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A novel application of stand-alone photovoltaic system in agriculture: solar-powered Microner sprayer

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In this paper, a stand-alone photovoltaic (SAPV) power supply system for Microner sprayer is identified and proposed. The designed system was composed of three main parts: sprayer, solar power supply and control system. Initially, the control board and data acquisition system were designed and simulated by the Proteus software and then implemented using an AVR microcontroller and tested via LabVIEW in the laboratory. Next, a prototype system was fabricated for evaluation purposes. A PV panel size of 88.5 cm^2, positioned horizontally above operator's head that generates 26.4 Wh/day was used as a solar energy source. A small 2 Ah (12 V) battery is installed in the system as a stabiliser. This sprayer can work seven to nine hours daily. It is calculated that the average loss of collected energy due to non-application of maximum power point tracker was approximately 25%.

Keywords: photovoltaic; Microner sprayer; LabVIEW; solar power supply

Abbreviations

L	load (Wh)
T	time (h:min)
V_{PV}	PV voltage (V)
I_{PV}	PV current (A)
V_b	battery voltage (V)
I_b	battery current (A)
V_{OC}	open circuit voltage (V)
I_{SC}	short circuit current (A)
V_w	working voltage (V)
I_w	working current (A)
V_L	load voltage (V)
η_{PV}	conversion efficiency of the photovoltaic (%)
I_L	load current (A)
P	power (W)
P_{max}	maximum PV power (W)
P_{loss}	loosed PV power (W)
C_s	battery storage capacity
C_A	PV generator capacity
C_U	battery useful storage capacity (W h)
A_G	generator area (cm^2)
G_d	mean daily radiation (kW h/m^2/day)
A/D	analog-to-digital convertor
θ_c	cell temperature

1. Introduction

World demand for energy is projected to more than double by year 2050 and to more than triple by the end of this century (California Institute of Technology 2005). Incremental improvements in existing energy networks will not be adequate to supply this demand in a sustainable way. Accordingly, it has become imperative for the power and energy engineers to look out for the renewable energy (RE) sources such as sun, wind, geothermal, ocean and biomass as sustainable, cost-effective and environment friendly alternatives for conventional energy sources. Shi et al. (2012) reviewed the state of the art in designing RE systems, specifically solar-based energy system, ground source-based system and day-lighting system, to gain optimum performances in sustainable buildings. Among the RE sources, photovoltaic (PV) attracts a special focus. The sun as a resource of all kind of RE sources just provided less than 2.6% of the world's energy (International Energy Agency 2009). More regions of Iran's land possess large resources of energy. Iran has the second largest resource of natural gas and fourth of oil in the world (Energy Information Administration 2012). But it is clear that Iran has the second largest resource in the next decades (California Institute of Technology 2005) and it is necessary to search for alternative substitutable energy resources. Iran, with a high amount of solar irradiance, more than 60% clearness (see Figure 1), and high altitude from the sea level (mean height is 1200 m), has a suitable geographical and meteorological situation for solar energy-based systems (Moini, Javadi, and Dehghanmanshadi 2011).

The non-availability of RE resources all the time throughout the year has led to research in the area of hybrid

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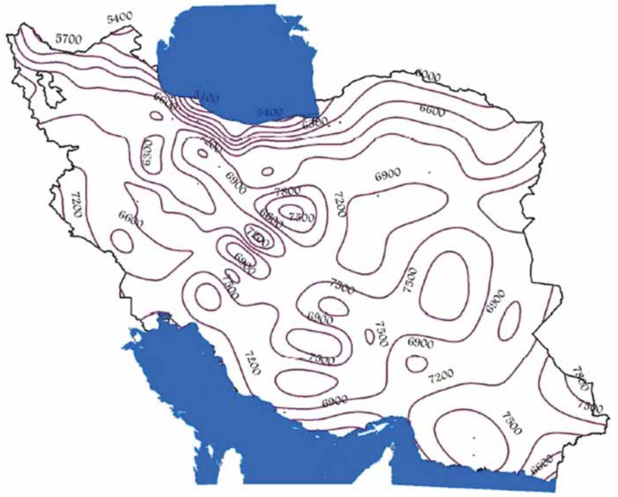


Figure 1. Total of global solar radiation received in a horizontal surface at annually (Moini, Javadi, and Dehghanmanshadi 2011).

