SECTION-VIII

NON-CONVENTIONAL ENERGY

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Experiments on Harnessing Non-Conventional Energy Sources in Antarctica

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Abstract

During the Fifth Indian Scientific Expedition to Antarctica, an experimental model of Solar Photovoltaic (SPV) system designed and developed by the Bharat Heavy Electricals Limited (BHEL) was tested in Dakshin Gangotri (DG) and Schirmacher hills (SH). This paper discusses the experimental results of this system. Performance of the system was found to be better in Antarctica compared to that in India as expected. Possible reasons for this also have been discussed. The effect of albedo on the SPV system performance has also been discussed. Due to lack of data on the solar radiation components and other few meteorological parameters for the period of testing, the experimental results arc mostly confined to qualitative analysis. A feasibility study for the wind energy conversion system was also done during this Expedition.

Introduction

Besides the huge ice cover and massive floating icebergs around it, the Antarctic continent is known for its typical climatology. While scientists all over the world are trying to study the climatology of Antarctica, energy experts are fascinated by the long sunny days of summer and extremely high wind velocities throughout the year. This aspect of Antarctic climate has triggered an interest to develop suitable energy conversion system and exploit the non-conventional energy resources by several expedition teams. With this in mind, one more dimension was added to the objectives of the Fourth Indian Expedition. Based on the feedback from this Expedition, BHEL started developing a SPV system prototype for testing during Fifth Expedition. Also, design and development work was taken up for a wind energy conversion system for the Sixth Expedition. The SPV system was installed and tested during the Fifth Expedition in DG and Schirmacher hills. The results of this experiment are quite encouraging.

Objectives

BHEL participated in the Fifth Expedition with the following objectives:

— to study the performance of BHEL made SPV modules in Antarctic environment,

— to study the endurance and stability of the SPV system, including materials like cables, structures etc.,

— to identify suitable utility for the solar and wind energy systems,

— to conduct a site survey for installation of a windmill during Sixth Expedition,

— to study the structural and foundation aspects for installing a windmill at Maitree station in Schirmacher hills.

Solar Radiation

The major source of depletion for solar energy in Antarctica is cloud. In the absence of cloud, solar radiation is affected by the following factors:

1. *Radius vector of earth:* As the solar distance varies while earth passes from perigee to apogee, the intensity of solar beam outside the atmosphere varies by approximately 7%.

2. *Altitude:* Other factors remaining constant, intensity of solar radiation will be greater in elevated regions due to smaller air mass traversed. The Antarctic plateau has greater elevation and hence, high radiation intensities occur there.

3. *Solar elevation:* This is a function of hour angle, latitude and solar declination. In the absence of depleting atmosphere, the direct radiation falling on a horizontal surface on earth varies with the sine of the angular elevation of sun.

$$S = I \sin \alpha$$

where, I is the intensity of solar beam outside the atmosphere and α is the sun's angle of elevation and S is the direct radiation falling on the horizontal surface of earth. In the presence of atmosphere, S is further reduced due to losses in the atmosphere.

4. *Turbidity;* The intensity of solar radiation is reduced because of scattering and absorption by dust and other suspended particles in the atmosphere. The turbidity value for the atmosphere over Antarctica is quite low, thus the losses due to atmospheric turbidity are also low in Antarctica.

5. *Albedo;* Part of the radiation reflected from the earth's surface gets reflected back by the atmosphere thus contributing to the diffused radiation. Since about 95% of the area of Antarctica is covered by ice and the albedo value ranges from 80% to 90% over this area, contribution to diffused radiation by albedo factor is quite significant.

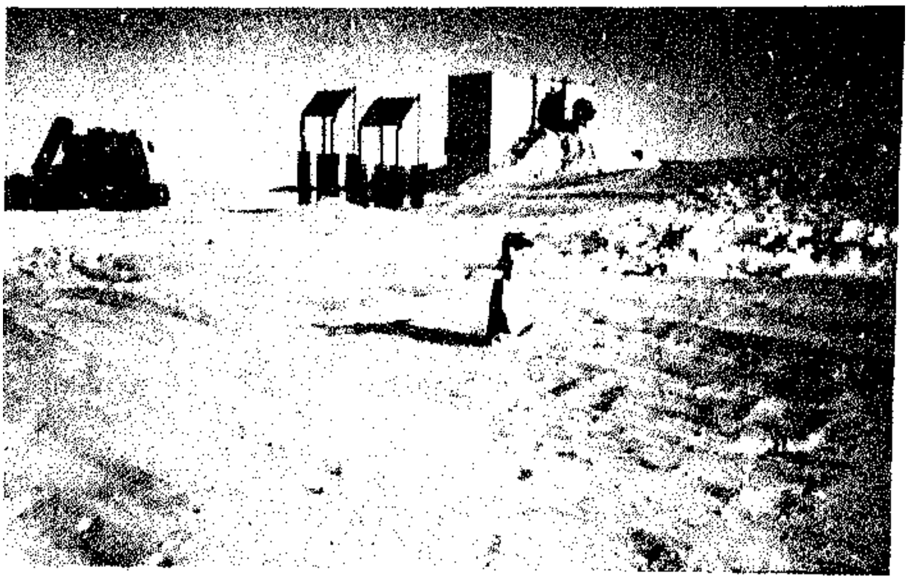
The global radiation consists of the direct radiation and diffused radiation. While on a clear sunny day, major contribution to global radiation is from the direct component, on a cloudy or blizzard day, it is the diffused component which is the major contributor.

