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Self Powered Instrumentation Equipment and Machinery using Solar Panels

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1. Introduction

Energy and water are required by any human being in order to live decently. Most of the rural population of the developing world lives without access to formal electrification. Electricity is one of the prerequisites for significant sustainable economic growth, being a reliable and reasonably priced energy essential for value-added agricultural and post-harvest processes. Modern energy supply also enables more intensive agriculture by providing irrigation (pumps) and immediate post-harvest treatment (cooling) and storage. Solar radiation can be converted into electricity using photovoltaic panels. Industrialized countries present a trend towards grid-connected photovoltaic systems, as battery energy storage is not required and the electricity is supplied to the network. Therefore, it is more economically interesting to supply the electricity produced by a photovoltaic system to the electricity network than to use it to drive a chiller.

Providing a reliable water supply for both human water pumping systems and agricultural needs in rural areas is one of the main applications of PV energy. The least expensive method of pumping water using PV energy is by connecting a DC motor without batteries (Abidin & Yesilata, 2004). Battery-less systems that directly couple PV modules to variable speed DC pump motors seems to have high potential for energy efficient and cost effective reverse osmosis desalinization (Ghermandi & Messalem, 2009). A simple irrigation fuzzy logic model analyzed the pumping system together with the crop to obtain the time of year to irrigate for compensating the lack of water (Damak et al., 2009). The use of pumped water for energy storage is an innovative alternative to battery storage due to its unlimited storage duration (Manolakos et al., 2004).

Many machines have been constructed thinking in photovoltaic powering. As photovoltaic panels can provide excellent energy on places with daily radiation of 4-6 kWh/m^2 prototypes are being constructed so that life becomes easier. For example, in African countries milling the average daily consumption (2.5 kg of grain) takes three hours (Chinsman, 1985). A PV-driven stone mill was constructed using two 50 W PV-panels and a battery of 85 Ah. Feed costs on dairy farms accounts for approximately half the cost of producing milk (Gardner et al., 1995). The feed dispensed to animals was measured to be within 6% of the programmed ratio and the cows adapted to eat from the feeder with training. The solar panels worked efficiently charging the batteries to provide 2.5 days of reserve capacity to 50% depth of discharge (DOD). VaxiCool mobile freezers have been constructed in order to store and transport vaccines and drugs in remote areas.

Wireless instrumentation sensors have reduced its size and power demand. All these low-cost and lightweight devices need a compact energy source or if possible eliminate battery use. Actually worldwide research is carried out on alternatives solutions to batteries in what is called power harvesting (Vullers et al. 2009). Harvesting energy from the ambient can be done using vibration energy, thermal energy and light.

Solar panels can be used for supplying energy to measuring instruments and for small machines used during food harvesting. Instruments for taking measurements on sites were no electricity is available are generally supplied from a solar panel. Batteries are used in order to provide the energy required by the instruments during the night and under cloudy days. In this chapter a simple monitoring system that samples chloride in rivers is presented. Food production equipments require electric motors to operate; so soft start motor controllers are required to avoid current peaks in squirrel cage motors reducing solar panel sizing. Its application for a greenhouse automatic moving shelter is illustrated. A final application which uses solar panels is for prickle pear fruit cauterization to increase its shelf-life.

2. Important

If PV systems are constructed with rudimentary electronics, it is possible that most of the power generated by the solar panels can be wasted and dissipated as heat by the system components. It is worthwhile to investigate modern and sophisticated means of managing electrical power in PV systems using power electronics. Furthermore, since solar energy systems are relatively expensive in comparison to other energy sources, it would be advisable to maximize energy efficiency.

Only 30% of PV applications apply energy to motors being 15% of them alternating current motors. Its main application is for pumping water in rural areas with direct current motors, which although are bigger than AC motors, are easily started. In applications where the motor is hanging like in the greenhouses or in other equipments, weight becomes an important feature to be considered. Actually at homes, DC motors are rarely used and AC motors move most of the appliances. Squirrel cage induction motors have increased its efficiency decreasing its weight while DC motors are used as variable speed drives; actually inverters control AC motor speed without reducing its torque. AC motors driven by PV systems which are properly managed by PWM (pulse width modulated) soft starters reduce starting current peaks, increase batteries life, reduce its recharge rate and solar panel size. A PWM (pulse width modulated) soft starter was developed and later in this chapter it is applied to control a greenhouse shade curtain.

Rapid population growth, land development along river basin, urbanization and industrialization increase rivers pollution and environmental deterioration. All developed countries have the decision to maintain the water quality of their rivers. River water quality has to be characterized to identify changes or trends in quality over time or emerging problems. Pollutants discharge into the rivers can be spotted, as well as their possible sources in order to make recommendations for improving water quality in rivers. Ecosystems depend upon high water quality for provision of drinking water, cycling of nutrients, and biodiversity maintenance. Nitrogen and phosphorus are essential plant nutrients, but when streams become enriched with these nutrients changes to species composition can result.

Real-time monitoring platforms can collect valuable data with extremely high temporal resolution without missing data in risky events like storms. Water monitoring sensor technology has been evolving, and most monitoring systems can work for weeks and even months without maintenance or calibration. In-situ automatic calibration can be performed without personal and a chloride sensor photovoltaic driven will be analyzed latter on this chapter considering autonomy and in-situ calibration. As monitoring platforms operate unattended and require relatively little maintenance, continuous monitoring programs quickly become more cost-effective than programs that rely on data-gathering personal. Data transmission via radio, cellular and phone telemetry provides a real-time picture of the water quality and automatic reports via internet provide water information to everybody.

For all fresh produce, climatic conditions and growing practices affect the quality at harvest. Successful marketing of still alive fresh fruits and vegetables depends on maintaining the quality harvested. Worldwide postharvest fruit and vegetables losses are as high as 30 to 40% and even much higher in some developing countries. Reducing postharvest losses is very important ensuring that sufficient high quality food is available to every inhabitant in our planet. World production of vegetables amounted to 487 million ton, while that of fruits reached 393 million ton. Freshness is a very important quality attribute and can be achieved by storing fruits and vegetables for short periods (days) under the proper conditions. The last example in this chapter, analyzes a cauterization technique to avoid water loss in prickle pears. Simple equipment creates a diaphragm coating in the cauterized zone. Farms require of many equipments operating in parallel so a PV grid system should be used in the future.

3. Equipments working with PV panels

There are a many equipments working with PV panels. In this section three different applications were selected from hundreds of application as they will represent clear examples. The first one will talk about monitoring systems for water quality, the second one a controller for increasing PV system efficiency and the third a machine which cuts and cauterizes prickle pears increasing its shelf life.

3.1 Automatic chloride detection in rivers

Water quality monitoring can control and detect possible pollution sites on streams, rivers and effluents (Gray, 1999). Bakker et al. (1997) developed ion selective sensors by introducing a polymeric membrane sensible to ions or cations within the circuit. Dissolved oxygen, electrical conductivity and nitrates were monitored on the Wissahickon River (Kozul & Haas, 1999). Ion-sensitive sensors are cheap to construct and although their accuracy is in the order of parts per million, they can be used in environmental sensing of wastewater.

Chloride can destroy river habitats (Detwiler et al., 1991) and free chlorine concentrations from 0.03 to 0.05 mg/l killed fish depending on the exposure time (Augspurger et al., 2003). Chlorinated wastewaters have the potential to affect fish and mussel habitats (USEPA, 1985). Mussel exposure to concentrated chloride is harmful and should be less than 20 parts per billion. In the total residual chloride criterion, the 4-day average concentrations should not exceed 11 mg/l more than once every 3 yr on average (Tikkanen et al., 2004).

3.1.1 Block diagram of the monitoring system

An autonomous water quality monitoring system has to consider the variables to be evaluated, their calibration and sensor cleaning. If the sensors are positioned in a river where water flow is intense a special sensor should be used. Timing between researchers visits are important as calibration liquids can expire or rain effects on framing can become dangerous. Positioning of the sensor and acknowledgement of available radiation hours per day and per season is necessary for proper energy harvesting management. Energy was stored in batteries or capacitors where it is ready to use by the sensors, datalogging and transmitting equipment.