RE systems. In the past few years, a lot of research has taken place in the design, optimisation, operation and control of hybrid RE systems. It is indeed evident that this area is still emerging and vast in scope [90]. A standalone photovoltaic (SAPV) system is a suitable choice far from the grid network such as rural regions (Luque and Hegedus 2003; Mellit et al. 2008; Shen 2009). SAPV systems consist of a PV generator, an energy storage device, an AC or DC consumer and elements for power (Mellit and Benghanem 2007). Solar energy has been exploited mostly in the form of PV technologies for the provision of lighting in Kiribati [91]. Agriculture activities consume a large amount of energy and usually needs energy at place far from the grid, so SAPV can be a good choice in this area. Using solar energy for drying of agricultural product was reported by Lamnatou et al. (2012) and Sami, Etesami, and Rahimi (2011). Using PV for water pumping and irrigation was reported in Arrouf and Ghabrour (2007), Oi (2005), Ghoneim (2006) and Vick and Clarck (2009) and for reducing in the salinity of irrigation water in Tigrine et al. (2012). Solar energy in greenhouses and poultry for heating, ventilating and supplying electrical energy for feeding systems and other electric consuming was reported by van Ooteghem et al. (2010) and Abdel-Ghany and Al-Helal (2011). Innovative and small-scaled applications such as solar-powered soil moisture detector (Arrif and Ibrahim 2010), powered screw press by PV module to extract seed's oil (Mpagalile, Hanna, and Weber 2007) and solar-powered automatic lawn mower (Ramos and Lucero 2009) were reported recently. In a recent work, we developed and set up an outdoor test rig for acquiring test data to evaluate the performance of the PV energy system (Karamirad et al. 2013). A general approach on modelling PV modules was reviewed and validated experimentally. Specifically, four- and five-parameter analytical models as well as artificial neural network approaches were tested and discussed.

The aim of this research was to design, develop and evaluate a SAPV power supply system for Microner sprayer. These sprayers use small DC motors to rotate a disc to produce and distribute droplets (Villette et al. 2005). Because of their ability to control droplet size by controlling the rotational speed of spinning disc, they are also called control droplet atomiser. The advantage of this sprayer is low energy consumption and fine droplet production. Fine droplet makes it possible to spray more area with a defined liquid and so it saves time and working power. The solar-powered Microner sprayer makes it possible to spray large area of rural lands that are far from the grid.

2. Materials and methods

The prototype system consisted of three main parts: sprayer, solar power supply and control system. Solar power supply and data acquisition (DAQ) unit was developed to evaluate system's performance. Electronic circuit and controller parts were designed and simulated in the Proteus 7 software (Rodway 2012).

The sprayer (SKN-3000) selected in this project was invented by Sabz-Kosh-Negin Company. This sprayer has three spinning discs that are mounted on a 4.5 m lengthened boom. An installed sealed lead-acid 12 V battery gives 8–16 ha/day spraying capability. PV module and control unit was installed on an aluminium platform that was specifically designed for this project. Figure 2 shows the SKN-3000 sprayer with an aluminium platform.

2.1. *Solar power supply and control system*

Sizing of the system was carried out according to the initial values of solar radiation, module specifications and energy demand of DC motors. The main specification of the PV

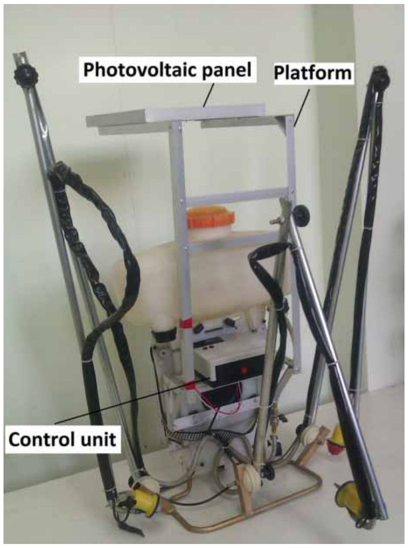


Figure 2. SKN-3000 sprayer.

module used for the system was:

- 21 V open circuit voltage,
- 0.61 A short circuit current,
- 18 V maximum power voltage and
- 0.56 A maximum power current.

