Harnessing Maximum Power from Solar PV Panel for Water Pumping Application

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Abstract. The problem of fast depleting fossil fuels is triggering exploration of alternate sources of electricity. Among such sources, Solar Photo Voltaic (PV) energy is gaining prominence due to its plentiful availability. Water pumping is an important application of solar PV power. However people are not opting for it in large numbers as the 'cost per watt' for solar pumping systems is high. The cost component can be reduced by harnessing more power per unit installed capacity of the solar panel. One method of realising this is by Maximum Power Point Tracking (MPPT) wherein a Power Electronic (PE) converter is used to match pump with the PV panel. Present paper deals with the MATLAB based simulation study of solar PV driven Permanent Magnet (PM) DC motor (brushed) Pump System. Two cases are considered: a) System without MPPT b) System with MPPT. It is shown that by varying duty cycle of the converter at different radiation levels, the pump speed and hence the useful mechanical output can be enhanced with MPPT. The simulation study reveals that the output power becomes the maximum when the motor voltage becomes the maximum. Hence it is proposed that the motor voltage can be used as a control parameter for varying the duty cycle of the converter in achieving maximum output.

Keywords: Solar PV, Water Pumping, Maximum Power Point Tracking.

1 Introduction

Water pumping is an important application of solar PV power. However people are not opting for it in large numbers as the 'cost per watt' for solar pumping systems is high. This is evident from the fact that around the world only 60000 solar pumping systems are installed [1]. This number is just 5000 in India [2]. Hence it is necessary to devise the means of reducing the cost component. This can be realised by harnessing more power per unit installed capacity of the solar panel.

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Solar PV panel exhibits typical Voltage vs. Current (V-I) (Fig.1) and Power vs. Voltage (P-V) (Fig.2) characteristics [3] as a function of solar radiation. At each radiation, represented proportionally by the panel short circuit current Iph, there exists a particular operating point at which the output power of the panel becomes the maximum. The process of controlling the operating point of solar PV panel so that it always corresponds to Maximum Power at the corresponding radiation is referred to as Maximum Power Point Tracking (MPPT). This needs matching between the Load and PV panel and can be accomplished by connecting a Power Electronic (PE) converter with variable duty cycle (D) as the interphase between the PV panel and the load [4]. Presently different control parameters are employed to vary D viz.:

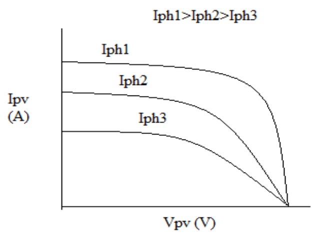

Fig. 1. 'V-I' plot for PV Panel

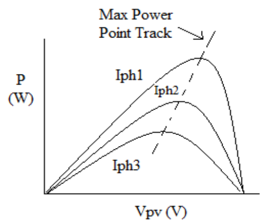

Fig. 2. 'V-P' plot for PV Panel

i) Power: In this method, the PV panel power (Ppv) is monitored continuously and D is varied till Ppv becomes maximum. But for computing power, it is necessary to perform multiplication as P = Vpv x Ipv. However, the need for multiplication operation makes the controller comparatively complicated.

ii) Speed: In this method speed of the pump (w) is monitored and D is varied till w becomes maximum which automatically means output power also becomes maximum. But speed being a mechanical parameter, monitoring it requires a transducer making the control system comparatively complicated.

Present paper deals with the simulation of solar PV driven water pump system. Two cases are considered: a) System without MPPT b) System with MPPT. Simulation is done using MATLAB - Simulink (version 7.5).

2 Solar Water Pumping

A typical Solar PV water pumping system with and without the provision of MPPT is shown in Fig.3 and Fig.4 respectively. Details of different components considered for simulation and testing purpose are given below.

PV Panel: The PV generator selected is parallel combination of two panels, each of rating: 74Wp (totalling 148Wp), Vm = 16.4 V, Im = 4.5A, Sun Technics Make. PV panel can be represented by a simple equivalent circuit [5] with a current source having a diode in parallel and resistance Rs in series (Fig.5). The current and power are given by the equations (1) & (2).

$$Ipv = Iph - Id \tag{1}$$

$$Ppv = Ipv \times Vpv \tag{2}$$

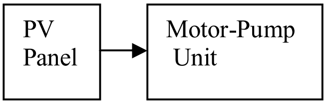

Fig. 3. Solar Pumping without MPPT

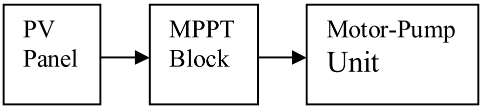

Fig. 4. Solar Pumping with MPPT

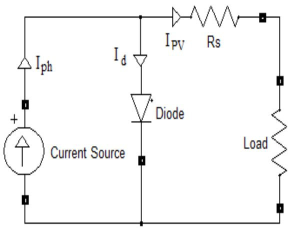

Fig. 5. PV Panel Equivalent Circuit

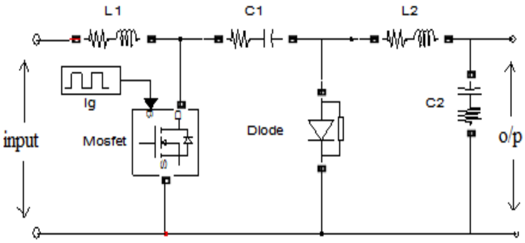

Fig. 6. Buck-Boost Converter

where Iph: short circuit current of the PV panel (A); Ipv: Load Current (A); Id: Diode Current (A); Vpv: Output Voltage (V); Ppv: Output Power (W). From experiment, Rs is found to be = 2.13 ohm. Iph, being directly proportional to the radiation, is used as a measure of radiation.

