INVESTIGATION OF PERFORMANCE IMPROVEMENT IN A SOLAR PUMPING SYSTEM WITH MAXIMUM POWER POINT TRACKER(MPPT)

Özcan Atlam [1] Feriha Erfan Kuyumcu [2]
e-mail: oatlam@kou.edu.tr e-mail: erfan@kou.edu.tr
[1] University of Kocaeli ,Thecnical Education Faculty, 41300, İzmit, Kocaeli, TURKEY
[2] Kocaeli Üniversity, Electrical Engineering Faculty , 41300, İzmit, Kocaeli, TURKEY

Key words: Photovoltaics, Solar Pumping system

ABSTRACT
In this paper, a solar pumping system with MPPT is investigated for performance improvement. As compared to normal system without MPPT, 82 percent additional performance can be achieved at sampled irradiance levels. Especially under low solar radiations, system torque is improved. So active operating region is expanded by MPPT. System consists of permanent magnet dc motor (PM), centrifugal pump and Siemens - SM55 solar panels. In the analysis, Matlab/Simulink program is used for system modelling.

I. INTRODUCTION
In photovoltaic pumping system, maximum power transfer is expected between photovoltaic solar panel (PV) and pump motor at wide irradiance interval. If not, performance may drop to low values or collapse.

A typical PV has nonlinear current-voltage (I-V) characteristics. So PV maximum power points vary with irradiance. Generally in direct coupled systems, a mismatch exists between PV and pump motor characteristics in respect of operation on maximum power of PV. To overcome this problem, control circuits with maximum power tracker (MPPT) are added to the system. For dc loads, MPPT consists of a dc/dc converter which is connected between PV and dc motor. The electronic device continuously matches the output characteristic of the PV to the input characteristic of the dc motor. For a given irradiance, PV maximum power points are estimated by sensing open circuit voltage(V_o) or short circuit current (I_{sc}) of PV [1,2]. The chopper ratio of DC/DC converter is adjusted according to defined maximum power point. Hence, impedance matching is provided for the tracking. For this study, it is assumed that, control losses are neglected. Additional performance is analyzed for sampled PV pumping system parameters,.

II. SYSTEM MODEL
PV pumping system consists of permanent magnet dc motor (PM), centrifugal pump and Siemens - SM55 solar panels.

In this study, SM55 type Siemens solar panel is used as PV generator. The I-V expression of the PV system, which consists of Np strings in parallel and each parallel string consists of Ns panels in serial, is given by equation (1).

$$Vp=Ns*1.8390*\ln[(s*Np*3.45-Ip+Np*2.58*10^{-5})/(Np*2.58*10^{-5})] \quad (1)$$

Where, *Vp* is output voltage, and *Ip* is output current of the PV system. The cofficient *s* is the ratio of an irradiance level to the standard irradiance level of 1000 W/m^2. Hence the value *s* identifies the rate of irradiance with dimension per unit (pu.). In this model, to obtain the Ip-Vp curves, values of *Ip* are varied between zero and *s*Np*3.45* under any *s*. The power (P) is;

$$P=Vp*Ip \quad (2)$$

For a given *s*, the maximum power (*Pm*) is equal to maximum of *Vp*Ip* values. At maximum power condition, the current is *Ipm*, voltage is *Vpm*. Hence as a function of *s*, *Pm* is;

$$Pm(s)=Vpm(s)*Ipm(s) \quad (3)$$

For PM-centrifugal pump load, following expressions can be given[3-5]:

$$Vmot= Imot.Ra +K\omega \quad (4)$$

$$Eb= K.\omega \quad (5)$$

$$T=K.Imot =kp.\omega^2 \quad (6)$$

$$Pmech =Vmot.Imot- Imot^2.Ra =T.\omega \quad (7)$$

At above expressions, *Vmot* : is motor terminal voltage(V), *Imot* : armature current (A), *Ra* :armature winding resistance (ohm) , *Eb*: back emf (V), *T:* Torque of motor (Nm), ω : angular shaft speed (rad/s), *kp*: torque constant (Nm/(rad/s)^2), *Pmech*: mechanical power (W). Using equations (1-7), system performance can be analyzed. The operating points of owerall system exist when equations (1,4,6) are satisfied at same time step.

