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A Modified Cooling System for Stand Alone PV Greenhouse in Remote Areas

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Abstract. Agricultural efforts are normally carried out in remote areas where electricity from national electric grid may not exist or grid connection is very expensive. Greenhouses industry is one of the most important agricultural practices in remote areas. Greenhouses help in extending the gardening activities and allows us to cultivate certain plants all over the year; by controlling air temperature and relative humidity inside greenhouse. In greenhouses, cooling and pumping equipments dominate the demand for electricity. Therefore, a stand-alone photovoltaic (PV) system is necessary to feed that demand. Medicinal herbs, for example are the most suitable plants to be cultivated in the greenhouses. They often need a temperature range of 15 - 21 °C and about 70% relative humidity to grow. As the climate in Egypt is not suitable all over the year to cultivate these medicinal herbs, it is preferable and necessary to use PV-based control greenhouse to cultivate these medicinal herbs in Egyptian remote areas. This paper presents a proposed greenhouse cooling system, which uses a stand-alone PV system to feed the electrical loads of the greenhouse. At the same time, it introduces the complete sizing procedure of the greenhouse stand-alone PV system.

Key words

Greenhouse, cooling system, pump, sump, PV system, battery.

1. Introduction

The main purpose of a greenhouse is to improve the environmental conditions in which plants are grown. Greenhouses are usually equipped with some environmental modification devices such as cooling, ventilation and heating systems. Ventilation can remove excess heat, increase air

mixing, and reduce temperature stratification in the greenhouse [1]. During summer, in Egypt, ventilation alone is not enough to maintain optimum interior temperature. Therefore, water evaporative cooling systems are usually used to reduce the interior air temperature to an acceptable level. The cooling of these systems is commonly accomplished by using an electrically driven fan, pad and a certain shading technique [2]. The function of the fan and pad is to prevent greenhouse overheating and cool the plants during hot weather. Whereas, the function of the shading technique is to absorb the solar thermal radiation and penetrates only the sunlight that is necessary for growing of plants. Therefore, to electrify the previously mentioned cooling equipments, that are used in remote area greenhouses, it is necessary to use a well designed stand-alone photovoltaic (PV) systems. The main objective of this paper is to introduce a proposed greenhouse cooling system, which uses a stand-alone PV system to feed the electrical load of the greenhouse. At the same time, it introduces the complete sizing procedure of the greenhouse PV system.

2. Proposed cooling system

This system is responsible for reducing the air temperature inside the greenhouse that affects the greenhouse environment and consequently the growing of cultivated plants. The proposed cooling system consists mainly, of four components, as shown in Fig. 1. These components are aluminum pad, cool air fan, pump and sump. The pad-fan system requires sufficient makeup water to replenish the water evaporated from the pad into the incoming air.

When large quantities of air are pulled through the evaporative cooling pads that are saturated with water, a substantial cooling effect is realized due to the evaporation of that water. This makeup water is supplied by a reliable pump, which pumps the water from sump and delivers it to the pad. Therefore, the pad can be kept wetly during the cooling system operation. This cooling technique can insure a reduction of greenhouse interior temperature to about 10-25 oC. Greenhouse shading is an auxiliary cooling technique which is used in this work, to absorb the solar thermal radiation and to penetrate only the sunlight that is necessary for growing of plants. Another auxiliary cooling technique is used in the proposed greenhouse sides. This technique is based on using the polyethylene white coating material layer, which can reflect about 50% of the incident solar thermal radiation. It is to be noted, that the water impermeable plastic material cover is used in the proposed greenhouse to protect the interior of the greenhouse from the surrounding weather conditions.

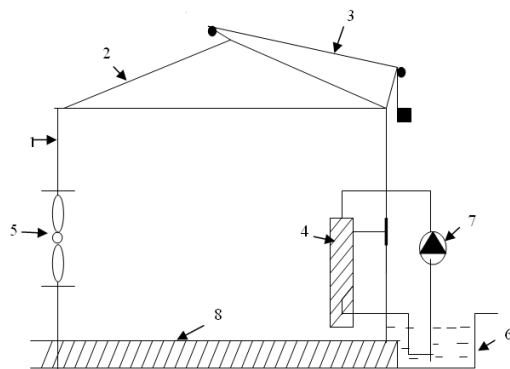


Fig.1 The proposed greenhouse cooling system.