Other specifications are summarised in Table 1. Metrological data for sizing SAPV systems in the Karaj (Iran) region (latitude 35°48′ North and longitude 50°58′ East) were extracted from the NASA database (NASA 2011). Table 2 shows the data required for this investigation.

In Iran, usually spraying is done at April–September. The average of daily collected energy ($\overline{G_d}$) during these months is 5.51 kWh/m^2/day and the minimum daylight

Table 1. Some specifications of solar module.

Cell technology	Poly-crystalline silicone (p-Si)
Efficiency at STC[a], η_{PV}	16.8%
Panel dimension	$320 \times 290 \times 25$ mm^3
Panel weight	1.5 kg
Number of cells	4
Operating temperature (°C)	−40°C to +85°C
Voltage temperature coefficient V/K	78 ± 10
Power temperature coefficient %/K	−(0.5 ± 0.05)
Current temperature coefficient %/K	0.06 ± 0.01

Note: [a]Standard test condition (STC) refers to 1000 W/m^2 solar irradiance at 25°C cell temperature and air mass of 1.5 (2005).

Table 2. Some metrological data from NASA site.

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Insolation (kWh/m^2/day)	2.73	3.62	4.5	5.51	6.39	7.35	7.04	6.56	5.64	4.05	2.94	2.38
Daylight hours (h)	10	10.9	11.9	13	14	14.5	14.3	13.5	12.4	11.3	10.3	9.8

