PN-AAV-497
ISN-46212
0365710

STAND ALONE PHOTOVOLTAIC ENERGY SYSTEM FOR A MEDICAL DISPENSARY

by

SUTENDRA SHARMA

ACKNOWLEDGEMENTS

OBJECTIVE

1. INTRODUCTION: TERRESTRIAL APPLICATIONS OF PHOTOVOLTAIC ENERGY SYSTEMS

2. ELEMENTS OF PHOTOVOLTAIC SYSTEM

3. SYSTEM DESIGN PROCEDURES

4. PRESENT STUDY

5. CONCLUSION

ACKNOWLEDGEMENTS

I express my sincere gratitude and thanks to Dr. Martin Bush, Administrative Director, TAET Program for giving me invaluable suggestions and advice for the rapid implementation of the project.

Thanks are also due to Dr. Roberto Pagano and Professor Erich Farber for providing me the facilities to work and assemble the system.

Not but the least thanks are due to Mr. Vann Chesney, Engineering Technician for helping me in the workshop and assembling the Photovoltaic System in a very short time. TAET staff deserves thanks for typing the manuscript at a short notice. Finally, USAID is thanked for financing my participation in the TAET program.

Thanks are also due to Principal Dr. O. N. Wakhlu, Regional Engineering College, Srinagar, and Government of India for Sponsoring me for TAET program.

OBJECTIVE

Photovoltaics (PV) have proved their indispensability in space programs and, Satellite operations. Now PV are also finding applications and increasing usage on earth. Some of the applications are like warning signals at railroad crossings, highways, tidal warning stations, lighthouses; communications and repeater stations, TV and Radio; Educational TV and Radio, Security and Surveillance networks, camping and Vacation sites; Electronic watches and calculators, and Battery Charging. Therefore terrestrial applications of photovoltaics is presently considered a viable power source. PV systems can prove to be very useful sources of power for remote areas and military outposts which are not connected by any utility grids, and the cost of fuel transportation is very high. Keeping this view in mind the Stand Alone PV System for a medical dispensary is an interesting application. The main objective of this project is to demonstrate the efficiency of such a PV system for loads encountered in a small medical dispensary where storage of costly and perishable medicines at a low temperature is an overriding consideration in comparison to the overall cost of the system.

Chapter 1: INTRODUCTION

Photovoltaics is already a suitable and fast effective means of providing electricity for a variety of terrestrial application (Table 1.1) These can be categorized by their small and predictable electrical loads, and often by their remote location, or need for independent reliable and unattended operation. Until now, solar cells have been used for limited and very diverse applications. Satellites, electronic calculators and watches, a one person airplane and various prototype electric cars have been designed which obtain most or all their power from photovoltaic panels. Water pumping, irrigation projects, a water desalination plant, and a professional radio station are operating entirely on solar cells. Radio repeater stations, railroad crossings and mobile transmitters are operating on solar cell power in many parts of the world (Pulfrey 1978). Despite the demonstrated versatility of solar cells, there are four major limitations, that could prevent them from making significant contribution to the terrestrial applications energy demand: (1) Cost of solar cell; (2) the amount of annual sunshine at a site; (3) the type and timing of the PV output power, and (4) the space required to generate a significant amount of photovoltaic electricity. Some factors are considered in Chapter 3 for the sizing of the Photovoltaic Energy Systems for a medical dispensary.

Chapter 2: ELEMENTS OF PHOTOVOLTAIC SYSTEM

Solor electricity performs no function until it is integrated into a system that matches the power supply with its load. There are a variety of electric power conditionings devices that usually must be

added to a photovoltaic array to convert the solar energy to a form that can be used by a load. Many energy applications require electricty during the nighttime or on cloudy days, and a photovoltaic array is unable to provide this. Therefore, for the proper operation of a photovoltaic energy system, the photovoltaic power packs needs to be extended into a system that includes solar cell arrays, energy store, the possibility of interconnection with a non-solar generating plant. In addition, there may be a need to use concentrators to increase the power output from solar cell. The elements that would have to be incorporated into such a terrestrically located photovoltaic power system are shown in Fig. 2.1. Now some of the elements of a PV system are discussed briefly; as the same are required for the System design procedure (Chapter 3)

2.1 Insolation

The designer of a PV system must be able to ascertain the amount of sunlight or Insolation that will exist per given area at the location where the PV array is to be installed. It is necessary to know not only the amount of sunlight that can be collected but also its typical spectral distribution and how this is influenced by atmospheric conditions on the basis of an air mass (AM) number. Where the number refers to the secant of the angle between the positions of the solar beam at the zenith and at the time under consideration, measured at sea level e.g. when the sun is overhead the angle is zero and conditions can be classed as AMI. The air mass number is therefore a measure of the thickness of the atmosphere between the observation point and the sun. According to this classification AMO is used for sunlight outside the earth's atmosphere. At present most

workers in the photovoltaics field quote results in terms of standard spectra, which for terrestrial conditions are often based on the data of Moon (1940) and for extra-terrestrial conditions are based on Thekaekara's data (1974). At the laboratory level a common procedure is to simulate terrestrial sunlight by the simple expedient of filtering the light from a $3200^{o}K$ color temperature tungsten halogen lamp through water and adjusting the intensity until a reference solar cell detactor indicates a power density of 100mW cm^{-2}.