- 1 polyethylene white coating reflects 50% of radiation
- 2 water impermeable plastic material cover
- 3 greenhouse shading (woven water-porous shade curtain material)
- 4 aluminum pad
- 5 cool air fan
- 6 sumps
- 7 pump
- 8 soil

3. The proposed electrical system

The proposed greenhouse electrical system shown in Fig. 2 is the source of the electrical energy required to DC power to the cooling system electrical loads. Therefore, the PV array and battery subsystems must be sized to provide continuous DC power to valves, pumps and fans.

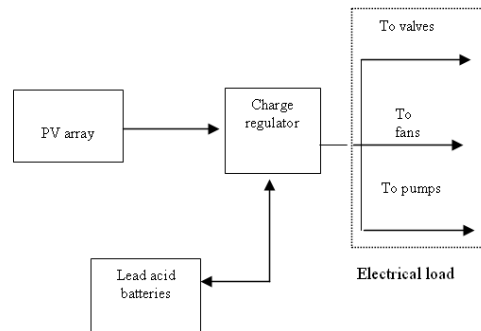


Fig . 2 The proposed greenhouse electrical system.

4. Cooling System Design

A. Cooling Pad

The needed pad area depends upon several factors including the type of pad material used. The pads should be continuous along the entire length of the greenhouse wall. There are several pad materials on the market. Among these are pads fabricated from aluminum, from plastic and fibers. The used type of pad material in this work is aluminum. Aluminum pads have minimum maintenance, weather resistant and more compatible lightweight. It is recommended that one square foot of pad be provided for each 250 cubic feet per minute (CFM) of air moved by the fans [3].

B. Pump and Sump

The pumps are sized for the system to supply at least 0.5 gallon of water per minute per linear foot of pad system. The sump should have a capacity of 1 to 1.25 gallons for each linear foot of pad in order to hold the water that drains back to the sump when the system stops [3].

C. Fans

Regardless of the type of pad material used, the fans should have the capacity to provide a minimum of one air change per minute in the greenhouse. The fan capacity should be based on total CFM delivered at 1/8 inch static water pressure. Standard measurement of airflow indicates how many cubic feet of air passes by a stationary point in one minute. The higher the number, the more air is being forced through the system. In controlled environment where a precise temperature of air is critical to plant growing, power tube fan is required, which constructed from heavy gauge steel. The power

tube fan is available in sizes from 12 to 30 inches. The 12 and 18 inch fans are direct drive units. The 24 and 30 inch fans are belt driven. The Performance ratings of power tube fans are shown in Table 1 [4].

Table 1: Performance ratings of fans.

Model	Fan Size	Motor HP	Drive Type	Fan RPM	System CFM*	Motorized Shutter Model	Framed Opening
PTFA12F17	12	1/6	Direct	1,725	1,250	LRW16E	17" x 17"
PTFA18H16	18	1/3	Direct	1,625	3,650	LRW21E	22" x 22"
PTFB24H	24	1/3	Belt	784	4,850	LRW27E	28" x 28"
PTFB30J	30	1/2	Belt	627	7,550	LRW33E	34" x 34"
PTFB30L	30	1	Belt	815	10,450	LRW33E	34" x 34"

5. The Electrical System Sizing

A relatively simple sizing procedure [5] can be adopted to size the stand-alone PV system of the greenhouse. Where, the system sizing in this case is based on the yearly energy balance between the radiation and the load and is implemented for an array with a fixed panel orientation.