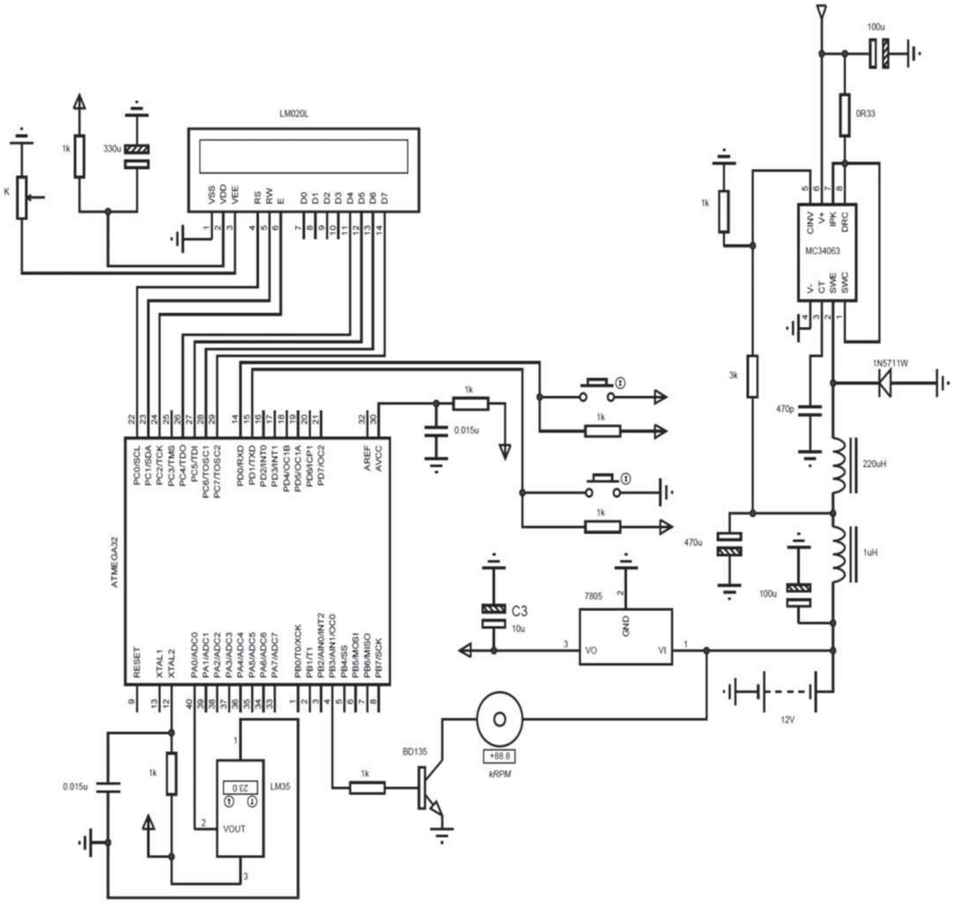


Figure 3. Schematic circuit of charge control and dc motor control unit.

time is 12.4 hours. PV generator capacity (C_A) and storage capacity (C_s) can be found by

$$C_A = (\eta_{PV} \cdot A_G \cdot \overline{G}_d)/L, \tag{1}$$

$$C_s = C_U/L, \tag{2}$$

where A_G and η_{PV} are area and conversion efficiency of the PV generator, respectively, $\overline{G_d}$ is the mean value of the daily irradiation on the surface of the generator and L is the mean value of daily consumed energy by the load. In Equation (2), C_U is the useful energy storage capacity of the accumulator. Iso-reliability curves for the Karaj region were not established, so the calculation was based on the recommended values of C_A and C_s as $C_A = 1.3$ and $C_s = 4$ (Luque and Hegedus 2003). Energy consumption of this system is assumed to be constant. Using datasheet, power of the used DC motors (P) is 1.2 W and assuming a 5 h working time (t) for a day, the mean value of daily consumed energy L is derived as

$$L = P \times t. \tag{3}$$

Based on this calculation, the required generator surface area was obtained to be 88.4 cm^2 and the battery capacity was derived as 24 Wh. Accordingly, a PV module with mentioned specifications and a 12 V–2 Ah battery were chosen. For simplicity and financial consideration, this project did not use some efficiency improvement accessories, such as sun trackers and maximum power point tracker (MPPT), so some energy losses will occur due to the absence of the mentioned parts.

The amount of power losses in the system can be determined by comparison of current rate and voltage generated by the PV panel with the maximum energy produced in ideal mode. As shown in Equation (4), the latter can be measured, using the short circuit (SC) current and open circuit (OC) voltage at any moment (Luque and Hegedus 2003):

$$P_{\max} = 0.64 \times V_{OC} \times I_{SC}. \tag{4}$$

The ratio of acquired energy to the total accessible energy is

$$E_{\text{loss}} = (V_w \times I_w)/P_{\max}, \tag{5}$$

where V_w and I_w are the working voltage and current, respectively. Charge control and DC motor control units were designed in the Proteus 7 software and installed on the aluminium platform. The charge control unit limits the charging voltage to 14.4 V. Figure 3 shows electronic circuitry of charge control and DC motor control units.

DC motors provide two speeds by pulse width modulation (PWM) signals. The control unit also shows battery charge status and ambient temperature. Weather temperature is recorded using an LM35 sensor and the signal is sent to the A/D convertor port of the microcontroller. Table 3 shows states of charge control unit.

Table 3. Charge control working states.

Battery voltage (V_b)	Load	PV panel
$V_b \geq 14.2$	Connected	Disconnected
$10 \leq V_b \leq 14.2$	Connected	Connected
$V_b \leq 10$	Disconnected	Connected