2.2 Photovoltaic Arrays

A PV array is taken here to refer to the structure of the panels (modules or subarrays) that houses and supports the solar cells in a photovoltaic system. For systems designed for use under concentrated sunlight conditions the definition includes the focussing and cooling apparatus also.

Present day modules intended for operation in unconcentrated sunlight consist of a support board (e.g. alumnium, flexiglass, fiberglass, glass) to which the solar cells are affixed, an encapsulating convering (e.g. glass or polymeric) and usually a supporting frame as designed to facilitate connection of modules into a closely packed array. Also the modules construction must contend with conditions like humidity, air pollution, bird droppings, highwinds, hail, sand, rain and snow, vandalism and aesthetic considerations. The climatic factors turn out to be very demanding of the encapsulant, especially as the capital-intensive nature of PV Power systems requires component lifetimes of at least 20 years. Some potential candidate materials have been identified e g. for covers soda lime glass, low expansion coefficient borosilicate glass (corning 7070), acrylic, FEP teflon, Seron and Mylar; for sealants - acrylic, polyvinyl butyral and poysulfides; for adhesives - acrylic, epoxy, FEP

Teflon and methyl phenol types of silicons.

For a module of given exterior dimensions and comprising solar cells of given conversion efficiency and operating characteristics, the electrical output will depend upon the number of cell and their method of interconnection. In order to obtain the desired operating current and voltage values a combination of series parallel level connections is usually necessary either at the cell level within a module or at the module level within an array. A reliable photovoltaic system would include series-parallel interconnection at both levels so that the shadowing or failure of one cell would not reduce the module output power to zero, as would be the case if all the cells were connected in series.

The installations of PV modules is another important factor. The collection of solar radiation by PV modules can be increased by tracking the sun continually. Alternately power output from the PV power systems can be increased by orienting the solar cell modules to the south and tilting them at an angle equal to the local latitude.

The use of larger photovoltaic arrays can also for a problem of finding suitable sites for their installation. The roof tops of houses, apartment blocks, office buildings, shopping centers and large industries, covers for parking lots, sheltered waterway, existing mountainside, and deserts have been suggested as the convenient and possible sites for PV installations.

One of the approaches to solve the array cost problem is to incorporate cheap sunlight concentrators into the array, so increasing the power level and hopefully reducing the dollar per watt figure for the array. However, the concentrators have not been considered favorably for terrestrial application of photovoltaics.

2.3 Power Conditioner

For application where PV power systems are designed to supply a predictable and small (less than a few kw) load, a simple battery charge system is usually adequate (fig. 2.3). A series blocking diode prevents discharge of the battery through the solar cell during low insolation conditions, and a shunt regulator prevents overcharging of the batteries that otherwise occur during periods of prolonged insolations. The strategy here is to choose an array and battery size capable of supplying the load on demand and to waste any power that might on occasion be generated in excess of the demand (load plus battery charging). This type of power conditioner is most suitable for stand alone systems that require low loads ($\lesssim$ 1KW). The application of this concept to larger loads ($>$ 5KW) might not be acceptable for at least two reasons. Firstly, the sheer area of collector required for a self-sufficient supply is likely to be prohibitive. Secondly, the electrical sizing is such that it would be difficult to rationalize the amount of energy that may have to be dissipated wastefully. A more practial PV supply at this level would not therefore be expected to stand alone and would incorporate a back up supply from a non-solar generator source (fig. 2.1). For a residential supply in a high insolation area this back up might be in the form of a diesel generator so that the independence from the conventional electrical grid could be achieved if so desired. However, interconnection with the local utility might be more acceptable to many consumers, and would certainly be the case at intermediate load level application (.5-10MW). It may be mentioned that the interconnection of the PV system with the utility grid will necessitate the use of an inverter to convert Direct current

produced by photovoltaics to alternating current transmitted by utility grids.

Buresch (1983) has discussed many electrical circuit diagrams Series and Shunt regulators that conditions the output power from photovoltaics arrays.

2.4 Energy Storage

Almost all the small point of use PV power sytems that are in use today incorporate an energy storage element to provide power during periods of inclement weather and at night. Secondly, batteries are the obvious choice for storage of PV electricity because of simplicity of conversion and compatability of terminal voltages. However, a number of electricity storage scheme are being investigated for PV energy systems (Table 2.1). At present there is no practical alternative to lead acid batteries. This expense of $\sim$\$70 KWh^{-1} can be tolerated because of the modular size which allows installation at the load center. An alternative may have to be developed before any significant adoption of batteries can be expected from users of electricity at the kilowatt level to megawatt level. A techno-economic criteria is expressed as an energy density of aound 100 $Whkg^{-1}$, a long life of around 2000-2500 cycles and cost of around \$20 - 35 Kwh^{-1}. Table 2.2 enables some comparison of past and future batteries to be made.