A. Radiation and Load Data

The chosen zone is a remote area of Sinai (Saint Cathrine) was selected as the site under consideration. The area is located approximately in the middle of Sinai Peninsula of Latitude $27^{\circ} 17'$, north and Longitude. $33^{\circ} 46'$, east [6]. Fig. 3 shows the monthly averaged daily irradiation data. Temperature data are usually given in the form of minimum and maximum ambient temperatures as indicated in Fig.4.

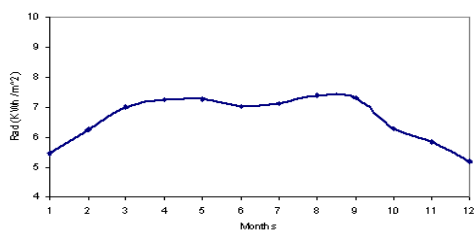


Fig. .3 Solar radiation of Saint Catherine.

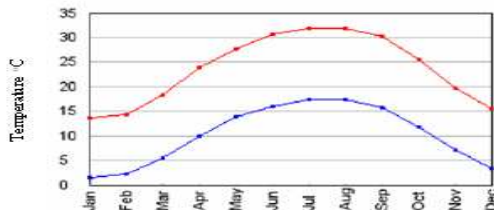


Fig. 4. Maximum and minimum temperatures of Saint Catherine.

The electrical load data gives detailed information about the equipments to be powered: their number, nominal power, nominal operating voltage and the number of hours of operation in a typical day. Table 2 shows these data for a typical greenhouse cooling system.

Table 2: Data for the greenhouse electrical loads.

Appliance	Number	Nominal power(W)	Total power(W)	Nominal voltage (V)	Operating hours
Water valve(on-off)	2	16	32	24	All day
Water pump	2	75	150	24	All day
Fan	4	225	900	24	All day
Total Power (W)			1082		

B. The Sizing Procedure

1) The number of series-connected modules

The DC operating voltage V_s of the system is specified to be 24 V. The number of modules N_s [7], which are to be connected in a series string, is directly determined by the DC operating voltage, as

$$N_s = \frac{V_s}{V_m} \quad (1)$$

Where V_m is the nominal voltage of the module at STC. = 9.6 V(obtained from the PV system located in the PV Dept., Electronic Research Institute ,Giza, Egypt) .

2) The number N_p of parallel strings

This number is directly related to the current requirement of the load.

The equivalent load current [7] is calculated from the equation

$$I_L (A) = \frac{E_L}{24 V_s} \quad (2)$$

Where E_L (Wh/day) is the typical energy requirement of the load.

Now defining the nominal current I_P which is required from the photovoltaic generator when working at its maximum power point and irradiated by the standard spectral distribution AM1.5 radiation at 1 kW/m².The energy balance [7] for a typical day can then be written as:

$$E_L (Wh/day) = PSH I_P V_s \quad (3)$$

Where, in Eq. (3) the radiation incident on the panel is expressed in peak solar hours (PSH).

Clearly, PSH is numerically equal to the irradiation in kWh/m² day [6]. Using Eq.(2) and Eq.(3) the nominal current I_P can be obtained according to the following equation:

$$I_P = \frac{24 I_L}{PSH} \quad (4)$$

The number of modules to be connected in parallel is then calculated using the following equation [7]:

$$N_P = \frac{I_P}{I_m} \quad (5)$$

Where I_m is the nominal current supplied by the individual photovoltaic module when illuminated under standard conditions = 2.4167 A (obtained from the PV system located in the PV Dept., Electronic Research Institute, Giza, Egypt)

3) The Storage Battery Capacity

The storage battery capacity can be regarded as serving two purposes. One is to provide a reserve capacity to cover an exceptionally long period without sunshine, (or system failure). The other purpose is to provide seasonal storage [8].

The amount of reserve capacity C_R required depends on several factors. Climate is the most effective factor; where sunny arid regions require less than foggy coastal regions. The accessibility of the site, the regularity of system monitoring, and the consequences of system failure are other important considerations. Normally, reserve capacity of 4 days is adequate for St. Catherine site [6].