III. MPPT CONDITION
For tracking maximum power points of PV with dc motor, system uses a dc/dc converter. This converter may be

buck or boost type in respect of normal(direct coupled) operating characteristic of PV- pump motor. Assuming power converter is ideal, all of PV power is delivered to motor [3]. Under MPPT conditions, motor is driven by maximum power of PV.

$$Vmot.Imot = Vpm.Ipm \quad (8)$$

Motor input characteristics are defined by chopper ratio (*D*) of dc/dc converter. For maximum power tracking, there is a critical value of *D* with respect to given a irradiance level ($D=D_m$). Hence motor input voltage and current expressions:

$$Vmot = Vpm.D_m \quad (9)$$

$$Imot = Ipm / D_m \quad (10)$$

In order to determine D_m, using by equations (3-7) firstly shaft speed ω_m and back emf Eb_m at maximum power are calculated for a given s (irradiance). These values also depend on pump load.

$$\omega_m = [(Pm-Im^2Ra)/kp]^{1/3} \quad (11)$$

$$Eb_m = K.\omega_m \quad (12)$$

When motor input values (current and voltage) are transformed to PV side by use of D_m,

$$D_m^2 .Vpm - D_m.Eb_m - Ipm.Ra = 0 \quad (13)$$

The positive root of equation (13) is equal to D_m . Hence using equations (9,10) motor input values are solved. And then performance can be analyzed under MPPT condition. For normal system without MPPT, PV output current and voltage values are equal to those of motor input. For analysis, PV pumping system is simulated based on Matlab/Simulink program environment as shown figure 1.

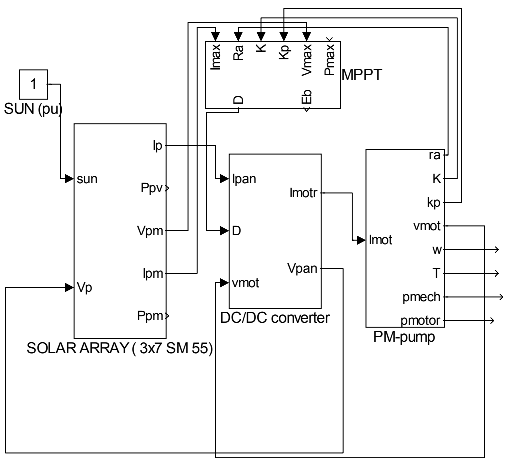

Figure 1. PV pumping system at Matlab/Simulink

IV. RESULTS AND DISCUSSION

PV pumping system is analyzed for both MPPT and normal conditions. PV system consists of 3x7 SM55 solar panels (for single SM55, Vo=21.7 V., Isc =3.4 A., Ipm=3.1 A., Vpm=17.4 V at 1000 W/m^2). Other parameters are : Ra=2 ohm, K=0.6 and kp=0.001 $Nm/(rad/s^2)$. The ratio of irradiance level *s* is sampled as 0.1-1pu. According to analysis results, system performance is improved by MPPT. These results are shown by figures (2-6). For the average mechanical power at sampled irradiance levels, PV system with MPPT gives approximately 82 percent additional performance compared to normal system. Motor input power (Pmot=Vmot.Imot) mtches to PV maximum power point for overall irradiance levels.

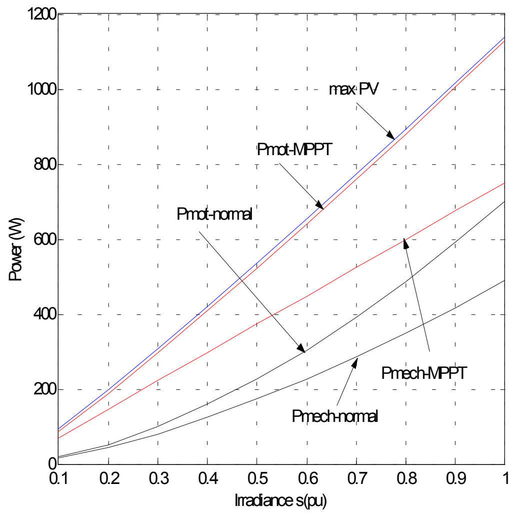

Figure 2. Power versus *s* irradiance

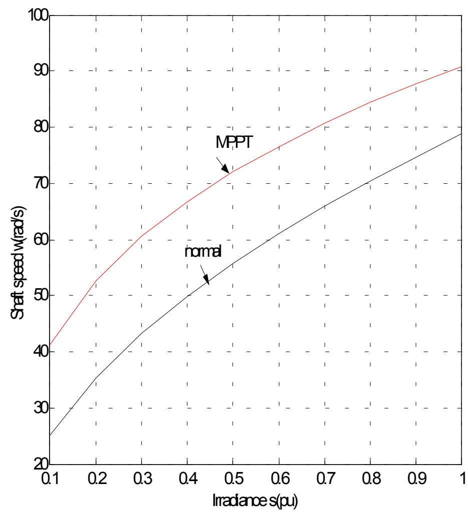

Figure 3. Shaft speed versus *s* irradiance

Also using MPPT, higher speed and torque are provided at same irradiance conditions. Assuming least operating torque of system is equal to 2 Nm, normal system must wait until irradiace gets to 0.3 pu. Whereas for system with MPPT, 0.1 pu irradiance level is sufficient to actively operate. Thus active operating region of pumping system is expanded by MPPT.

