shorting together the terminals of the cell, the photon generated current will follow out of the cell as a short-circuit current ($I_{sc}$). Thus, $I_{ph} = I_{sc}$. When there is no connection to the PV cell (open-circuit), the photon generated current is shunted internally by the intrinsic p-n junction diode. This gives the open circuit voltage ($V_{oc}$). The PV module or cell manufacturers usually provide the values of these parameters in their datasheets [9].

The output current (I) from the PV cell is found by applying the Kirchhoff's current law (KCL) on the equivalent circuit.

$$I = I_{sc} - I_d \qquad (3)$$

Where $I_{sc}$ is the short-circuit current that is equal to the photon generated current and $I_d$ is the current shunted through the intrinsic diode. The diode current $I_d$ is given by the Shockley's diode equation;

$$I_d = I_0 \, (e^{qVd/kT} - 1) \qquad (4)$$

Where:
- $I_0$ is the reverse saturation current of diode (A),
- q is the electron charge ($1.602 \times 10^{-19}$ C),
- $V_d$ is the voltage across the diode (V),
- k is the Boltzmann's constant ($1.381 \times 10^{-23}$ J/K),
- T is the junction temperature in Kelvin (K).

Replacing $I_d$ of the equation 3 by the equation 4 gives the current-voltage relationship of the PV cell where V is the voltage across the PV cell and I is the output current from the cell.

The reverse saturation current of diode ($I_0$) is constant under the constant temperature and found by setting the open-circuit condition. Using the equation 4, let I = 0 (no output current) and solve for $I_0$.

$$0 = I_{sc} - I_0 \, (e^{qVd/kT} - 1)$$
$$I_{sc} = I_0 \, (e^{qVd/kT} - 1)$$
$$I_0 = I_{sc} \, /(e^{qVd/kT} - 1)$$

The PV cell output is both limited by the cell current and the cell voltage, and it can only produce a power with any combinations of current and voltage on the I-V curve. It also shows that the cell current is proportional to the irradiance.

### 3.4. *Photovoltaic module*

A single PV cell produces an output voltage less than 1V, about 0.6V for crystalline silicon (Si) cells, thus a number of PV cells are connected in series to archive a desired output voltage. When series-connected cells are placed in a frame, it is called as a module. Most of commercially available PV modules with crystalline-Si cells have either 36 or 72 series-connected cells. A 36-cell module provides a voltage suitable for charging a 12V battery, and similarly a 72-cell module is appropriate for a 24V battery. This is because most of PV systems used to have backup batteries, however today many PV systems do not use batteries; for example, grid-tied systems. Furthermore, the advent of high efficiency DC-DC converters has alleviated the need for modules with specific voltages. When the PV cells are wired together in series, the current output is the same as the single cell, but the voltage output is the sum of each cell voltage.

Also, multiple modules can be wired together in series or parallel to deliver the voltage and current level needed. The group of modules is called an array. The module is made of 72 multi-crystalline silicon solar cells in series and provides 150W of nominal maximum power [2].

## 4. Modelling of PMDC Pump Motor

SIMULINK is chosen for this purpose because it offers a tool called "SimPowerSystems" which facilitates modelling of DC motors with its DC machine tool box. The model is then put into the MATLAB simulation [1]. The flow rate of water in positive displacement pumps is directly proportional to the speed of the pump motor, which is governed by the available driving voltage. They have constant load torque to the pump motors. It has the normal operating voltage of 12 to 30V and the maximum power of 150W.