Thus C_R [8] will be given in terms of the ampere hour required per day (Ahr = $\frac{E_L}{V_s}$) and the

number of the storage day SD, as

$$C_R = Ahr \times SD \quad (6)$$

Having selected the reserve capacity, the next step in determining the total capacity C_t is to determine the required battery capacity that is required to provide seasonal storage C_{ss}.

Where, C_{ss} [8] can be given as a function of the battery discharge d, as

$$C_{ss} = C_t \times d \quad (7)$$

The excessive depth of discharge will shorten the battery life .Therefore, the suitable value of d is chosen, in this case, as 0.7.

Once the value of d is chosen, the total battery capacity can be calculated, as

$$C_t = C_{ss} + C_R = \frac{C_R}{1-d} \quad (8)$$

6. Results and Discussion

The complete results of the sizing the greenhouse electrical system are illustrated in Table 3 .Where, the DC operating voltage of the system is specified to be 24 V and the nominal max-power voltage and current of the used module at STC are: 9.6 V and 2.4167 A , respectively. The Specifications of different components of the greenhouse are shown in Table 4. Fig. 5 presents the hourly data for PV stand alone system. As cleared, the PV stand alone system with battery bank is able to provide energy approximately all time of the day without excess electricity to dissipate. The load could be met; and the battery state of charge is shown in fig 6, ranges between 96 and 99.5 %.

Table 3 The sizing procedure results.

ITEM	SPECIFICATIONS
Number of series-connected PV modules	3
	70
The number of parallel strings	
The storage battery capacity	15000 Ah
The number of used batteries	5 batteries in parallel (each of 24 V & 3000 Ah)

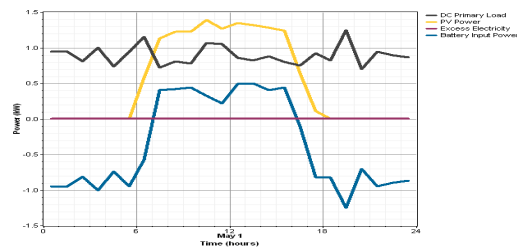


Fig. 5 Hourly data for stand-alone PV system.

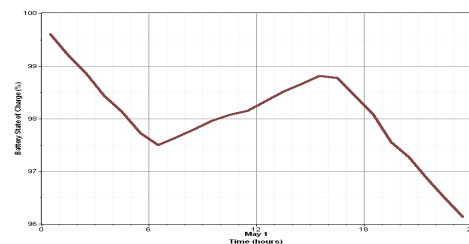


Fig. 6 Battery state of charge.

Table 4 Specifications of different components of the proposed greenhouse cooling system.

Item	Specifications
A- Greenhouse	
- Volume	13762 ft ³
B- Pad	
- Dimensions	Length (height)=6.5 ft Width= 5.5 ft
- Pad area	35.75 ft ²
- No. of pads	2
C- Pump	
- No. of pumps	2
- The capacity of one pump	3.25 gallon /min
- Pump power	1/10 hp
D- Sump Reservoir	
- Tank size	10920 liter
- Tank dimensions	length=20m height=1m width=0.5m
E- Power tube fan	
- No. of fans	4
- Fan capacity	3650 ft ³ /min
- Motor power	1/3 HP

7. Conclusion

The PV powered greenhouse is the best and clean method to grow Medicinal herbs in remote areas. This method helps to cultivate plants, all over the year, that might otherwise be impossible to be cultivated during certain seasons, and also it helps to protect the plants at a good quality. The proposed greenhouse cooling system is designed. The design parameters and specifications of each component in the cooling system are illustrated. The greenhouse volume is 13762 ft³. Two aluminium pads are used; each has area of 35.75 ft². Two pumps are used to provide sufficient water to keep the pads wet during operation. The pump power is 1/10 hp and the mass flow rate of water is 3.25 gallon /min. The fan capacity is 3650 ft³ /min. The

complete sizing procedure of the stand-alone PV system is presented. The number of series-connected PV modules is 3. While, the number of parallel strings is 69. Five batteries are used in parallel, each has 3000 Ah.

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