Motor-Pump Unit: It is a monoblock of PMDC Motor (brushed) and Centrifugal Pump. The specifications are: 12V, 70-100W, total head: 9m, Tata BP Solar make, Motor Inertia: 6.83×10^{-3} Kgm^2, Armature Resistance: 0.7 ohm, Armature Inductance: 0.12×10^{-3} H, C: voltage constant = 0.033 V/rad/sec. The DC motor is modelled representing the permanent magnet as separate excitation with constant voltage source.

Load Equation: The pump is used to lift water with delivery head, Hd = 5m and suction head, Hs = 1m. The characteristic 'Torque (T, Nm) vs. Speed (w, rad/sec)' is experimentally found yielding the load equation (4).

$$T = 4.8 \times 10^{-6} w^2 + 0.00019 w + 0.092 \quad (4)$$

Converter (MPPT Block): Buck-boost converter (Fig.6) is employed as MPPT block [6]. The switching is done by MOSFET operating at 20 kHz. The converter is designed for a duty cycle range of 0.3 to 0.6.

3 Case I: System without MPPT

In this case, PV panel is connected directly to the motor-pump unit (Fig.7). Input required for this block is the information of radiation and the same is given in terms of Iph. The output variables are: current & voltage for panel as well as Motor (Ipv= Ia, Vpv= Va); Motor speed & torque (w, T). The simulation is run for different Iph and plots of speed and output power as a function of Iph are obtained (Fig.9 & 10).

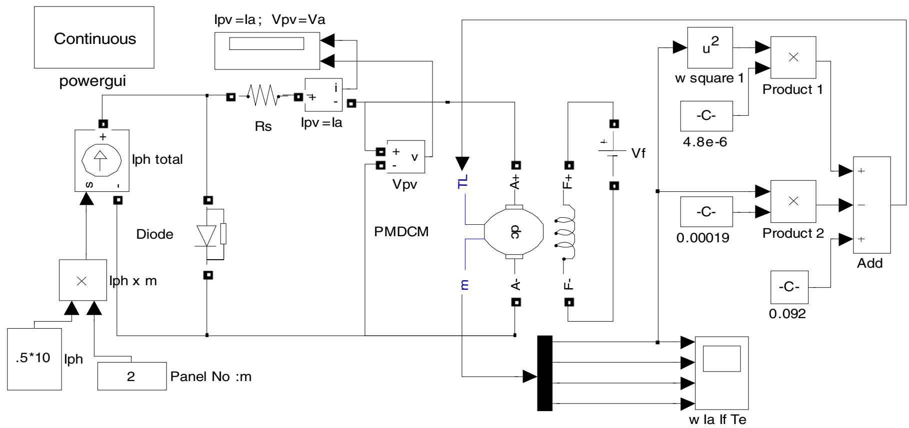

Fig. 7. Panel Pump Model without MPPT

4 Case II: System with MPPT

The complete model of PV panel, the converter and the motor-pump unit is realised as shown in Fig.8. Inputs required for this module are: a) Radiation level (given in terms of Iph). b) Duty cycle D for converter. The output variables are: panel current & voltage (Ipv, Vpv), Motor current & voltage (Ia, Va), Motor speed & torque (w, T). The simulation is run for different Iph and at each radiation for different duty cycles D. The plot of maximum power and speed as a function of Iph is obtained (Fig.9 & 10).