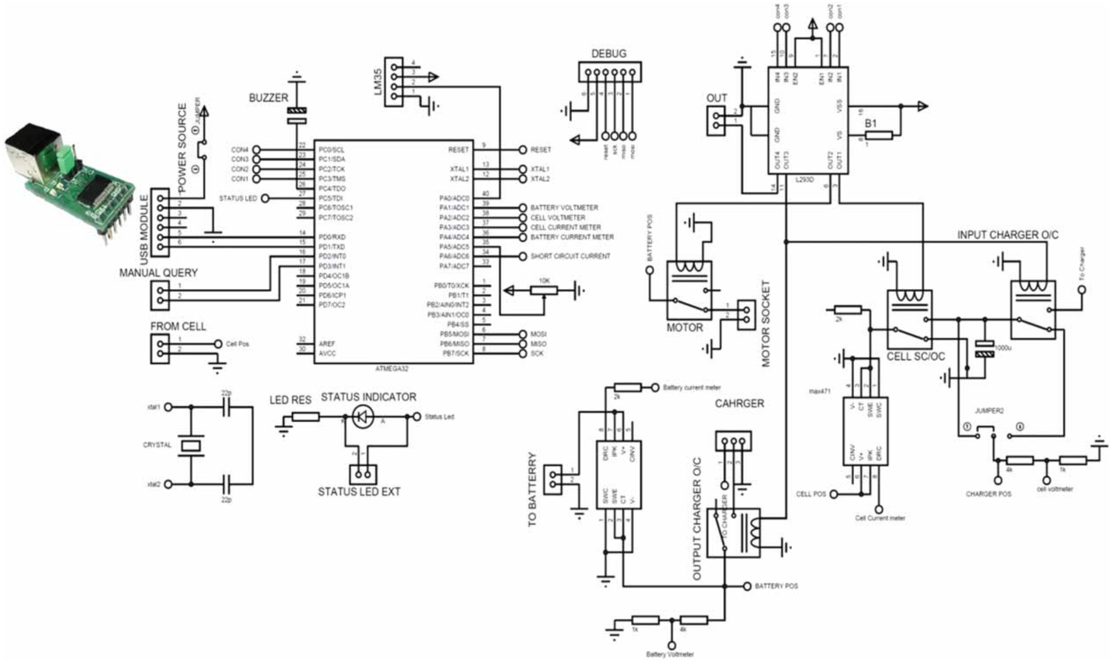
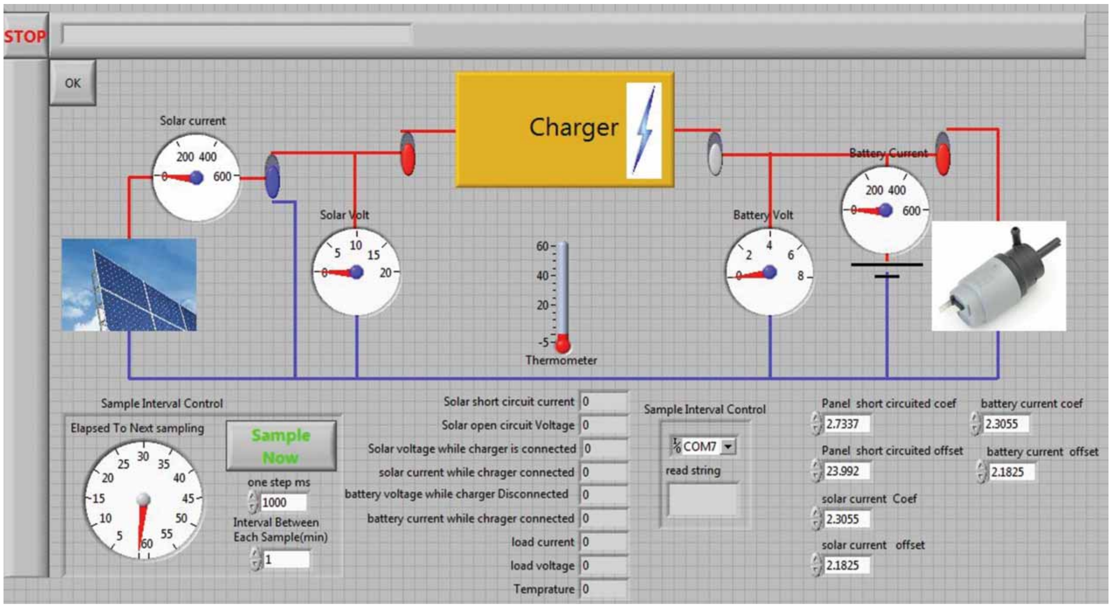


Figure 4. Schematic circuit of DAQ system.