A chloride measuring valve was designed for automatic sampling, calibration and cleaning of an ion-sensitive chloride sensor for environmental detection on rivers and effluents. Valve optimization decreased contamination of the calibration (buffer) liquids to a minimum value. The system presents photovoltaic panels for energy harvesting and stores the remaining energy in batteries. The system avoids the use of electrical cables becoming a wireless sensor although its power consumption is relatively high when compared with wireless sensors. Sampling measurements were taken continuously for 7 days with the valve at the wastewater effluent at Nativitas on the river Texcoco near Mexico City (Hahn et al., 2006).

3.1.2 Valve development

A 10 cm diameter by 30 cm long stainless-steel valve was coupled with a pair of stepper motors (model Step-Syn 103G770, Sanyo Denki Co., Ltd, Japan) for its automatic operation. The stepper motors presented a resolution of 2°/step and consumed a power of 10w and required a battery of 12 v at 70 A/h, auto-charged by a solar cell. Valve operation presented three options: sensor cleaning, sensor calibration and effluent or river sampling and an ATM 89C51 microcontroller provided the control of both stepper motors.

The right stepper motor (Fig. 2) drives two bottles (calibration liquids) weighing 60 g each. The right lateral wall presented four holes connected to the plastic tubes; when the bottle necks and the wall holes coincided liquid began to flow into the cavity. Each hole served a function during calibration: filling the sensor cavity or refilling the bottle where the solution is stored, Fig. 3. A 70 mm long shaft with a hollow section centered by a bearing was fixed to the valve bottom by a structure and had the sensor inserted at its centre. Three holes made on the rotating tube control the liquid flow towards bottle 1, bottle 2 and for distilled and sampled water disposal. Four of the plastic tubes introduced liquids to the sensor cavity (reference liquid 1, reference liquid 2,distilled water and sampling water) and three plastic tubes removed liquids from the sensor cavity (reference liquid 1, reference liquid 2 and disposal water).

The left stepper motor (Fig. 2) drives the worm used by the brush cleaner, and works together with right stepper motor for introducing distilled water, reference 1, reference 2 or sample liquid to the sensing cavity. The left stepper motor is the responsible of keeping whichever of the four liquids in the sensing cavity as well as its disposal. Basically the three operations are briefly described, but more detailed information is presented by Hahn, 2004.

Sample measurement: The valve samples the liquid after introducing it to the sensor cavity through a spoon mechanism. The spoon delivers the liquid to the drain channel and then to the sensor cavity. At the end of the measurement the liquid remaining on the sensor cavity returns to the stream.

Washing operation: A control signal stops the right stepper motor movement, and distilled water flows towards the sensor cavity. Once the cavity is full the left stepper motor drives the brush washer (worm-operated) through the sensor cavity, and advances for 40 mm. The brush is moved in both directions three times to obtain a better cleaning operation. Once the brush cleaning action is finished, it returns to its initial position and the water gets out from the cavity.

Calibration operation: Two bottles carried by the main gear contain the calibration solutions. The bottles have to be synchronized with the right lateral wall holes. The bottle in front of the plastic tube starts filling the sensor cavity with the high concentrated sodium chloride liquid. One minute later, after the measurement is taken the first bottle is refilled. Later the second bottle is aligned to the plastic flexible tube repeating the same procedure done with bottle 1.

3.1.3 Energy management of the sensor

Table 1 shows the time required for each operation so that the energy required can be obtained in a watt-hour basis. It is assumed that after every measurement washing takes place and that a measurement is taken every ten minutes. Sampling the river chloride will take 3 W per hour. Washing uses a brush to clean the cavity and takes 3.25 W-hr for cleaning six times per hour. Calibration is only done once and could be done every week if liquid is always maintained on the cavity. Therefore it was noted that the washing liquid (distilled water) should stay on the cavity until the next sample is taken.

Although the most important part of the sampling is the sensor it requires of a data logger for storing data and a WI-FI transmission equipment in order to transmit the information to a place nearby the sensor. Currently, there are two dominant short range wireless standards frequently incorporated into mobile devices: WiFi and Bluetooth. WiFi: IEEE 802.11 offers high-bandwidth local-area coverage up to 100 meters (Pering et al., 2006; Crk & Gniady, 2009). However WiFi transmission consumes higher power in the order of 890 mW, compared to only 120 mW for Bluetooth due to simpler radio architecture (Agarwal et al, 2005).

The energy used for monitoring, data-logging and transmitting the information is shown in Table 2. A limit of the number of operations per hour is ten after considering that the sensor will be operating continuously as the measuring operation will take half an hour. The washing routine can be adjusted to work in the other half an hour. It can be noted that the energy consumed by the sensor increases with the number of samples and seems higher than the data logger and transmission energy consumption.

A low power consumption data logger was developed for storing the measurement with a resolution of 0.2% at any voltage ranging between 0-5V. The logger can record up to 8 channels of 10-bit data and stores data in a 512Kbyte memory. The logger uses 'D' sized batteries and its consumption was of 523μA, indicating that they have to be replaced every year. Its power consumption is in the order of 2.5 mW and when the data logger is not working it stays in sleep mode reducing the power supply voltage to a minimum. Campbell Scientific data logger CR800 acquires 6 analog inputs with a 13 bit AD converter with an accuracy of 0.06% of the voltage signal. During sleeping mode it consumes 0.6 mA and up to 28 mA using the RS232 communication port. The applied voltage can be from 9.6 up to 16 volts avoiding the use of a solar cell regulator. The worst case power will be 28mA x 16V= 0.448 W. These results are much higher than the ones obtained by the embedded system which never exceed 0.1W, but for a case in which another datalogger is used it was considered as 0.5 W-hr.

3.1.4 Selection of solar cells and storing elements

The selection of the batteries and solar panels was done for the highest energy consumption (ten operations per hour). A ship vessel was constructed so that the system floated in the river. The total weight of the monitoring system, batteries and solar cells accounted for 25 kg, considering aluminum surrounding the solar panels and thin coating glass to protect them. The vessel structure was elaborated with fiber glass and could hold up the weight, Fig. 4. Three solar cells were installed; one superior in flat position and the other two in the sides with the proper slope for optimum energy harvesting.

Tilting of the solar panel has been always a concern as it has been recognized that tilting helps in:

1. More power production results from better sun angle;
2. Rain water promotes module cleaning and;
3. Improved airflow cooling allows more energy output.

Horizontal modules increase energy production in the summer and decrease its production in the winter, spring and autumn; therefore a reduction in energy production over a one-year period is noted. Figure 5 shows a simulation throughout the year for three different angles and the horizontal position. The red line is the production energy; the violet represents the incident energy and the green the power on the horizontal plane. As tilting increases the red and green lines tend to separate further apart being the highest at the summer. The red and green lines were exactly equal without tilting, Fig. 5.a., but at a tilting angle of 19° the red line was higher than the horizontal installed panel from the beginning of the year to day 90 and from day 243 to the end of the year (Fig. 5.c.). In the rest of the year the flat panel produced more energy. At a tilting angle of 80° energy production decreased notably, Fig 5.d.

In this particular application the monitoring system floating in the river is continuously moving avoiding that dust is collected in the flat panel. A capacitor sensor providing a variable signal between 0-5 V, detected the floating vessel movement. As the movement frequency is in the order of one second and the air movement was of 1 ms^{-1} the dust did not accumulate in the panel surface.

The energy/day required for sampling ten times during the 24 hours is 279.84 W. Adding the energy required for calibration to this value gives the final 280.86 W/day. If two days of autonomy are needed due to cloudy days, the 12 V battery should manage 93.62 Ah for a battery discharge of 50%. Two batteries of 50 Ah can be used to provide the system requirement. The determination of the photovoltaic cells (PV) depends on the energy used per day which is 23.41 Ah; the effective amperes required from the batteries will be 27.54 Ah considering a lead battery efficiency of 0.85. Table 3 shows the panels required to provide the energy.

Lead acid batteries were selected as they present a low self-discharge rate, and low maintenance requirements. Its recharging is slow after deep discharges and at higher operating temperatures a shorter battery life is expected. The battery charger used a semiconductor switching element between the array and battery which switched on/off at a variable duty cycle to maintain the battery at or very close to the voltage regulation set point reducing power dissipation to a minimum. At noon the battery voltage reached the regulation voltage set point and the controller began to regulate the PV array current; the current followed the same profile as the solar irradiance. Towards the end of the sunlight hours the PV array current output decreased to a low value wherein regulation was not

required to limit the battery voltage below the regulation set point of the controller. Once the sun sets the battery voltage begins a gradual decrease to its open-circuit voltage.
Two different installation panel setups were tested and the current measured with an Elnet GR current datalogger. The first setup was the inverted V (Fig. 4) and the second one presented two parallel panels of 30 W each with a slope of 19º and a 25 W flat panel of 25 W. The latter presented a higher current after noon up to 6 AM as the slope angle with respect to the water level was directed towards east (tilted west). The total current obtained per day in the parallel red curve was of 51.66 A which can be used for all the day required only of 23.41 A. The black line with the inverted V shape produced 49.6 A during the day, while the parallel panels tilted east produced a minimum value of 47.56 A. The generated energy difference was not considerable different, but as sunny days appear in the mornings and rain in the afternoon, the inverse V was selected due to its stable and compact design.

