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OPTIMIZATION OF POWER TRANSFER IN A SOLAR ENERGY SYSTEM

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ABSTRACT This article presents an approach to maximize the transfer of power to all load elements in a solar energy system. Transfer of power from the solar panel to batteries and motor utilizes a maximum-power-point-tracker (MPPT) and a DC/DC converter. This converter operates on optimum transformation ratios. Losses of the motor are minimized such that the energy fed to the load is kept minimum.

1. INTRODUCTION

This article describes the optimization of power transfer in a solar energy system. The system consists of 200 modules of solar or PV panels and 50 packs of lead-acid batteries supplying a motor with a helical pump. This system has to withstand 24 hours of operation as, for instant, a blood supplying system for a clinic in rural area, water circulation system for a resort in remote places, etc. The batteries can be either source or load in the system, while solar panels are weather dependent source. Both sources exhibit highly nonlinear characteristics. The structure of the system is shown in fig.1. In order to maximally use the energy available from the PV panels, detailed consideration of the power transfer throughout the system must be conducted.

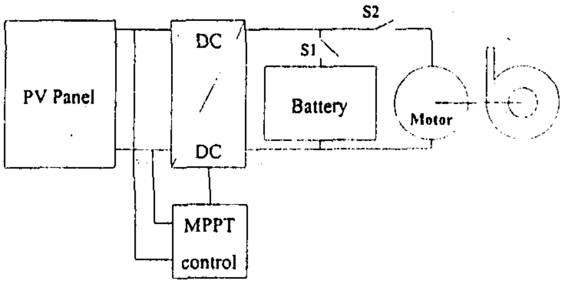

Fig. 1 Structure of a solar-energy system

It is always said that the solar energy is free. However, to convert it into a useful form of electricity is very expensive. Moreover, the electrical characteristics of the PV panels are highly nonlinear as described by [1-8]. These characteristics based on technical data from [8] are depicted in fig.2 and 3. The maximum power point tracker or MPPT control plays an important role to track maximum power available from the panels and lock them as instantaneous operating points. Those maximum power points are also shown in fig.2 and 3. The MPPT controller is usually implemented using microprocessor technology. Its description can be found in [5,8].

Our work described herein is concerned with how to maximally transfer the available power from the PV panel to feed the components on the right of the DC/DC converter (see fig.1). The converter acts as an agent to maximize the power transfer via its operation under optimum transformation ratios. These ratios are presented in the next section. Losses minimization for the motor coupled with pump is described in the paper.

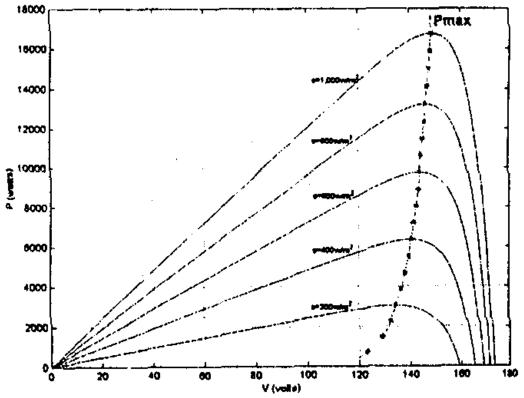

Fig. 2 Power vs voltage characteristics of PV panels (vary due to solar insolation)

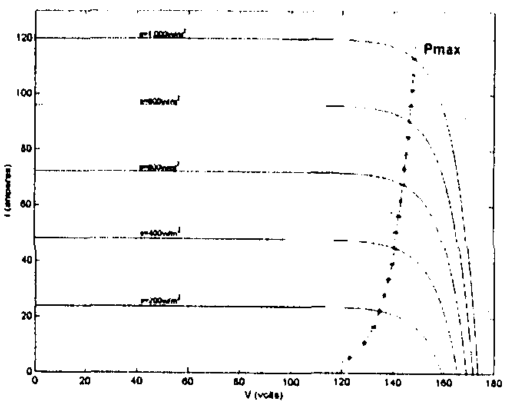

Fig. 3 Current vs voltage characteristics of PV panels (vary due to solar insolation)