Sample Interval Control
Elapsed To Next sampling
one step ms 1000
Interval Between Each Sample(min) 1
Solar short circuit current 0
Solar open circuit Voltage 0
Solar voltage while charger is connected 0
solar current while chrager connected 0
battery voltage while charger Disconnected 0
battery current while chrager connected 0
load current 0
load voltage 0
Temprature 0
Sample Interval Control
read string
Panel short circuited coef 2.7337
Panel short circuited offset 23.992
solar current Coef 2.3055
solar current offset 2.1825
battery current coef 2.3055
battery current offset 2.1825

Figure 5. Control unit in Labview space.

2.2. *Data acquisition unit*

A specially designed DAQ unit was used in this project. SC current, OC voltage, working voltage/current of module, battery voltage/current, load voltage/current and cell temperature were acquired in this system for future processing. The DAQ unit was developed and simulated in the Proteus 7 software. To capture the SC current of the solar module, the circuit is shortened. This system is based on the AVR microcontroller and LabVIEW 2010 (National Instruments 2012) software programming interface. Parameters are sensed using two current sensors, two voltage dividing circuits and a special circuitry for sensing SC current (see Figure 4).

The collected data were sent to the LabVIEW graphical user interface (GUI) on a PC by a serial to the USB convertor module, as shown in Figure 4. The LabVIEW provided a user friendly and simple GUI and it was possible to set time intervals between sampling points. Data were collected every 15 min and then four successive

Table 4. Some acquired data by data acquisition system.

Time	I_{SC}	V_{OC}	V_{PV}	I_{PV}	V_b	I_b	I_L	V_L	Θ_c
9:00	0.27	20.30	8.51	0.27	6.19	– 0.17	0.47	6.07	31.25
10:00	0.39	19.84	8.75	0.37	6.17	0.04	0.47	6.16	39.75
11:00	0.48	19.76	9.05	0.47	6.26	0.08	0.48	6.29	43.50
12:00	0.54	19.89	9.22	0.52	6.35	0.13	0.48	6.40	43.00
13:00	0.53	20.27	9.13	0.53	6.32	0.12	0.48	6.35	39.00
14:00	0.42	19.46	9.00	0.38	6.36	0.04	0.48	6.33	45.50
15:00	0.41	20.33	8.78	0.41	6.20	0.02	0.47	6.22	37.00
16:00	0.19	19.84	8.19	0.18	6.03	– 0.24	0.45	5.87	33.25
17:00	0.31	19.92	8.24	0.30	5.90	– 0.11	0.45	5.82	39.00
18:00	0.18	19.73	6.37	0.15	4.69	– 0.19	0.37	4.30	32.50

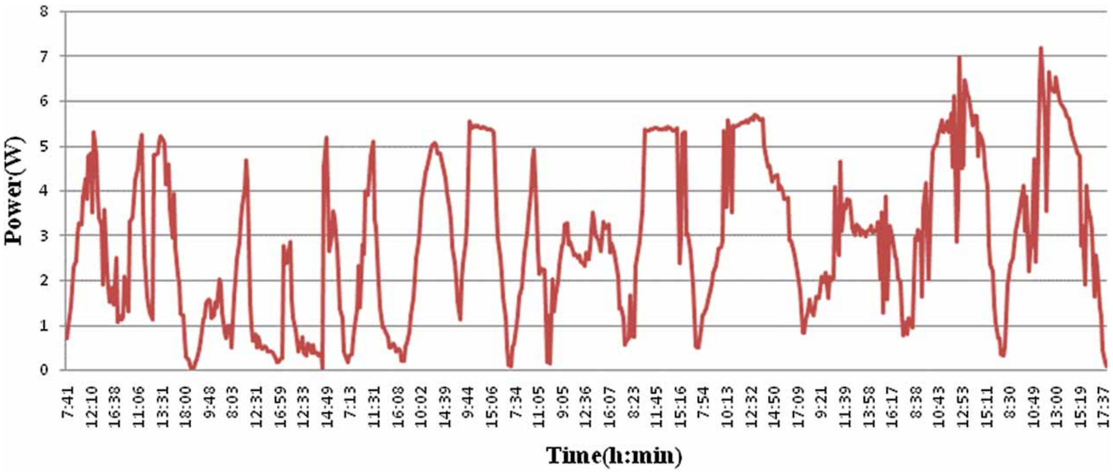


Figure 6. Trend of acquired power in evaluation days.

values were averaged to obtain mean hourly values. Figure 5 shows control panel in the LabVIEW interface. As shown in Figure 5, it is possible to change some calibration coefficient.