3.2 Movable shade curtains controller in greenhouses

Movab1e curtain insulation systems (heat blankets, thermal screens) reduce heat radiation losses at night inside greenhouses, and decrease the energy load on your greenhouse crop during warm and sunny conditions. These structures covered with polypropylene, polyethylene, or composite fabrics (Bartok 2005) are known as retractable roof shade houses; screens should reflect as much near infrared radiation and transmit high photosynthetic radiation. Energy savings of up to 30% have been reported, ensuring a quick payback period based on today’s fuel prices (Plaisier & Svensson, 2005).
Plants grow and pass from its initial transplanting state to its harvest state in 25 days requiring of a constant daily light integral, which can be achieved only through shading or supplemental lighting (Albright et al., 2000). Seginer et al., (2006) revealed that light control signals may use 3-day light integrals rather than a single-day integral. An embedded greenhouse shade curtain controller reduced solar radiation and temperature within the greenhouse (Droga et al., 2006).
Temperature inside the greenhouse is affected by the shade curtains. Soil temperatures were measured at three different times 11:00 a.m., 1:00 pm and 3:30 pm, Table 4. At 13:00 the soil temperature was 10°C warmer at the soil than the air temperature, and beneath the retractable roof the temperature difference was of 1°C.

3.2.1 Soft starter controller

Retractable shade structures with motorized roll-up systems (Fig. 8) were controlled by light sensors to regulate the amount of sunlight that reaches the plants (Pass & Mahrer, 1997). The retractable shade used a black Raschel woven shade with 60% transmission. The mechanism implemented used wires split 60 cm as guides for curtain sustain. A long tube drived by a single gear motor rolled the wire over it and moved the curtain in any direction. The retractable roof was opened seven times between 9:45 AM and 14:14 PM, and a 1/2 HP motor started fourteen times, Fig. 9. The energy used to move the shade curtain during the day was 3.95 Ah at full voltage application.
The soft start motor controller uses an inverter drived by an ATM89C51 microcontroller, Fig. 10. The inverter is composed by a 12-120 V transformer switched on and off by a pair of MOSFETS. The microcontroller reads the battery voltage in order to predict maximum voltage that can be applied to the motor; for example a battery voltage of 10 VDC can

provide 100V RMS (root mean square) to the motor. The PWM voltage presents many time delays (Fig. 10) stored as t_1-t_0, t_2-t_1, etc. in a look up table (LUT). At moment t_0 the first MOSFET will be turned on for the period given by the first data in the Table. After counting this time it will arrive to t_1 where it is turned off; the second data of the LUT will indicate the period that the MOSFET has to stay off, arriving to t_2. At this moment the next value of the table is acquired and the same MOSFET is turned on until t_3. The opposite MOSFET that operates as a switch will turn on and off during the negative part of the cycle.

The microprocessor program applies a starting voltage of 85 V RMS to the motor for a time period of 5 seconds, expecting it to turn. If it didn't rotate the voltage is increased by 5 volts for another 5 seconds and so on until it turns on, Fig. 11. Once rotating the increments take place every 30 seconds until full voltage is supplied. With an uncharged battery the maximum voltage that can be supplied decreases changing the PWM timing constants. The rest of the waveform can be reconstructed from the first quarter and its RMS value can be obtained from Equation 1.

The method of charging lead-acid batteries is with a constant voltage, current-limited source. That method allows a high initial charge current until the battery reaches full charge. The battery charger is also managed by the microcontroller. The PV system presented one battery of 50Ah with a maximum discharge capacity of 50% and 3 storage days in case cloudy days were present. When the system was drived by the soft start controller the energy usage per day decreased from 28.4 Ah to 23.02 Ah, Table 5. The motor load is disconnected when the battery voltage drops below 11V and reconnected when it gets back to 12.5V. The number of panels of 30W each decreased from seven to six, depending on the voltage applied. If the curtains are opened 12 times instead of 7 the 50W solar panels installed decreased to 6 when started with 84 V, Table 6.

3.3 Prickle pear cauterizer

Mexico is the first world producer with 79.4% of all the prickle pears, which are cultivated in 49,165 ha (Añorve et al., 2006). The prickle pear is rich in vitamin C and proteins, low in fat with high potentials of calcium, phosphorus and iron. The soluble solid content is high presenting fructose and glucose, meanwhile the pH is high and the acidity low (Pimienta, 1990). Fruits stored over nine days at ambient temperature presented a high incidence of spots and rots, and after 20 days almost 70% of the fruit gets damaged (Cervantes, 1998). Domínguez (1992) reported that freezing the pear at 10°C increased its shelf life to 16 days. Moisture control inside storage rooms can increase the shelf life up to 75 days (Barrios & Hernández, 2004). It is common to harvest prickle pears with a glove, rotating the fruit until it separates from the nopal leaf. Pear rots is a problem when deficient cuts are done under high moisture conditions. Pathogens as *Erwina caratovora*, *Agrobacterium tumefaciens*, *Fusarium oxisporum*, *Botrytis cinerea Pers*., and *Colectotricum. Sp*., attack the orifice left open in the fruit during harvest (Dominguez, 2006).

3.3.1 Energy consumption of the cutter

Electric pulses are applied to the heating resistance and its number determines the energy required for the cutting operation (Eqn. 2). The pulse number having a period of 100 ms is given by k; V represents the supplied voltage in volts and I the current in amperes. The temperature increased during the T_{on} period (Fig. 12) and decreased during the T_{off} period, Hahn (2009). By increasing the duty cycle (T_{on} /T) the voltage is applied for a longer time to the resistance and the set point temperature is obtained quicker. The heating resistance is of 125 Ω and the energy required is given by Eqn. 3. The voltage supplied by a 12 volts battery is given by Eqn. 4. Table 7 shows the effect of cauterization on rot production on prickle pears. Forty five days after harvest all non-cauterized prickle pears presented rots. After one month of storage, 79% of the cauterized fruits at 50ºC were healthy meanwhile no pear was rot at 150ºC. After two months of storage 78% of the pears were healthy.

If the prickle pear is cut in one second (10 periods) with a 50% duty cycle it will consume 2.88 W. A field worker takes 5 seconds to cut the next pear, when it is very close to him; otherwise it will take from 15 to 20 seconds. An average of 150 pears are cut per hour requiring a power of 432 W. The 5 W and 0.8 kg solar panel PV fixed on the worker cap was connected directly to the motor (without battery), Fig.13. Whenever, the sun hides or is cloudy it is important to have a 100 Ah lead acid battery which can be charged every 2 hours. Although a 100 Ah battery is the ideal it is too heavy to carry (38 Kg) so a 70 Ah deep cycle battery was selected as it is lighter (16.5 kg).

The cutting blade reached 150ºC after 83 seconds, and the resistance was disconnected automatically when it arrived to this temperature. Heat loss after 90 seconds decreased the cutter temperature to 140ºC. Cauterizing of fruits was the main work (Hahn, 2009), but it can be applied during nopal farm management just before the season starts, Fig. 14. The cauterized prickle pears are placed vertically in boxes with the cutting edge looking upwards. The boxes are closed to avoid any contamination and contact with the fruits before being transported from the field to the storage room. To reduce energy requirements, the resistance is now being substituted by a light focusing and converging system which can heat up to 130ºC without using energy.