TABLE 2.1

SUMMARY OF ELECTRICITY STORAGE SCHEMES

METHOD	CONVERSION	STORAGE MEDIUM	RECONVERSION	ELECTRICAL OUTPUT	CONVERSION EFFICIENCY
Battery	Electrochemical	Battery	---	dc	70-80
Pumped Hydro	ac -- pump	water	electromechanical (turbine)	ac	70-75
Compressed Air	ac -- compressor	Compressed Air	Expand + heat electromechanical (gas turbine)	ac	65-75
Hydrogen	Photoelectrolysis—gas electrolysis —gas	H_2 gas H_2 liquid H_2 slush metal hydride	fuel cell gas electro-mechanical	dc	35-50
Flywheel	ac -- motor	flywheel inertia	electromechanical (motor - generator)	ac	70-80
Superconducting magnet	electromognet	Superconducting magnet	---	dc	90-95

TABLE 2.2

STORAGE BATTERY DATA (Pulfrey 1978)

Battery type	Energy Density $Wh.kg^{-1}$	Life cycles	Cost $/KWh
Silver-Zinc	100-120	100-300	900
Nickel-Cadmium	33-40	300-2000	600
Nickel -Iron	22-33	3000	400
Lead-acid	11-22	1500-2000	50
Nickel-Zinc	60-88	250-350	20-25
Zinc-chlorine	66	500	10-20
Sodium-Sulfur	170-220	1000	15-20
Lithium-Sulfur	130-170	1000	15-20
Zinc-Oxygen	160	?	?
Aluminum-Air	240	?	?

Chapter 3: System Design Procedure for Stand Alone PV Systems

The design of a photovoltaic - electricity storage power system that is to act independently of any nonsolar generating plant involves calculations of array size and battery capacity, with a super imposed uncertainty in the form of the insolation. Because the location is likely to be remote, precise insolation data is not likely to be available and intrepretation through nearest weather stations may not be valid, especially in mountainous regions. By using data from weather stations in similar climatological zones some estimate of the insolation can be made, which then needs to be modified via a "variability factor" to allow for the variation from year to year both in mean and worst-case values. Bartels and Moffett (1973) have suggested a variability factor of 15%. According to them it is then reasonable to work with monthly insolation averages and high storage capacity. Consequently the system performance is unlikely to be seriously affected by short term (daily) fluctuations. For maximum solar energy collection, a good rule of thumb guide for fixed array orientation is to tilt at an angle equal to that of the local latitude, although for areas with large differences between summar and winter insolation it may be more expedient to fix the tilt angle at a value appropriate to maximum collection in winter.

In addition to insolation factors it is necessary to take into account likely array and ambient temperatures and their possible variation throughout the year.

Useful current can be delivered to the load and to charge the battery only if the array voltage exceeds the battery voltage plus the blocking

diode voltage drop. The worst case condition from this point of view will occur on a hot day (low array output voltage) when the battery is fully charged. The strongest factor influencing the selection of battery storage capacity is the occurrence of periods of continuous low insolation, and these are likely to arise in winter and on cloudy days. The array size is primarily determined by the mean insolation level and the required load.

Now we outline the procedure which determines the size of a simple photovoltaic power system to supply a daily load of 200 watt at 12V in Gainesville, Florida. A load of 200 watt is selected for a small medical dispensary, because there is need of two 50 watt (12V dc) light bulbs, and one refrigerator (12V, 5-6 amps) to store costly medicines at low temperatures. It may be mentioned here that not all the load is used at the same time e.g., light are only required at night time for 3-4 hours, and the refrigerator runs for approximately 8 hours in day. Therefore a provision for a small water pump (200W) can also be incorporated in the design of such a PV systems for a medical dispensary.

The procedure is outlined here (Buresh 1983):

(1) Determine the typical load electric energy demand on an average day for each month of the year (KWh/day). If monthly data are not available, then choose from different times of the year, preferably near the solstices and equinoxes (December 21st, March 21st, June 21st and September 21st). Plot the energy demand (KWh/day) versus time of year (month).

(2) Make a preliminary decision as to whether the PV array will be sized to satisfy the annual peak, average, or minimum energy demand.

If needed, calculate the annual average daily energy demand (KWh/day).

(3) Determine the total solar energy (TE) available at the site under consideration or an approximately south-facing surface and tilted equal to the latitude of the installation site. Establish a table of daily solar energy vs. month or season of year (KWh/m^2. day vs. time of year)

(4) Calculate a preliminary system design by choosing the type of power conditioning equipment needed. Will the system be utility-interactive? Will it have battery storage? Will it involve a maximum power tracking or control circuit?