2. DERIVATION OF THE TRANSFORMATION RATIO (D) FOR THE DC/DC CONVERTER

The DC/DC converter acts as a power-transferring device to the rest of the components of the system. This converter operates according to precalculated transformation ratio (D). In terms of electronic implementation of the device, this ratio can be referred to as firing delay factor of the switching components. There are 3 modes of operation to consider, ie (1) the PV panels supply the motor with helical pump directly, (2) the PV panels supply the battery banks under charging scheme, and (3) the PV panels supply both battery banks and motor coupled with pump simultaneously. The derivation of the ratio Ds must take into account the nonlinear characteristics of the panels, motor, and batteries. To derive these ratios requires the knowledge of component's models. Due to the limited space, the readers should refer to [1-8] for the PV panel model, [9-12] for the battery model, and [13-16] for the motor model. The helical pump is considered a parabolic mechanical load [15]. The summary of these derived ratios is what follows.

2.1 PV panels supply motor with helical pump

Running the motor and pump at steady flow is of our interest. During this operation the motor voltage can be expressed by

$$V_t = R_a I_a + k_b \left[\frac{-B/k + \sqrt{(B/k)^2 + (4k_b I_a/k)}}{2} \right] \tag{1}$$

where V_t is the motor armature voltage (V)
I_a is the armature current (A)
R_a is the armature resistance (Ω)
k_b is the motor constant (V/rad/sec)
B is the viscous friction of the motor (N.m/rad/sec), and
k is the pump constant (N-m/(rad/sec)^2).

Providing the MPPT tracks the maximum power available from the PV panels (P_{max}), to maintain this power to drive the motor one can state that

$$D_m = \frac{V_t}{V_{Pmax}} = \frac{I_{Pmax}}{I_a} \tag{2}$$

From the Eq. (1) and (2), case (1) transformation ratio can be expressed by

$$D_m - \frac{k_b}{V_{Pmax}} \left(\frac{-B}{2k} + \frac{1}{2}\sqrt{\left(\frac{B}{k}\right)^2 + \left(\frac{4k_b I_{Pmax}}{D_m k}\right)} \right) - \frac{I_{Pmax} R_a}{D_m V_{Pmax}} = 0 \tag{3}$$

Conventional numerical technique can be used to solved the Eq. (3) for the solutions of the ratio.

2.2 PV panels supply battery banks

Charging the batteries during the day can be achieved by using solar energy available. In this case, batteries are the PV panel's load. Even though batteries are nonlinear components, during charge time their terminal characteristics can be approximated by

$$V_b = V_0 + (R_{tot} \cdot I_b) \tag{4}$$

where V_b is the battery terminal voltage (V)
V_0 is the battery initial voltage for each charging rate (V)
R_{tot} is the equivalent internal resistance of the battery packs (Ω), and
I_b is the charging current (A).

In a similar manner to case (1), one can obtain the transformation ratio for case (2) as the following

$$D_b = \frac{1}{2}\left[\frac{V_0}{V_{Pmax}} + \sqrt{\left(\frac{V_0}{V_{Pmax}}\right)^2 + \frac{4 I_{Pmax} R_{tot}}{V_{Pmax}}} \right] \tag{5}$$

Again, to obtain numerical solutions for the ratio requires some computing based on conventional numerical procedures.

2.3 PV panels supply both batteries and motor coupled with pump

More complication is added to the problem of transformation ratio derivation when the PV panels have to supply both batteries and motor. Regarding to this, the currents are drawn from the panels to drive the motor and charge the batteries as can be seen from the Eq. (6) for the formulation of transformation ratio.

$$D_h = \frac{V_t}{V_{Pmax}} = \frac{V_b}{V_{Pmax}} = \frac{I_{Pmax}}{I_a + I_b} \tag{6}$$