3.3.2 Farm mode analysis

Theoretically an interesting system has been developed but not very useful to the producers who own a farm, Fig. 15. The producer hires ten workers so the system has to be changed in order to be economically feasible. A grid system is required as stored energy can be used by any worker. If 1500 pears are cut per hour and the working day lasts eight hours 34.56 kW are required per day. The current demand per day is 1440 A using 24 VDC motors. As there are 6 hours with radiation of 1000W/m^2, and considering a battery efficiency of 0.84, the panels should manage 282 A. This current without considering any class of autonomy is provided by 23 panels of 300 Watts. Cutting pears on cloudy days with high humidity is undesirable and cauterization is not as effective, so only harvesting is done during sunny days. Also the working day is divided so that during the middle of the day when radiation peaks the solar panels charge the batteries. The 29 battery bank handles 100 Ah each and the DOD were limited to 0.5. Operationally, the farm had two options for transferring the electricity which are shown on Fig 15 and 16. The latter one used cooper tubes over the soil making a DC grid, with low resistance and automatic disconnection when no worker was there. The system only works well when the freeway presents no nopal leaves which avoids the connecting box (motor to power line) movement. The second system presents the grid over the nopal tree and it's easier to work with, Fig. 16.

4. Figures and tables

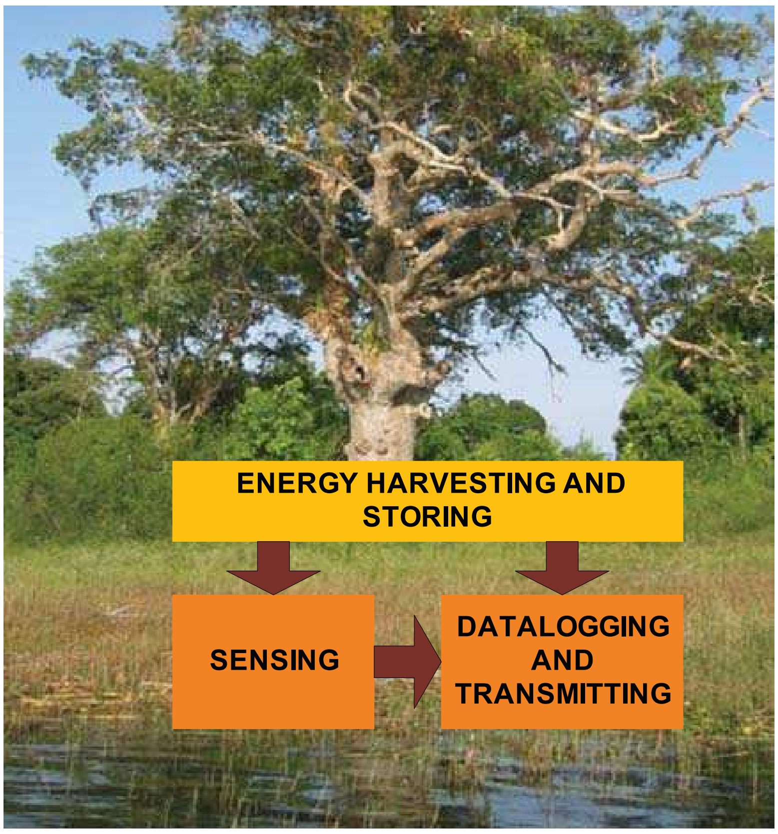


Fig. 1. Water quality autonomous sensing

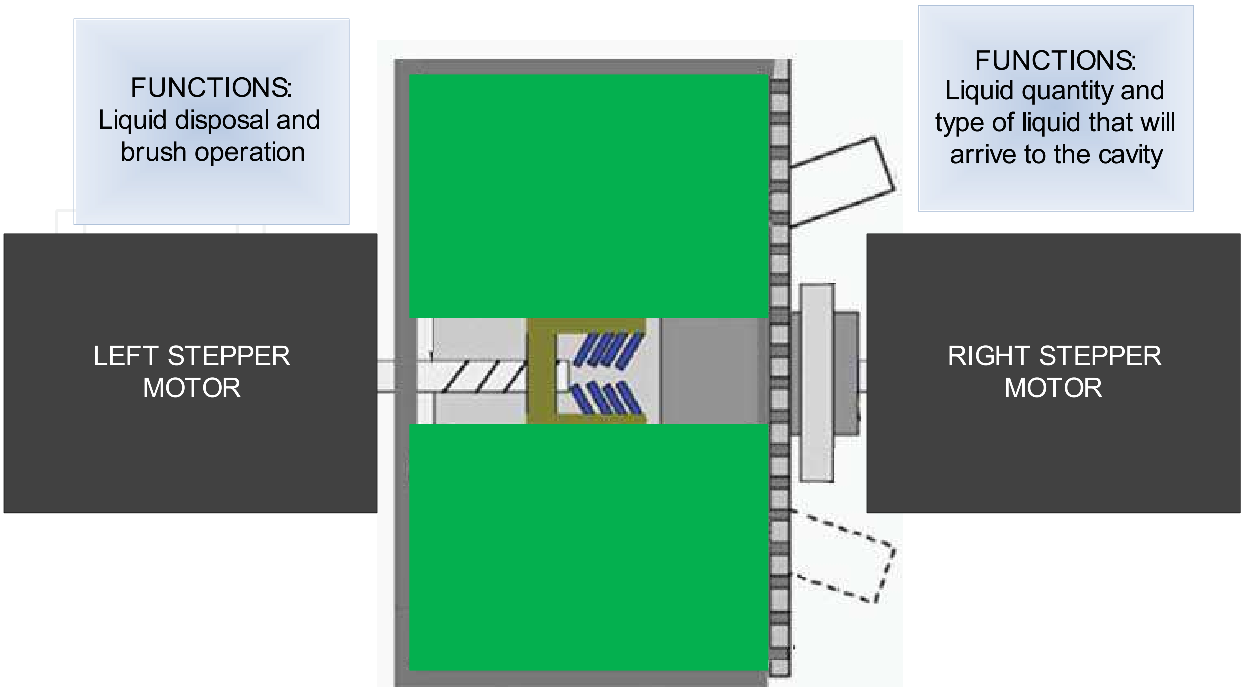


Fig. 2. Sensor simplest diagram design and motor functions

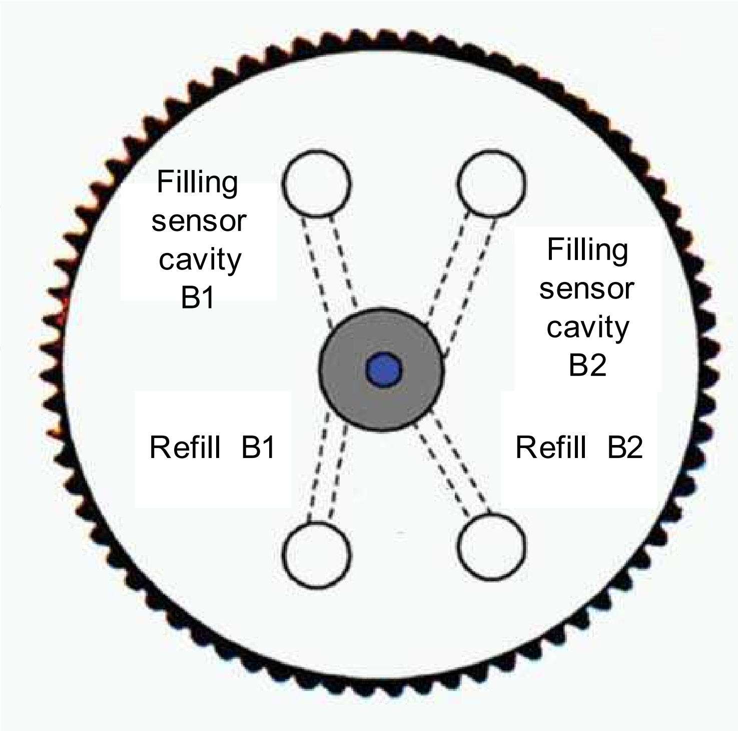


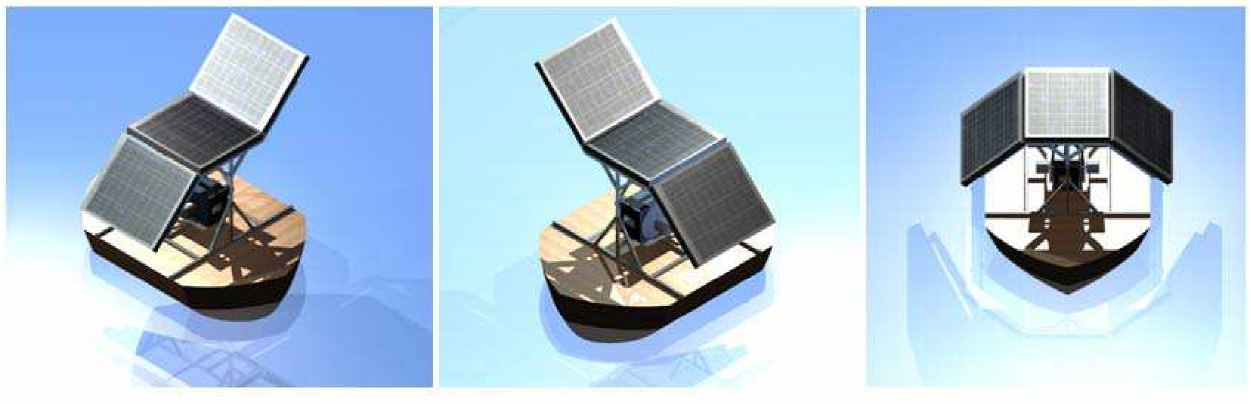
Fig. 3. Lateral view of the right wall and function realized per hole.