3. Results and discussion

Evaluation of the system was carried out during spring in 2012. Spring was chosen because of two main reasons. First, sprayers are mostly used in this season in Iran and second, the night and day lengths are approximately equal in this season. So, the measured values for radiation and energy are almost equal to the mean of annual values. Table 4 shows some of the acquired data. The most important parameter that was evaluated in this project was the generated energy by the system. The number of system's working hours in a day can be determined from the diagram of daily generated energy versus daily consumed energy by the sprayer.

Figure 6 shows generated power between 7:41 am and 17:37 pm (local time); as it can be seen, the

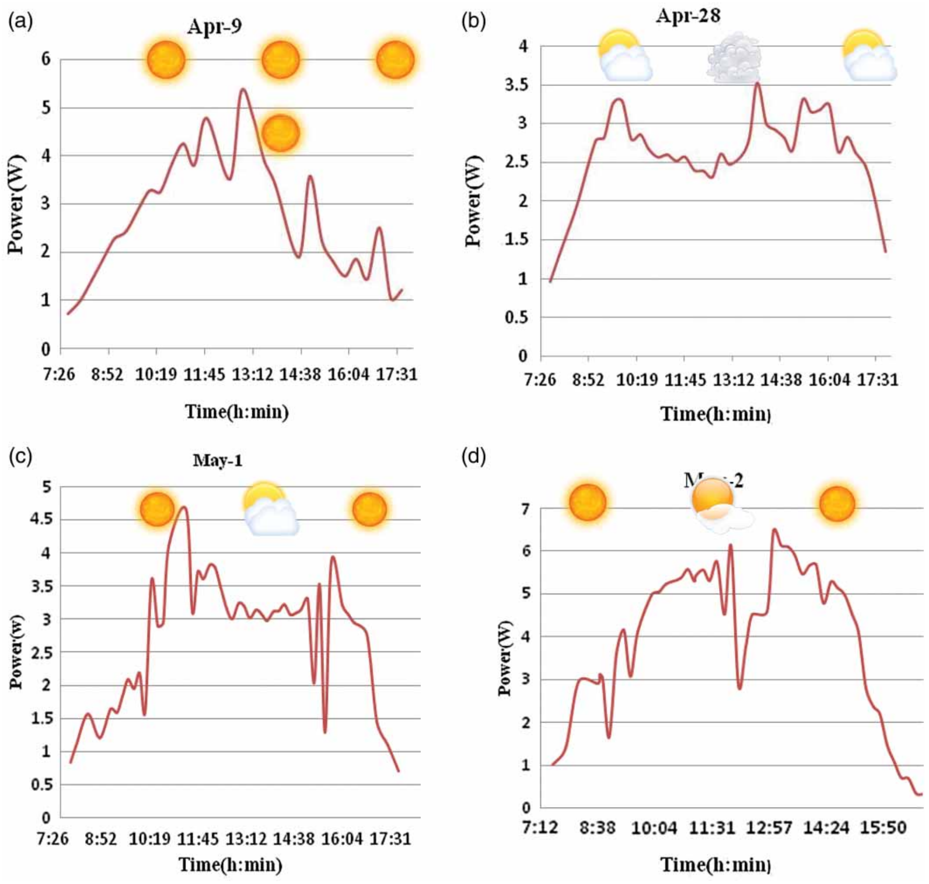


Figure 7. Energy product in 4 days of spring 2012.