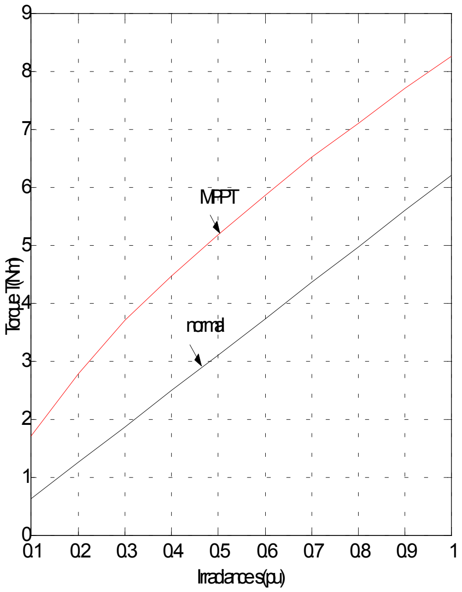

Figure 4. Torque versus versus *s* irradiance

When the system uses MPPT, the motor pump is driven by lower voltage and higher current relative to PV(figure 5,6). But powers of both PV and motor are equal. This driving form causes the torque to increase. DC/DC converter operates as buck type.

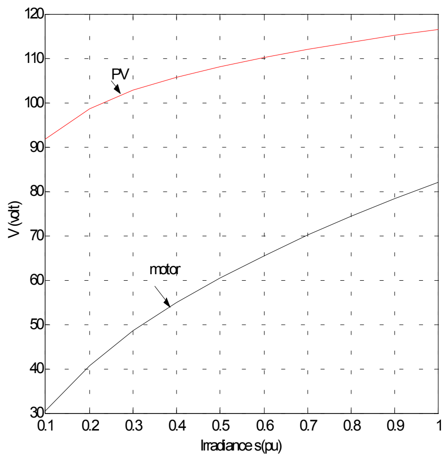

Figure 5. Operating voltages of PV and motor with MPPT

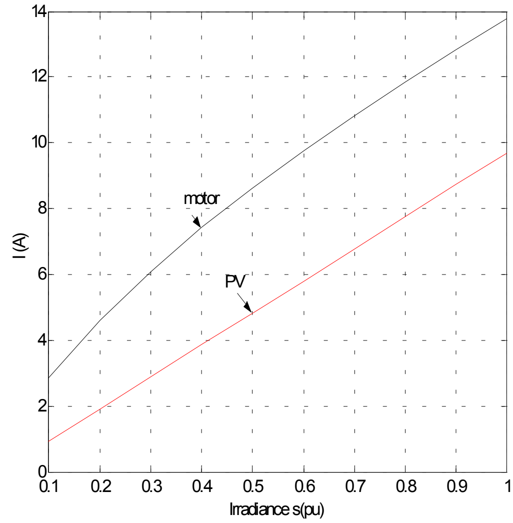

Figure 6. Operating currents of PV and motor with MPPT

In reality, some control losses due to MPPT, may exist. But this doesn't affect the performance advantage achieved by MPPT. The load conditions should be considered, while designing MPPT. Because optimal chopper ratio of dc/dc converter depends on pump load too.

REFERENCES

1. D. Langridge, W. Lawrance and B. Wichert, Development Of A Photo-voltaic Pumping system Using A Brushless DC motor And Helical Rotor Pump,Solar Energy, Vol.56, No.2, pp. 151-160, 1996.
2. Moreas-Duzat,R.Mercia,Analytical and Experimantal Photovoltaic Water Pumping System, Universitat-Oldenburg, 2000.
3. V.C.Mummadi, Steady –State and Dynamic Performance Analysis Of PV Supplied DC Motors Fed From Intermediate Power Converter, Solar Energy Meterial &Solar Cells, Vol.61, pp.365-381, 2000.
4. H Suehrcke, J. Appelbaum, B. Reshef, Modelling a Permanent Magnet DC motor/ Centrifugal Pump Assembly In a Photovoltaic Energy System, Solar Energy, Vol.59, No.1-3, pp.37-42, 1997.
5. M. Saided., Optimal Design Parameters for a PV Array Coupled To A DC Motor Via DC-DC Transformer", IEEE Transactions on Energy Conversion, Vol.6, No.4, pp.593-598. 1991.