	Basic operation	Operation number	Time per operation, sec	Energy W-hr
Measurement	Hollow shaft filling by gravity, sensing time and sucking liquid	6/hr	180	3
Washing	Brush moving, positioning and distilled water management	6/hr	195	3.25
Calibration	Bottle positioning, refilling and water disposal	1/day	370	1.02

Table 1. Energy in watts-hour, time per operation for each of the sensor measuring, washing and calibration

	Four operation/hr	Six operation/hr	Ten operation/hr
Sensor	5.18	7.27	10.16
Data logger	0.5	0.5	0.5
Transmission	1	1	1

Table 2. Energy in watts-hour, time per operation for each of the sensor measuring, washing and calibration



(a) (b) (c)

Fig. 4. Solar panels generate energy for chloride monitoring (a) facing east (b) facing west and (c) with flat panel in the top.

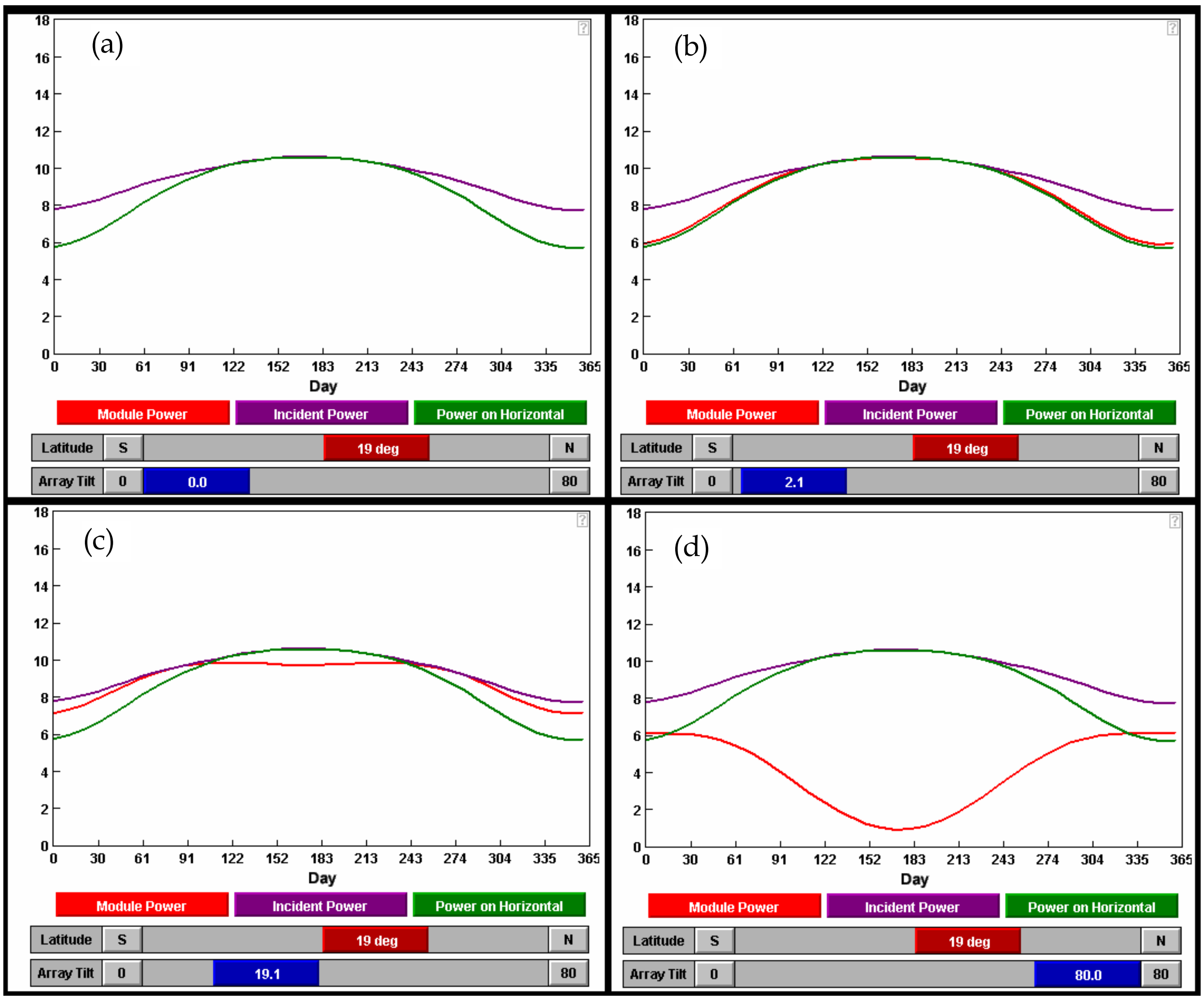


Fig. 5. Tilting in power production at (a) 0°, (b) 2.1°, (c) 19.1° and (d) 80° throughout all the year (http://energyworksus.com/solar_power_incident_angle.html).

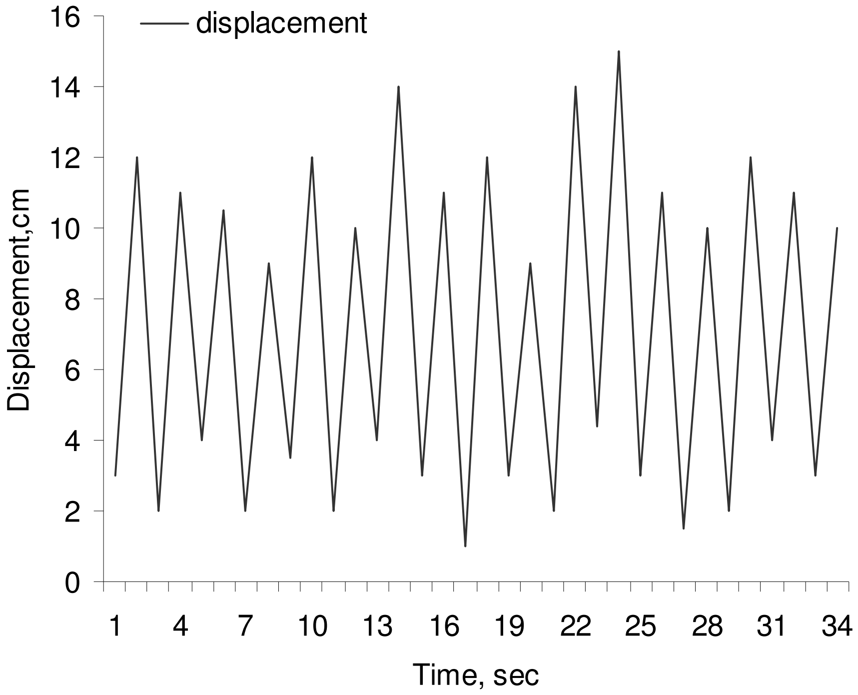


Fig. 6. Vessel vertical movement measured above the water surface.

Hours with high radiation	Current, A	Panel size	Number of panels	Weight, kg
5	5.51	90 W	3 of 30 W	11.7
6	4.59	85 W	2 of 30 W and 1 of 25W	10.6
7	3.93	70 W	2 of 20 W and 1 of 30W	8.5
8	3.44	60 W	3 of 20 W	6.0

Table 3. PV size required, amperes required to charge the battery and hours/day with a radiation over 1000 W/m^2.