(5) Determine the approximate PV size needed to meet the energy demand according to the equation.

$$AA = \frac{LE}{SE \times ME \times TC \times PF \times PCE} \qquad (3.1)$$

Where AA = array area (m^2)

LE = one day's load energy demand (KWh/day based on the annual peak, average or minimum

SE = Solar energy for one day at site under consideration (KWh.m^2 day), based on annual peak, average, or minimum.

ME = Module efficiency at the local cell temperature

TC = Temperature correction factor to adjust module efficiency to local cell temperature.

PF = Peaking factor for module or array.

PCE = Power conditioning efficiency for equipment such as inverter, battery, or maximum power tracker.

Dividing the daily energy demand (KWh) by the daily PV energy output (KWh/m^2) will yield the array area in square meters.

(6) Calculate the peak power rating of the array sized in step (6) by

multiplying the array area (m^2) by 100 W/m^2 and by the cell efficiency and array packing factor from equation.

$$PP = A \times 1000\ W/m^2 \times ME \times PF$$

Where PP = array peak power

(7) Plot the PV output and load input curves in the graph. Will long term storage or back power be needed?

(8) Estimate the load power requirement (W) throughout a typical spring or fall day or an annual average day. Draw an approximate plot of load power (W) versus time of day for a 24 hr period.

(9) Estimate the solar power available at the site being considered during different hours of a typical spring or fall day or an annual average day (W/m^2). Multiply the array peak power (step 6) by the annual average percentage of possible sunshine to obtain an approximation of the annual average midday power level. Also determine the hours of sunrise and sunset for a spring or fall day or a declination of zero. Plot the PV power output versus time of day on the same graph established in step (8) by using the three data points determined above.

(10) Examine the PV output and load input curves in the graph completed in step (7) and note the amount and times of PV energy surplus and deficit throughout the day. Will shunt term storage or backup power be needed?

3.2 Sizing of Battery Capacity

In a stand above system with battery storage, the PV array is usually sized so that its energy output throughout the year is never less than the loads energy demand. The system also must maintain a continuous energy supply at night and on cloudy days although there is little or no solar energy. The amount of battery storage needed will depend on the load

energy demand and on weather patterns at the site. Further the percentage of possible sunshine for the site will give a general idea of what fraction of any month or year has overcast skies. The sunshine percentage for each month and any available data indicating the longest continuous period without direct sunshine will help the designer predict how much storage is needed. The price of energy storage and extra PV array increases with size, therefore, having too much energy and storage capacity will waste money. Therefore there is a trade off between keeping the costs down and meeting the energy demand during low solar energy periods. Putting the solar energy surplus to work performing various tasks that are switched in when there is excess energy will decrease waste. Another solution would be to undersize the storage capacity and array and to meet periods of deficiency with auxilliary power, such as the utility or a diesel generator. On the other hand, the load may have to diminish or cease its energy demand during brief periods when solar energy is low.

The required battery capacity for a PV system is determined from the equation (Bartels and Moffett 1973, Pulfrey 1978)

$$B\ (Ah) = \frac{731.6}{.75} \times \bar{I}_L \times \sum_{j=1}^{12} \frac{D_m - D}{D_m} \qquad 3.$$

Where 731.6 is the average number of hours per month, I_L is the mean load current, 0.75 is the assumed permissible depth of battery discharge factor, and the summation is over 12 months for which the daily average insolation is less than the annual mean value D_m.

Chapter 4: PRESENT STUDY

4.1 System design calculation for a Stand Alone PV System.

A medical hospital wants to design a PV system to meet the electric energy needs of a small medical dispensary which is located in a remote, far flung and mountainous area and it is not connected by any utility grid. The small dispensary requires the provision of a small refrigerator and two light bulbs (50W each). It is now required to know how long an array will be needed to meet the energy demand. Also an idea about the possible battery storage capacity is required. Now we proceed to follow the step by step design procedure as outlined in the previous chapter 3. A major portion of this design was carried out by Dr. Martin Bush, Administrative Director, TAET:

(1) Typical load electric energy demand (peak): 2.5 KWh/day

12 V Refrigerator (60-70 watts)
2 light bulbs (50 watt each)
1 waterpump (200 watt)

(2) Total solar energy (T.E.) available at: Table 3
Gainesville (39' N) at the horizontal 4.895 KWh/$_m^2$ day
Surface.

(3) Stand Alone System is to be designed, and the power condition is supplied by that supplies current to load either from PV array or batteries depending on the amount of insolation.

(4) The array size AA ($_m^2$) is calculated from equation 3.1 using daily energy demand LE = 2.5 KWh/day, total solar energy for one day at site under consideration from Table 4.1 i.e., SE = 5.895 KWh/$_m^2$.day, Module efficiency = 0.1, packing factor of module = 0.8277, Power Conditioning Efficiency PCE = 0.90. The size of the array comes out to be 6.87$_m^2$.