To model a permanent magnet DC motor, the SIMULINK model applies a constant field, as shown in Fig. 1. The parameters of DC machine shown that correspond to the actual pump motor are unknown, thus they are chosen by modification of the default values and estimation from other references.
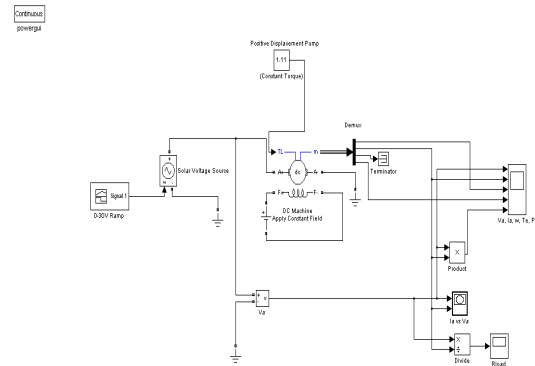
### 4.1. *Simulation results*



Fig.1. SIMULINK model of permanent magnet DC pump motor

Fig. 2 shows SIMULINK DC machine block parameters.
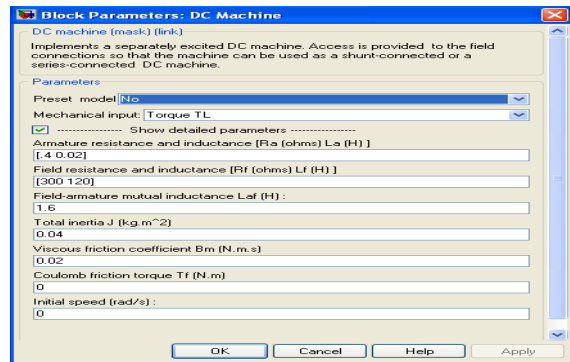


Fig.2. SIMULINK DC machine block parameters
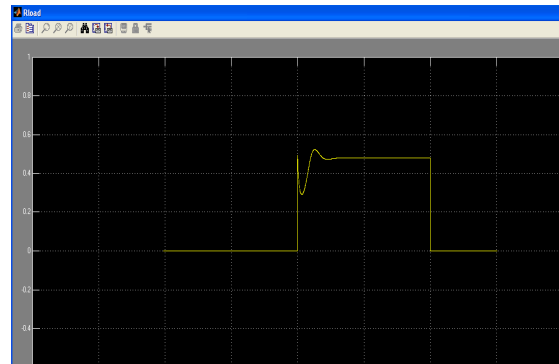
Fig. 3 shows SIMULINK plot of $R_{load}$.



Fig.3. SIMULINK plot of $R_{load}$

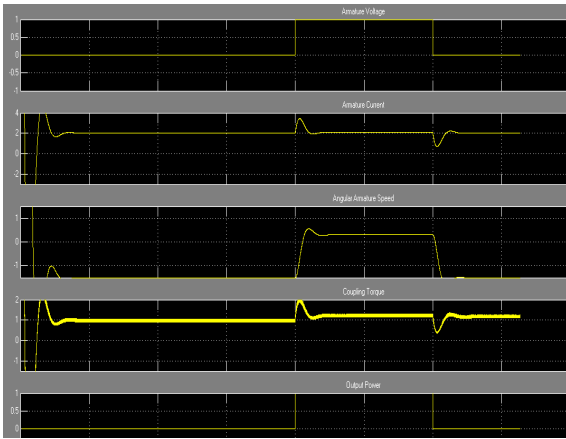Fig. 4 shows SIMULINK plots of $V_a$, $I_a$, w, $T_e$ & P.



Fig.4. SIMULINK plots of $V_a$, $I_a$, w, $T_e$, P

## 5. Conclusion & Future Scope

In this work, a simple but efficient photovoltaic water pumping system is presented. It provides theoretical studies of photovoltaic's (PV) and its modelling techniques. At last, it presents MATLAB simulations of the system. Simulations use SimPowerSystems in SIMULINK to model a DC pump motor, and then the model is transferred into MATLAB. The model used for simulations of DC water pump gives results within a reasonable range. The accuracy of model is, however, uncertain because the parameters are only estimates. If tests could be run on the real water pump motor or an equivalent sized motor to determine reasonable entries to SIMULINK block parameters, this could lead to more accurate simulation runs. Also, simply increasing the size of system and using a larger motor (5hp or above) could allow for better results in SUMILINK, though many PV water pumps rarely use such large motors. Physical implementation of the system remains for future research. It may also involve performance analysis on the actual system and comparisons with simulations.

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