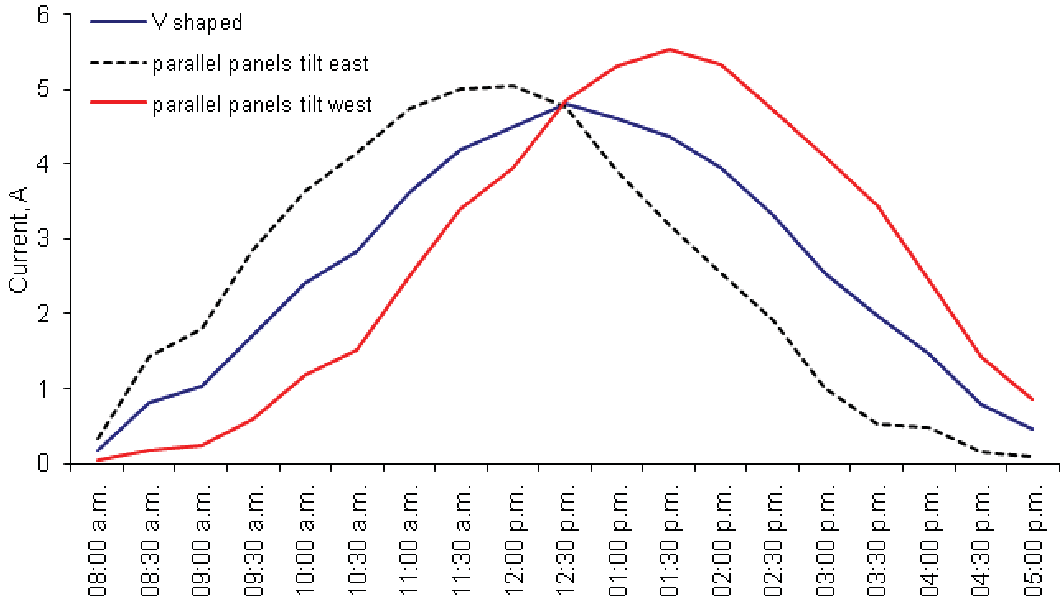


Fig. 7. Current produced for the same panels (two of 30 W and one of 25 W) fixed in different directions.

Fig. 8. Elements used for closing and opening the shade curtain including gear motor, pulleys and Raschel net.

	11:00 AM			1:00 PM			3:30 PM		
	OUT	GH	RET	OUT	GH	RET	OUT	GH	RET
Light level,	53	39	34	170	100	85	39	32	26
Air temp °C	26	30.4	27	29	34	30	24	28	25
Soil temp °C	35	26	25.5	39	29	29	33	24	23

RET: retractable; OUT: outside; GH inside the greenhouse

Table 4. Temperature and light intensity measured at different times outside and inside the greenhouse.

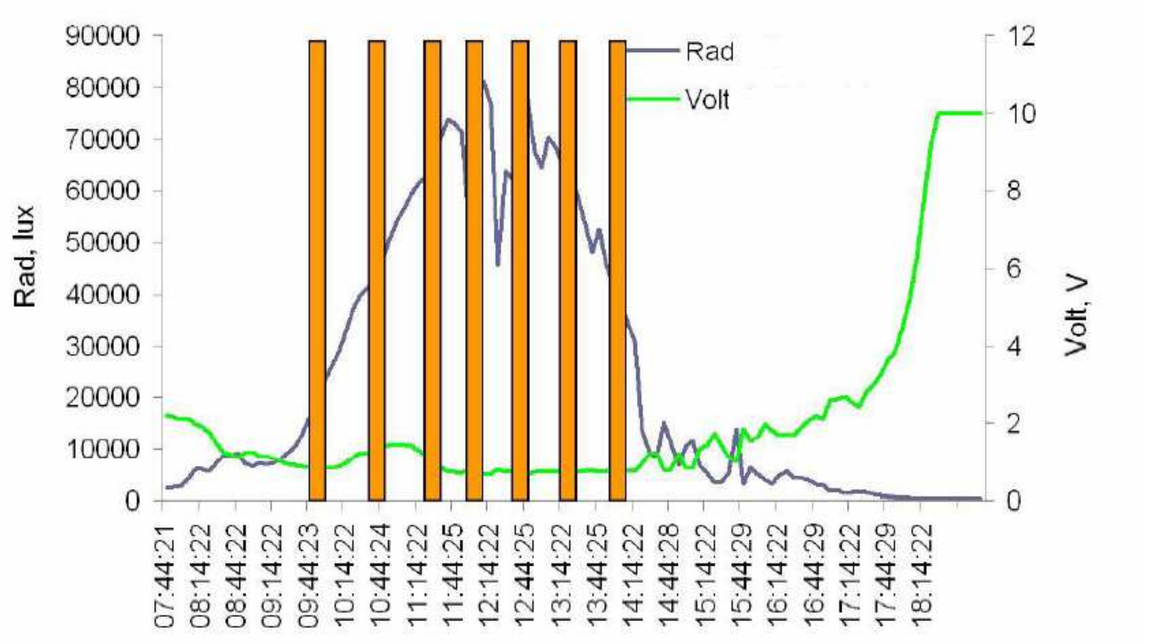


Fig. 9. Closing of the retractable roof and voltage obtained from the circuit.

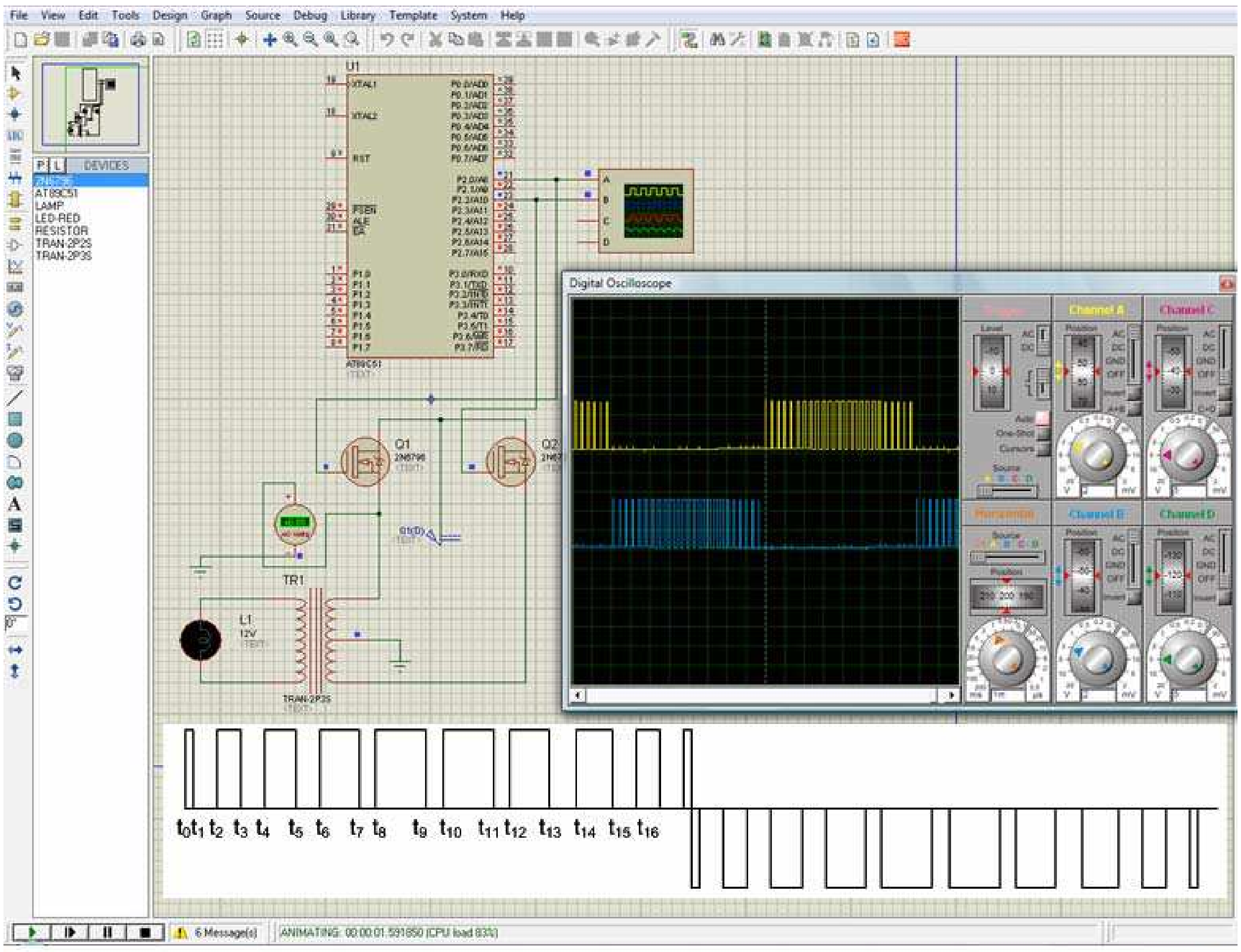


Fig. 10. Embedded closed loop PWM controller and PWM timing sequence.