TABLE 4.1

TOTAL HORIZONTAL RADIATION AT GAINESVILLE (29° 39'N)

($KWh/_m{}^2.day$)

Jan	3.269	July	5.976
Feb	4.176	August	5.907
March	5.154	Sept.	5.092
April	6.166	Oct.	4.137
May	6.099	Nov.	3.687
June	6.182	Dec.	2.899

Monthly Average = 4.895 $KWh/_m{}^2.day$

= 18 .9 $BTU/Ft^2.day$

(Ref. Kreider and Kreith 1981)

(5) The battery capacity is calculated from equation 3.2. The mean load current I_L is taken to be 10 amp, and $\frac{12}{j=1}$ $(D_m - D)/D_m$ is calculated from Table 4.1, its value is 0.0739577. The battery capacity comes out to be 721.6 Ah.

The present PV installation was designed by Dr. Martin Bush, Administrator Director, TAET. His calculations are based on the load consumption (2.5KWh) battery capacity (5KWh) and the PV panels ($35^{W}p$) available from SOLAREX (SX-110) As per his design a battery bank of 6 nos (100A_h) and 10 PV panels for a peak output of 350 W_p has been set up at TREEO Center. The system is able to run a ARCTIC KOLD d.c. refrigerator (12V, 5-6 amp), and two light bulbs (12V, 50W each). It may be mentioned here that our theoretical calculations based on equations of Chapter 3 come quite close to the system design of Dr. Bush. Further the system was operated for about 15 days. A schematic diagram of the system is given in fig. 4.1. Fig. 4.2 shows an I-V characteristic of PV array on a sunny day when the isolation was 504.4 $W/_m{}^2$.

The data was collected about the energy produced by PV array (tilted at an angle of 30° from the horizontal) and energy consumed by the load (refrigerator). The lights were switched off and on depending upon the amount of power available from the PV array and bank of batteries. We monitored the temperature inside the refrigerator. The lowest temperature in the freezer, was $- 5^o - + 2^oF$ depending on the ambient temperature.

Chapter 5: CONCLUSION

We are able to demonstrate that the Stand Alone Photovoltaic system (300 W_p) can run a d.c. refrigerator, and two light bulbs sufficient for a remote medical dispensary. However, more experimental data on the total solar energy available at the site, percentage of daily sunshine available, power output from PV array on clear days, cloudy days and semi cloudy days is requried before any definite conclusion can be drawn.