Wind Energy

Analysis of wind velocities from 1961 to 1973 at Novolazarevskaya Station indicates an annual wind speed of around 36 kmph. This shows the tremendous energy available from wind in Antarctica. Also in contrast to the gusty nature of wind in India, the variation of wind speed in Antarctica is found to be much less frequent. Hence, the quantity as well as the quality of wind power in Antarctica is found to be better than in India.

System Installation and Testing

The system is based on solar photovoltaic modules. Each module consists of 36 nos. of 100 mm diameter, single crystal silicon solar cells, connected in series (Fig 1). The modules are mounted on a stainless steel structure, which is supported by 400, X 400 x 2000 mm wooden pillars buried upto 1000 mm inside the ice with a clearance of 1000 mm above the ice surface to accommodate for snow accumulation. The modules face North at an angle of approximately 50° from the horizontal. The system output is taken to batteries through a control panel. The control panel includes a voltage sensitive relay for protecting the batteries from over charging and over discharging. DC bulbs are used as loads. The loads can be connected to SPV modules directly or through batteries. Testing was done at both DG and Shirmacher hills. The SPV modules are designed for 30W peak per module.



Eig 1. Solar photovoltaic modules being tested at Dakshin Gangotri during the Fifth Indian Expedition.

Typical performance of the system on a clear sunny day is shown in Figs. 2 and 4 for DG and Schirmacher hills respectively. A per module peak power of about 33 watts in DG and 29 watts in Schirmacher hills is observed. The output from these modules under similar insolation conditions in India is less.