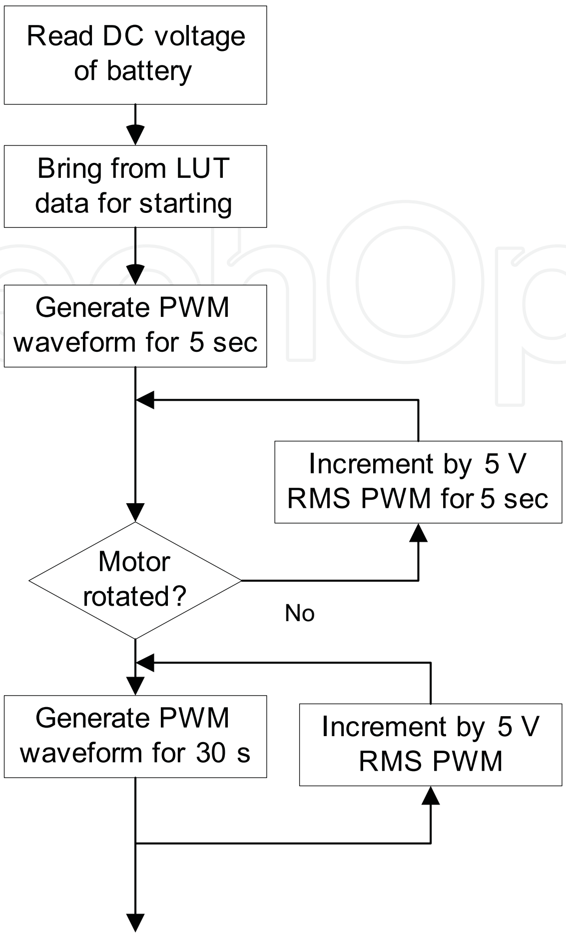


Fig. 11. Block diagram of the motor starter

	100%	90%	80%	70%
Daily current, Ah	3.95	3.73	3.5	3.2
Calculated current, Ah	28.4	26.88	25.2	23.02
Batteries	1	1	1	1
Panel @ 30W	7	7	6	6

Table 5. Current required daily for 7 openings under different starting voltages.

	100%	90%	80%	70%
Daily current, Ah	6.7	6.4	6	5.48
Calculated current, Ah	48.7	46.08	43.2	39.4
Batteries	1	1	1	1
Panel @ 50W	7	7	7	6

Table 6. Current required daily for 12 openings under different starting voltages.

Storage time (days)	Treatment efficiency, %			
	Without cauterization	50ºC	100ºC	150ºC
15	71	98	100	100
30	25	78	88	100
45	0	54	61	95
60	0	22	49	78

Table 7. Decrease in pricke pear rot during cauterization

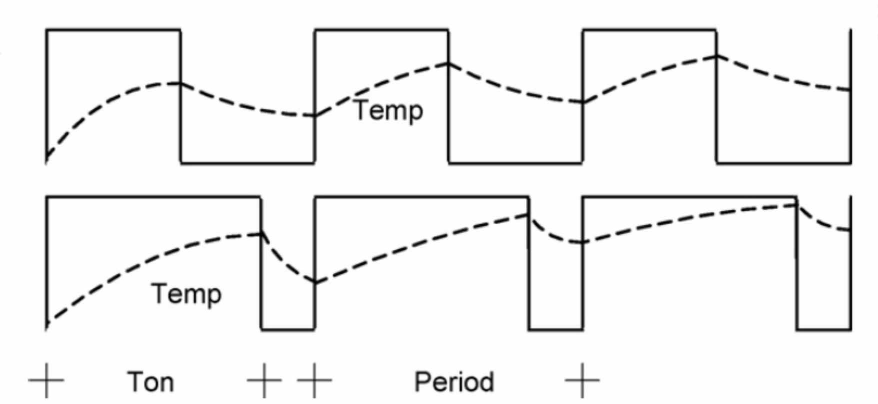


Fig. 12. Duty cycle and its effect on temperature increase.

Fig. 13. Lady cutting a pear wearing a PV cell in the cap

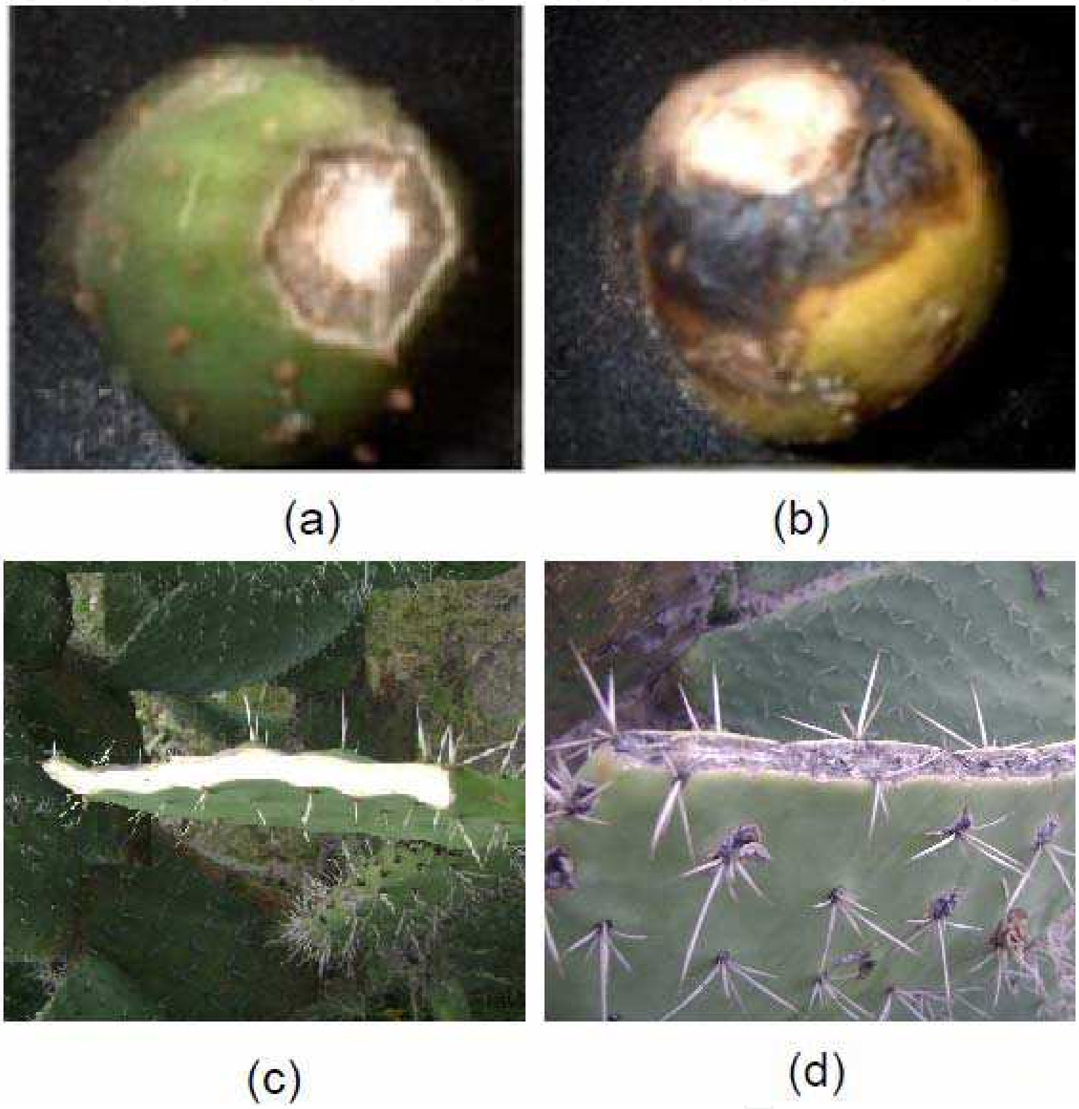


Fig. 14. Prickle pear (a) well cauterized, (b) beginning with rot; nopal (c) just cut and after (d) cauterization