In a similar manner to the above two cases, one can derive the Eq. (7) for the transformation ratio of this case. The numerical results are plotted against various levels of solar insolation as shown in fig.4. When insolation is below 150 w/m^2, one have to adopt the transformation ratios obtained for either case (1) or case (2) corresponding to real situation.

$$\frac{k_b}{2}\sqrt{\left(\frac{B}{k}\right)^2} + 4k_b\left(\frac{I_{pmax}R_{tot} - D_h^2 V_{Pmax} + D_h V_0}{D_h k R_{tot}}\right) + R_a\left(\frac{I_{Pmax}R_{tot} - D_h^2 V_{Pmax} + D_h V_0}{D_h R_{tot}}\right) - D_h V_{Pmax} - \frac{k_b B}{2k} = 0 \qquad (7)$$

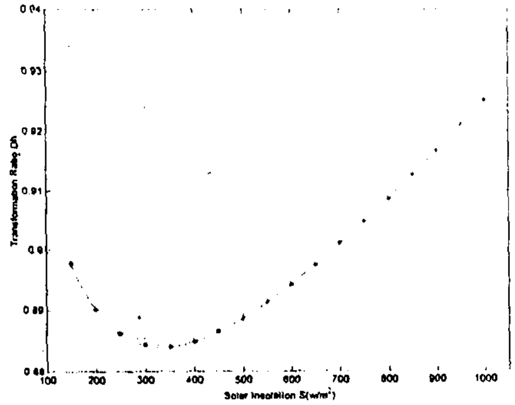

Fig. 4 Case (3) transformation ratio vs solar insolation

In terms of implementation, a microcontroller is required to choose the corresponding mode of operation based on current solar insolation. The ratio Ds should be computed off-line.

3. LOSSES MINIMIZATION IN MOTOR

Since the current from the PV panels is expensive, driving the motor must be safely conducted. One effective strategy is to minimize possible losses in the motor. In practice, this motor coupled with a helical pump is driven at constant field, constant motor current and voltage to meet the flow-rate requirement. The discussion of technology to implement this is omitted in the paper. It is of interest here to investigate how to drive the motor at minimum losses to save available power generated by the PV panels. Hence, the electrical power can be equated by

$$P_{in} = V_t I_a = P_{out} + P_\Sigma \qquad (8)$$

where P_Σ stands for motor losses. The composition of the losses is armature losses, field winding losses, core losses, brush losses, friction and windage losses, and stray losses. Details for these loss terms can be found in [16-18]. The previous work [4] omitted the core-loss terms, while [15] employed field control. The work [17] utilizes filtering concepts. In our work, the minimum principle ($dP_{in}/dI_a = 0$) is applied to derive an expression for motor current that guarantees minimum losses under fixed filed operation. Based on P_{in} of the Eq. (8), one can obtain the Eq. (9)

$$3k\left(\frac{V_t - I_a^* R_a}{k_b}\right)^2\left(\frac{-R_a}{k_b}\right) + 2I_a^* R_a + 2 + 2\left(\frac{fw V_t I_a^*}{\omega_n^2}\right)\left(\frac{V_t - I_a^* R_a}{k_b}\right)\left(\frac{R_a}{k_b}\right) + \left(\frac{fw V_t}{\omega_n^2}\right)\left(\frac{V_t - I_a^* R_a}{k_b}\right)^2 = 0 \qquad (9)$$

where I_a^* is the feeding current (A) to the motor under minimized losses condition ,
fw is the coefficient of the friction and windage losses, and
ω_n is nominal speed of motor (rad/sec).

According to our motor characteristics, the current is 12.50 A compared to 13.25 A of the conventional drive (without losses minimization).

4. CONCLUSIONS

This research contributes mainly to the design and development of an energy-saving controller of supervisory type. Due to the limited space, the design, implementation, and test results of this controller cannot be presented herein. Briefly, this controller has been implemented on a single-board with C codes to operate in real-time. This paper presents analytical details to obtain realizable functions embedded in such a controller. These consist of optimum transformation ratios and the motor current level to attain minimum motor losses.

5. ACKNOWLEDGMENT

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