Previous Page Blank

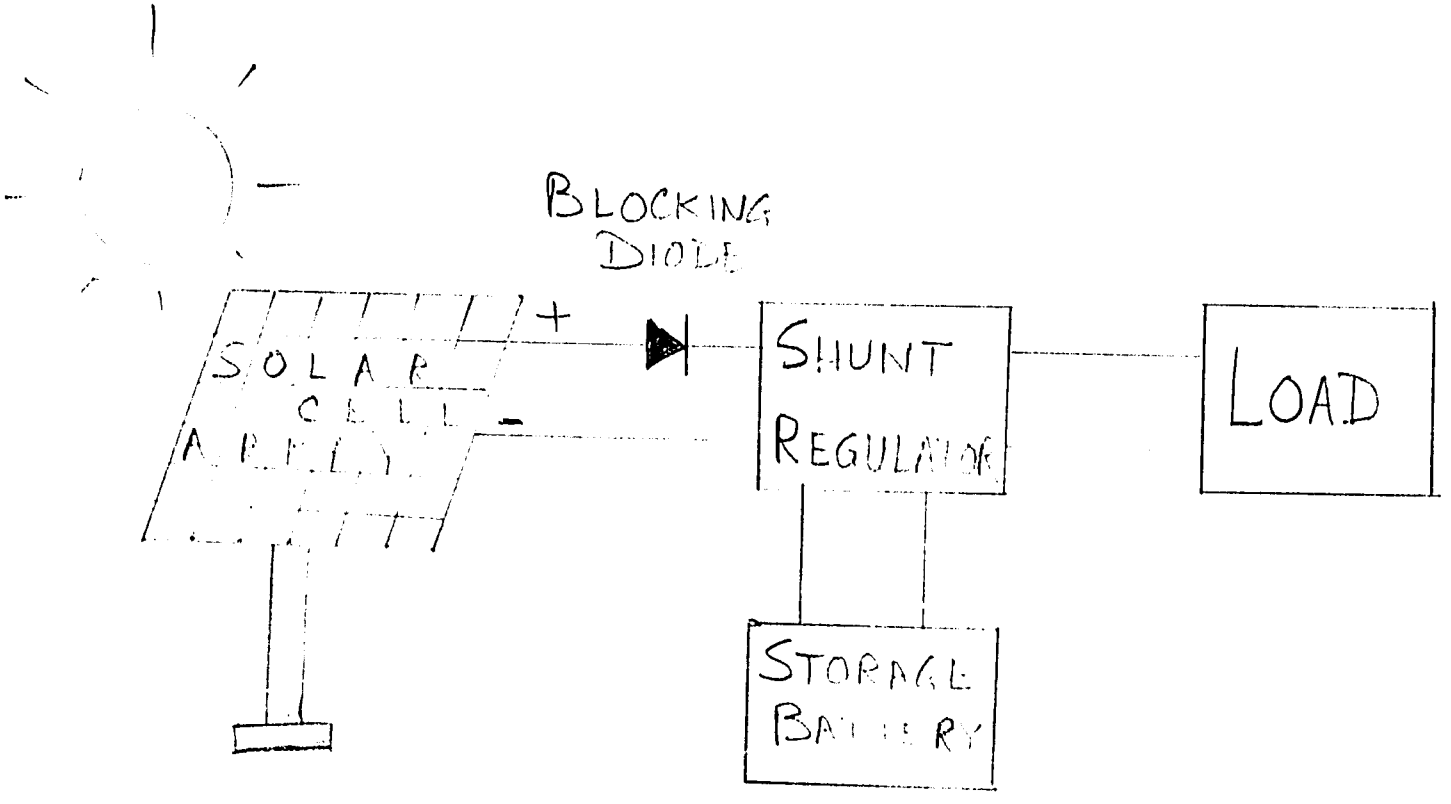
BLOCKING
DIODE
+
SOLAR
CELL
ARRAY
-
SHUNT
REGULATOR
LOAD
STORAGE
BATTERY

FIG. 2.2

BIBLIOGRAPHY

(1) Bartels, F.T.C. and Moffett, D.W., Proc. IEEE Photo Spec. Conf. 10th, Palo Alto, Calif. p. 258, (1973)

(2) Buresch, M.:, Photovoltaic Energy Systems, Design and Installation. McGraw Hill (1983)

(3) Kreider, Jan F. and Frank Kreith: Solar Energy Handbook, McGraw Hill 1981

(4) Moon, P., J. Franklin Institute. 230, 583 (1940)

(5) Pulfrey, D. Photovoltaic Power Generation: Van Nostrand (1978)

(6) Thakaekara, M. P., Applied Optics 13, 518 (1974)

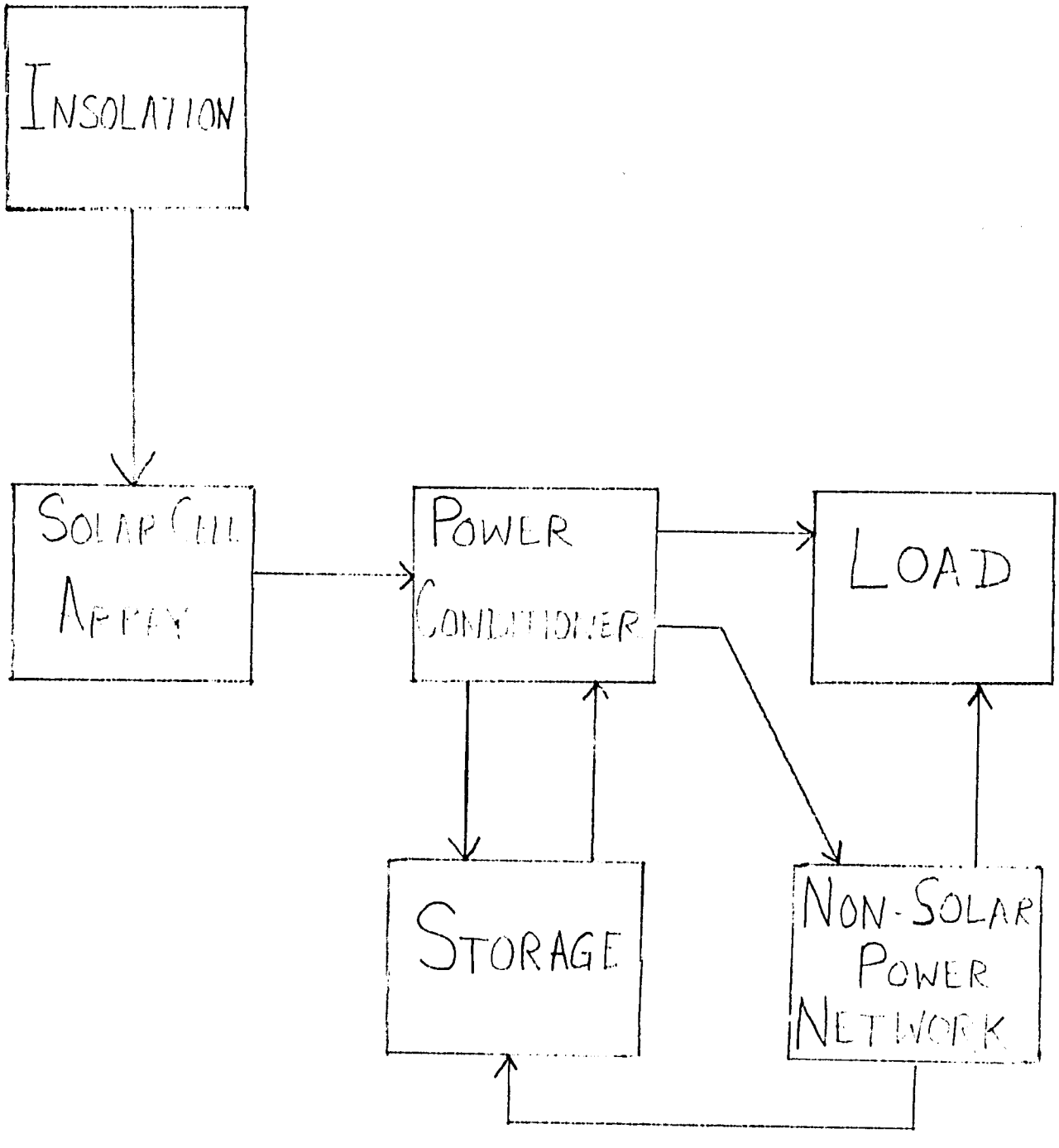
INSOLATION
SOLAR CELL ARRAY
POWER CONDITIONER
LOAD
STORAGE
NON-SOLAR POWER NETWORK