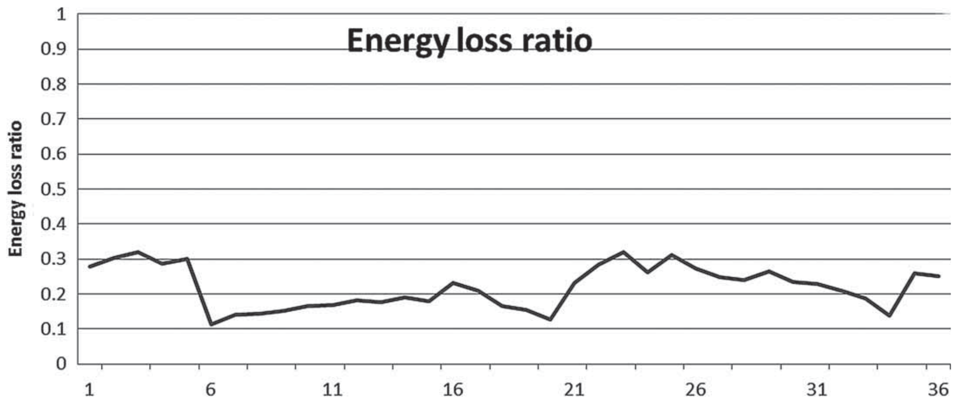


Figure 8. Energy losses ratio in several measurements.

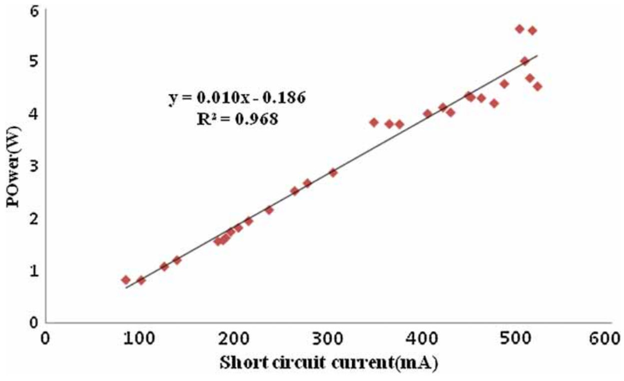


Figure 9. Relationship between SC current and panel power.

maximum power was obtained between 13:00 and 15:00 pm (local time).

Figure 7(a)–(d) shows the amount of stored energy by the system during four different days from 9 April to 2 May 2012. As shown in these figures, the generation of energy faces some steep fluctuations in the day length. These are due to a cloudy sky which was inevitable. During 9 and 28 April and 1 and 2 May, the acquired energy from the PV system were, respectively, equal to 24.3, 23.87, 31.16, 21 and 31.76 Wh. Since the power consumption capacity of the Microner sprayer is almost 3 W, this system could supply the required energy for 7–9 working hours in a day which is equal to spraying 10–15 h each day. In comparison to solar hybrid tractor (Mosazadeh et al. 2010), which provides only 18% of the required energy provided using the PV panels, this sprayer can provide needed energy for spraying completely from the sun.

Figure 8 shows energy loss ratio (sub-optimal working moments of the system) which is due to the absence of MPPT. The average amount that is resulted from measurement (and calculation) was 25. In spite of this, it should be considered that this energy loss would be compensated by a lower price and weight and less complexity of system, so it could be somewhat acceptable.

Furthermore, the measurements indicateda good relationship between the output energy and the SC current with a correlation coefficient of 0.96 (Figure 9). This relationship will guide us to future study about the solar radiation estimation and sizing calculations.

According to simulations in the RETScreen software (Natural Resources Canada 2012), which is a tool for evaluating all kinds of renewable energy systems, this system will save 5 l oil in a year and so could have a role in gas emission reduction.

4. Conclusions

For more effective exploitation of solar energy in agriculture in remote areas, a SAPV power supply system for Microner sprayer was identified. The designed system consisted of three main parts: sprayer, solar power supply and control system. A microcontroller and additional electronic circuitry were designed and used for charge controlling. Moreover, motor rotation controller unit, temperature illustration sensor and battery charge status displayer were the extra facilities that were added to the sprayer. The evaluation has been implemented by some data that was acquired using a DAQ system designed specifically for this system during spring season. This system can work 7–9 h a day. Being simple and light weighted, this sprayer can be easily used in farms in order to help resolve the environmental problems and delay the fossil fuel resources running out as well as being a symbol of practical use of solar energy in agriculture.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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