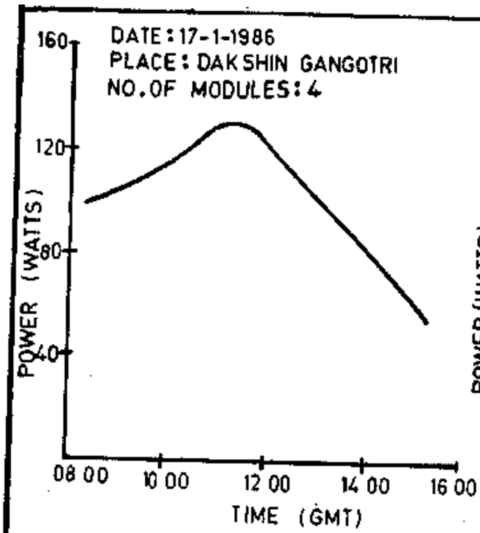


Fig. 2. Time Vs Power on a Sunny Day

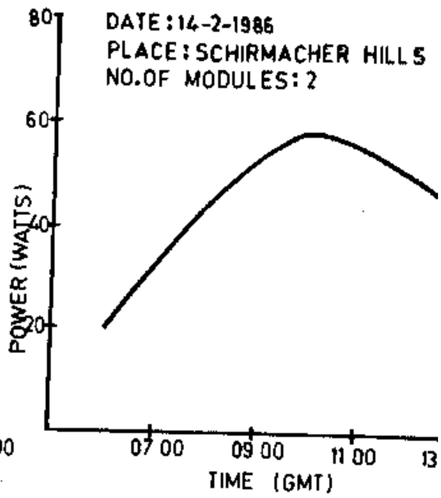


Fig. 4. Time Vs Power on a Sunny Day

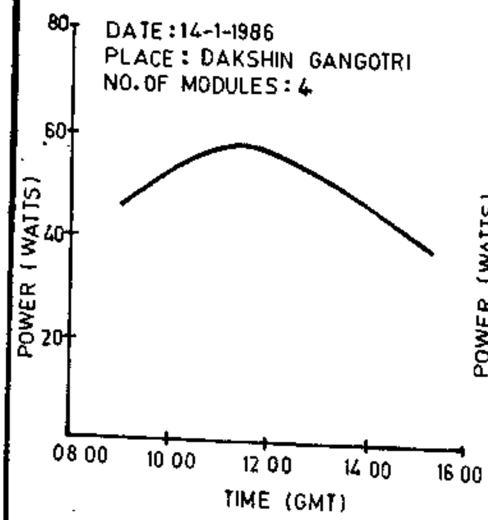


Fig. 3. Time Vs Power on a Cloudy Day

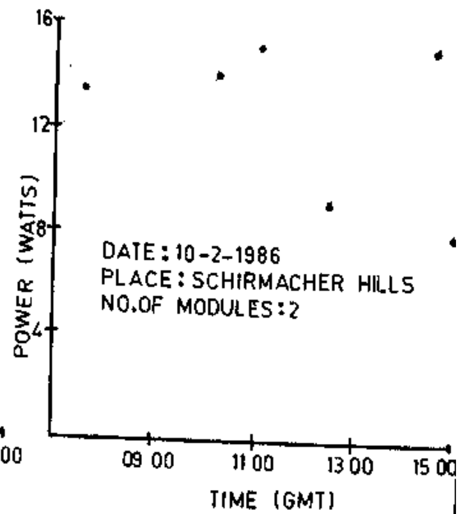


Fig. 5. Time Vs Power on a Cloudy Day

Under one sun condition, each module is expected to deliver a peak power of 30 watts at 27°C. The enhanced power output from these modules in Antarctica is primarily a result of the prevailing low temperatures in Antarctica. The performance of any solar cell is also dependent on temperature. Normally, the cell parameters are measured at 27°C. While in general terrestrial applications solar cells operate at about 40-50°C, in Antarctica, the temperature is normally below 0°C.

Qp, the peak power output from a .solar cell is given by,

$$Q_p = \eta \times Q_{in}$$

where, η is the efficiency of solar cell and Q_{in} is the insolation. The solar cell efficiency can be expressed as,

$$\eta = \frac{V_{oc} \times I_{sc} \times FF}{Q_{in}}$$

where, V_{oc} is the open circuit voltage, I_{sc} is the short circuit current and FF is the fill factor.

The temperature dependence of η can be expressed as,

$$\frac{1}{\eta}\left(\frac{\partial \eta}{\partial T}\right) = \frac{1}{Voc}\left(\frac{\partial Voc}{\partial T}\right) \times \frac{1}{Isc}\left(\frac{\partial Isc}{\partial T}\right) \times \frac{1}{FF}\left(\frac{\partial FF}{\partial T}\right)$$

Calculated temperature dependence of Silicon solar cell parameters under one sun condition for two different temperatures is as below:

T	V_{oc} (v)	$\frac{1}{Voc}\left(\frac{\partial Voc}{\partial T}\right)$ (% deg^{-1})	Isc (mA/cm^2)	$\frac{1}{Isc}\left(\frac{\partial Isc}{\partial T}\right)$ (% deg^{-1})	FF	$\frac{1}{FF}\left(\frac{\partial FF}{\partial T}\right)$ (% deg^{-1})	η(%)	$\frac{1}{\eta}\left(\frac{\partial \eta}{\partial T}\right)$ (%deg^{-1})
0°C	0.75	-0.253	38.296	+0.0295	0.863	0.074	26.83	-0.297
27°C	0.699	-0.275	38.599	+0.0293	0.845	0.083	24.67	-0.327

Though the absolute value of $1/\eta\ (\partial\eta/\partial T)$ decreases with decrease of temperature, there is significant increase in the efficiency of 2.16% from 27°C to 0°C. In conclusion, while I_{sc} remains almost constant over a range of operating temperatures, the effect of temperature on V_{oc} and FF betters the performance of any solar cell at lower temperatures. The difference in performance between DG and Schirmacher hills could be explained as follows:

1. The albedo value for DG is about 0.8 to 0.9 which gives concentrating effect on the modules which are tilted at 50° from horizontal; whereas, the albedo value at Schirmacher hills is only about 0.1 to 0.15. Also, the contribution to the diffused radiation by albedo factor is quite significant in DG.

2. The insolation level is lower in February than that in January. Since the system was tested in January in DG and in February in Schirmacher hills, the output is expected to be less in the latter.