FIG. 2.1

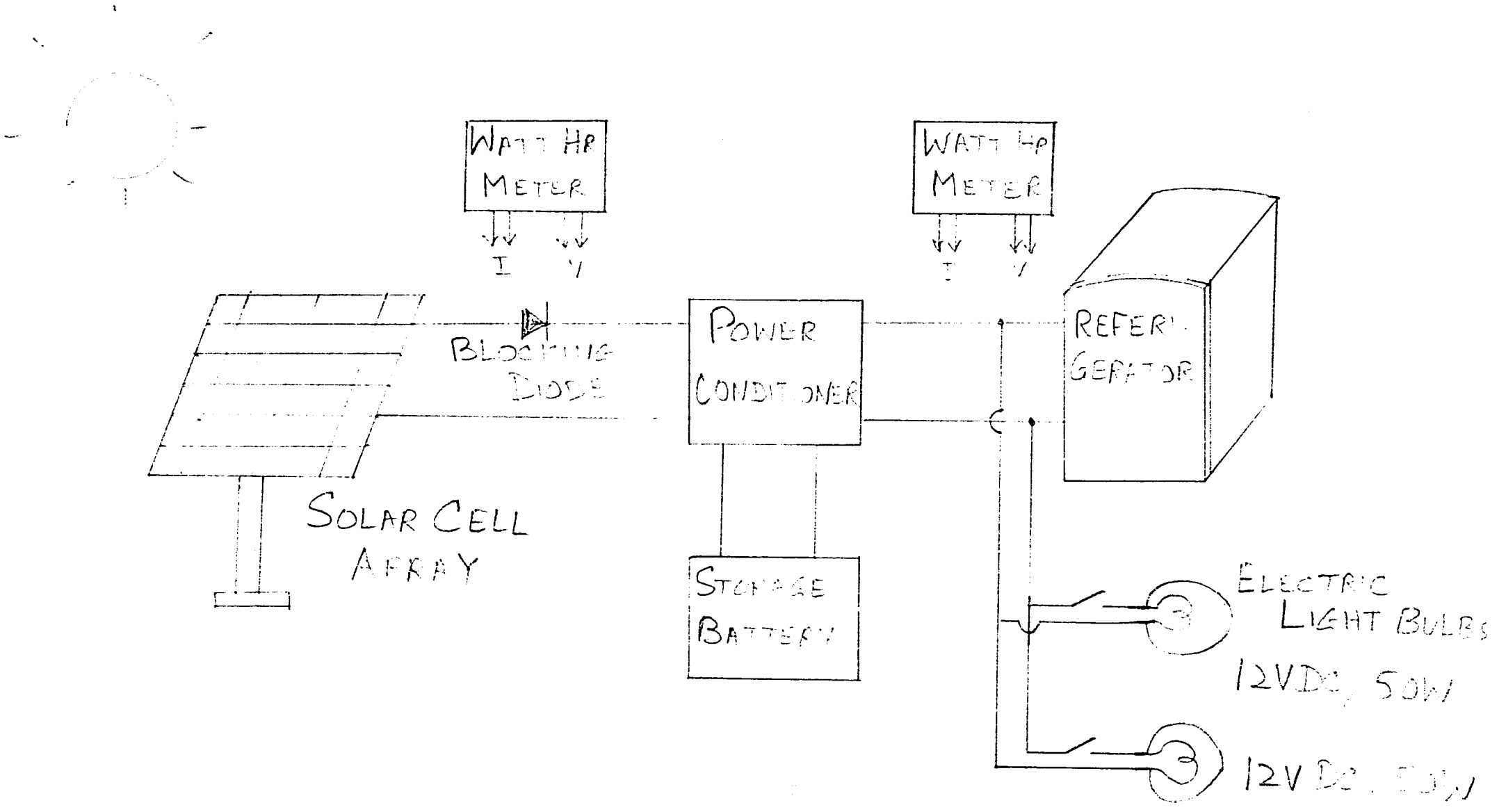
WATT HR METER
I
V
WATT HR METER
I
V
BLOCKING DIODE
POWER CONDITIONER
REFRIGERATOR
SOLAR CELL ARRAY
STORAGE BATTERY
ELECTRIC LIGHT BULBS
12VDC, 50W
12V DC