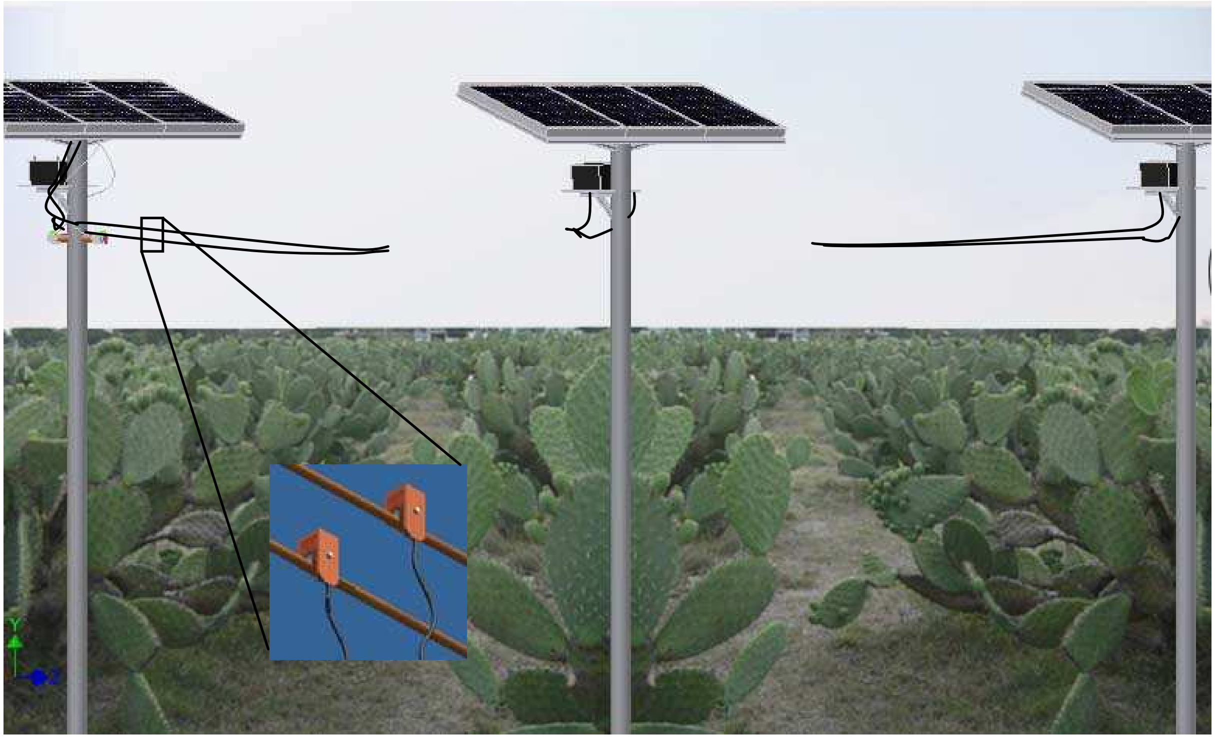


Fig. 15. Prickle pear farm with aerial grid cables

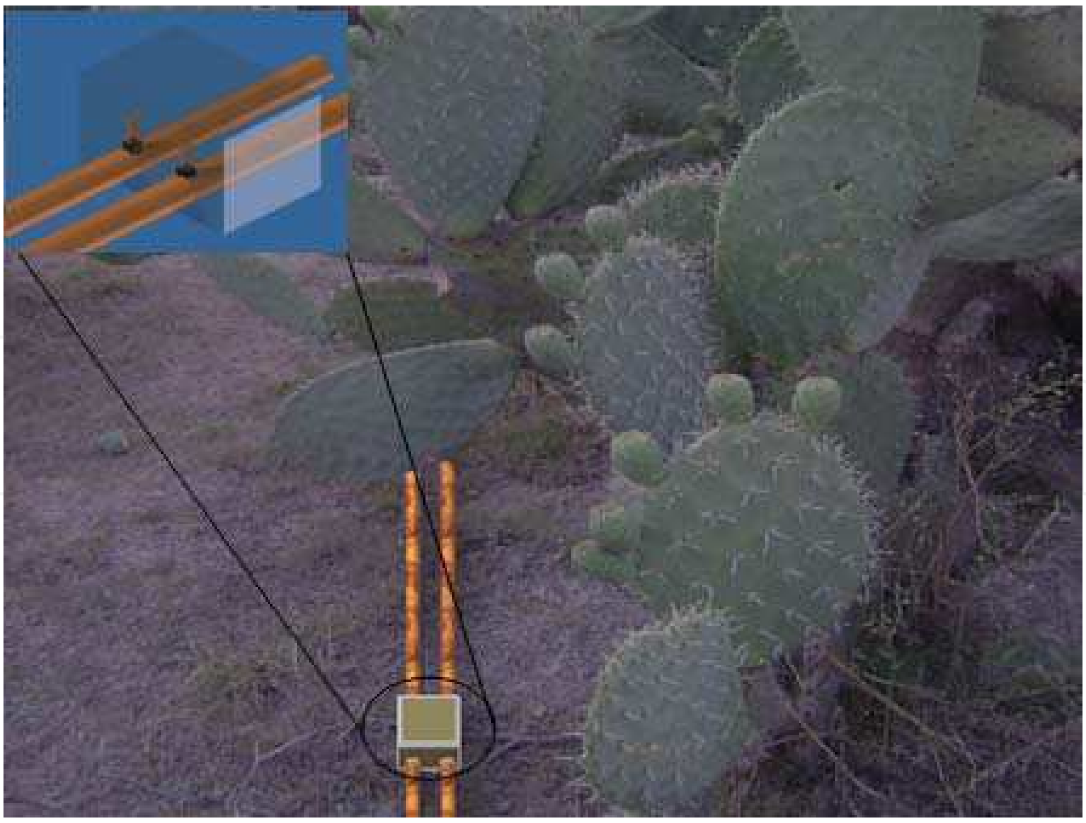


Fig. 16. Conductor in the soil and box connection

5. Equations

$$RMS = \sqrt{\frac{V^2(t_1 - t_0) + V^2(t_2 - t_1) + V^2(t_3 - t_2) + ... + V^2(t_n - t_{n-1})}{(t_1 - t_0) + (t_2 - t_1) + (t_3 - t_2) + ... + (t_n - t_{n-1})}} \quad (1)$$

$$E = 0.5kVI \quad (2)$$

$$E = 0.004kV^2 \quad (3)$$

$$E = 0.576k \quad (4)$$

6. Conclusions

Photovoltaic systems provide electricity to everyone where sun shines and even satellites use these panels to provide the energy they require for their operation and its crew. Agriculture PV grids can provide energy to remote locations for different applications like pumping water for irrigation and human consumption, small equipments for agro industry and home appliance management. It is our responsibility to save energy and to use clean energy to share a better life quality.

Monitoring sensors are becoming wireless and batteries more efficient and smaller. Actual batteries show an increased efficiency and higher storage capacity than ten years ago. Since solar energy systems are relatively expensive in comparison to other energy sources, it is advisable to maximize energy efficiency. PV electronics systems dissipate minimum energy as heat by the system components optimizing harvested energy. A monitoring self calibrated PV driven chloride sensor was presented in this chapter; another sensor could be used being the information available even without being in the river bank.

The third project presented in the chapter shows how PV cells were used for a simple fruit cauterizer and how PV grids can be managed to operate on a farm contour. Cauterizing can even be simplified and its energy consumption reduced. Another machine PV driven projects can be implemented by our team to solve special needs and contribute to make of the Earth a wonderful planet.

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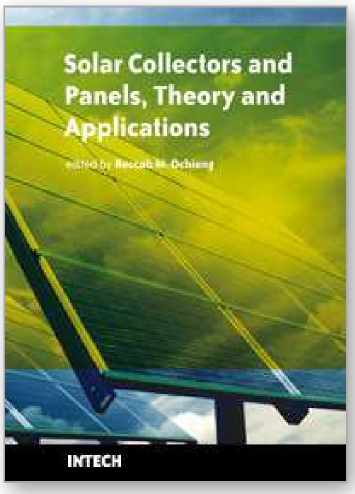

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