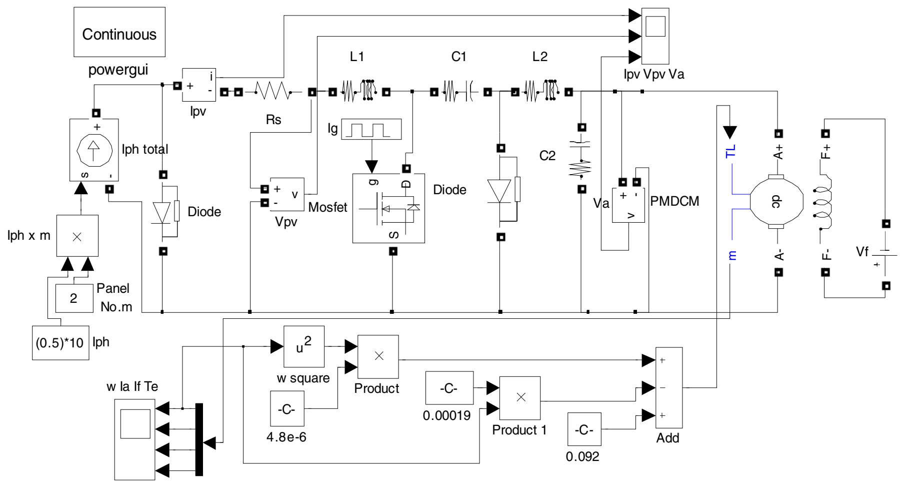

Fig. 8. PV Panel - Pump Model with MPPT

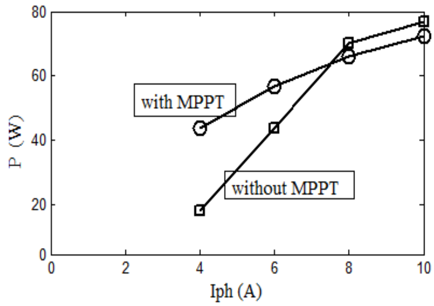

Fig. 9. 'Iph vs. P' comparison

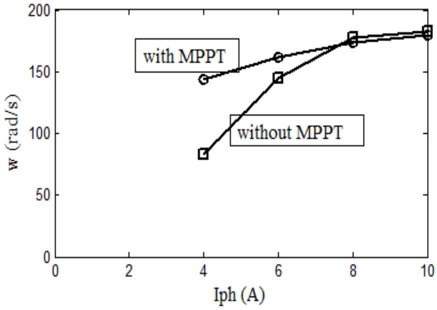

Fig. 10. 'Iph vs. speed' comparison

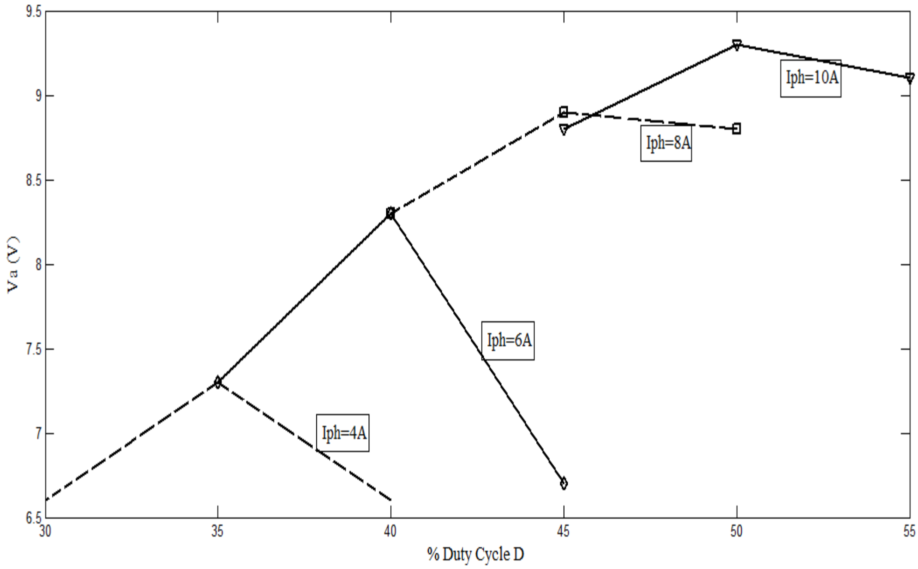

Fig. 11. '%D vs. Va' for pump with MPPT

5 Critical Observations and Discussions

Some important observations are made from the simulation study and results presented in the above sections 4 & 5:

a) On comparing the two schemes, it is found that in the scheme with MPPT there is an increase in the output power P and hence the speed w of the pump. This feature is quite considerable at lower radiation values and decreases as radiation increases (Fig.9 & Fig.10).

b) In the case of scheme with MPPT, it is observed that at a particular radiation, the output power becomes the maximum when the motor voltage Va becomes the maximum (Fig.11). This means for a particular radiation, there exists a specific motor voltage (Vamax) at which output power becomes maximum and this occurs at a specific duty cycle. Hence the motor voltage Va can be used as a control parameter for varying the duty cycle of the converter in achieving MPPT. Va can be continuously monitored and D continuously varied so as to realise Maximum Va which automatically assures maximum output power at the corresponding radiation. Monitoring Va is simple as it is an electrical parameter and using it in a controller is simple as there is no multiplication operation involved. This method to realise MPPT is simple than the other methods which use either power or speed as control parameters.

6 Conclusions

Water pumping is an important application of solar PV power. Present paper has dealt with the simulation of solar PV driven water pump system. Two cases are considered: a) Motor pump unit connected to the panel directly and b) the Motor pump unit connected to the panel through a PE Converter for MPPT. It is shown that by varying duty cycles at different insolation levels, the pump speed and hence the useful mechanical output power can be enhanced with MPPT. An important observation made is that the output power becomes the maximum when the motor voltage becomes the maximum. Hence it is proposed that the motor voltage can be used as a control parameter for varying the duty cycle of the converter for the system with MPPT in achieving maximum output.

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