FIG. 4.1

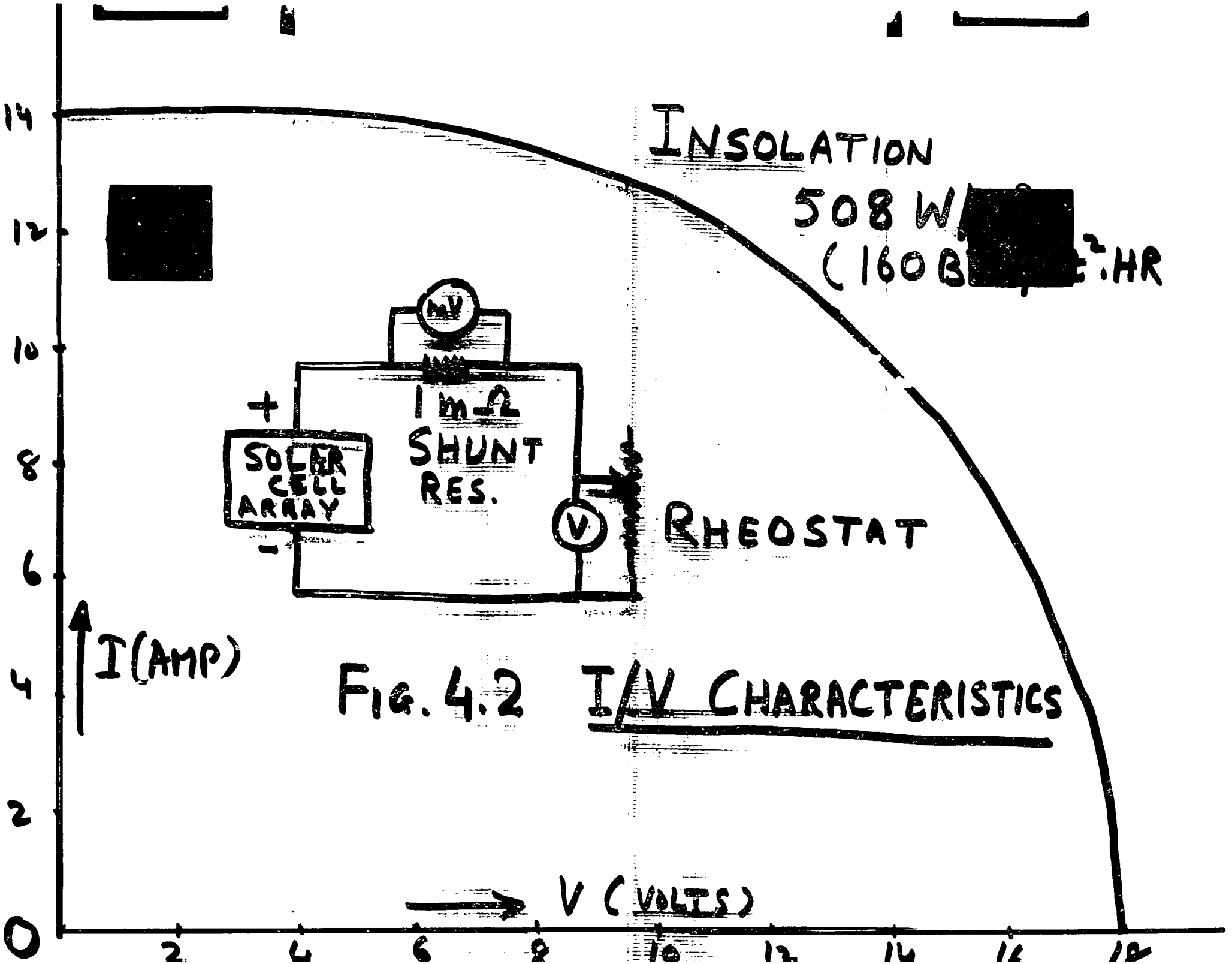

FIG. 4.2 I/V CHARACTERISTICS