Performance of the system on a cloudy day has been shown in Figs 3 and 5 for DG and Schirmacher Hills respectively. In the case of DG, since it was total overcast sky throughout the day, the contribution was mostly from the diffused radiation. In the case of Schirmacher hills, due to partial cloud condition, the performance is found to be erratic. It is interesting to observe the effect of albedo on diffused radiation while comparing the performance of cloudy day with that of sunny day. Reduction in output in DG on a cloudy day is much less than that in Schirmacher hills compared to respective sunny day performance. The results of battery charging from SPV modules on sunny days and cloudy days are shown in Figs 6 to 9. From Fig 7, it is seen that charging current in DG on a cloudy (total overcast) day varies smoothly within a narrow band. But due to partial cloudy sky, in Schirmacher hills (Fig. 9) the charging current varies erratically. In a total overcast day, it is expected that in Schirmacher hills also, the charging current will vary smoothly within a narrow band. Figs.1 10 and 11 give a general idea of solar insolation in DG and Schirmacher hills. Fig. 12 shows the I-V characteristics.

The system installed during the Fifth Expedition was found to be intact during the Sixth Expedition. The system has withstood the severe climate of Antarctic winter and several blizzards, without any physical damage or performance degradation. During the Sixth Expedition, the performance of the system at DG was monitored for a very short duration and it was found to be quite satisfactory.

Recommendations for Windmill

The monthly maximum and mean wind speed curves are plotted in Fig. 13 for Novolazarevskaya (lat. 70° 46'S; long 11° 49'E) in Schirmacher hills area. The annual average of wind speed is about 36 kmph for this location. Since India is planning for a permanent station in Schirmacher hills area, it would be appropriate to consider possibilities of utilising the wind energy for supplementing the energy needs in future. A site survey has been done for installation of a windmill. A suitable site has been identified. Main advantage of going in for wind and solar energy systems in Antarctica is that these resources are available naturally, locally and in abundance. The most suitable application of wind power is space heating since the demand and supply are complementary. In other words, wind power is most plentiful when the heating requirement is at maximum on cold windy days when cold is penetrating. For any other application, a back up system is necessary to account for non-windy periods. This may be a battery bank system of suitable capacity, which will represent a substantial cost of the system and also require attention in maintenance regularly. For the existing huts of Maitree station, a 1.5 kW solar photovoltaic system would be sufficient to provide power for minimum required lighting applications during the summer. It is suggested that a simple windmill may be designed and tested to have experience and confidence initially in Schirmacher hills and based on the feed back, improved systems could be installed subsequently in line with the coming up of the permanent station there.

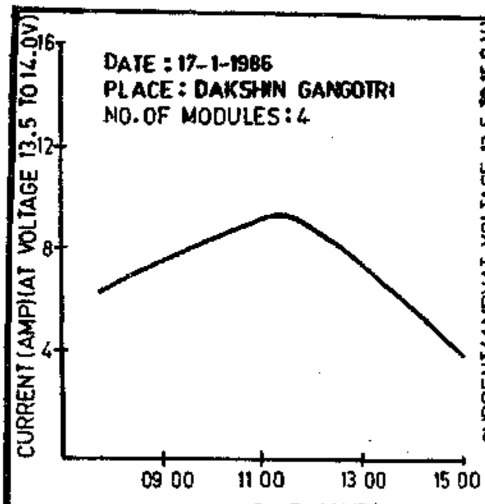


Fig. 6. Time Vs Current on a Sunny Day

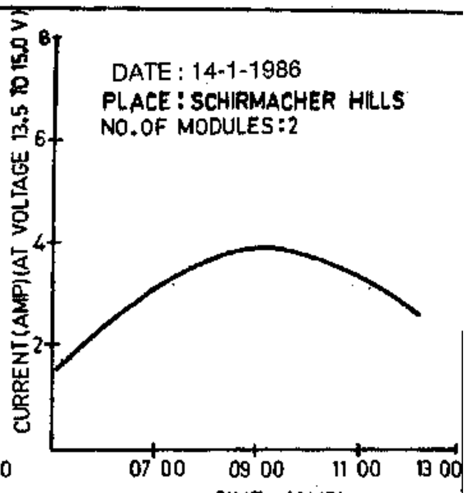


Fig. 8. Time Vs Current on a Sunny Day

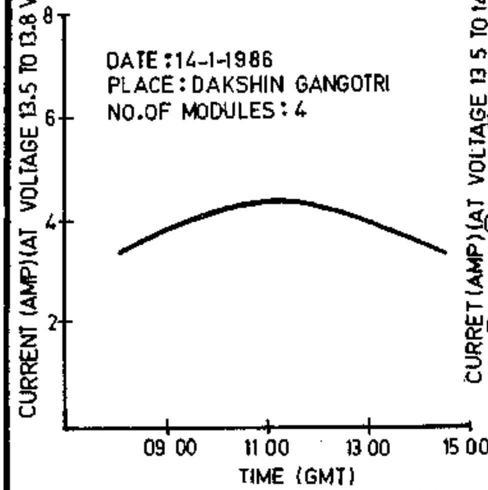


Fig. 7. Time Vs Current on a Cloudy Day

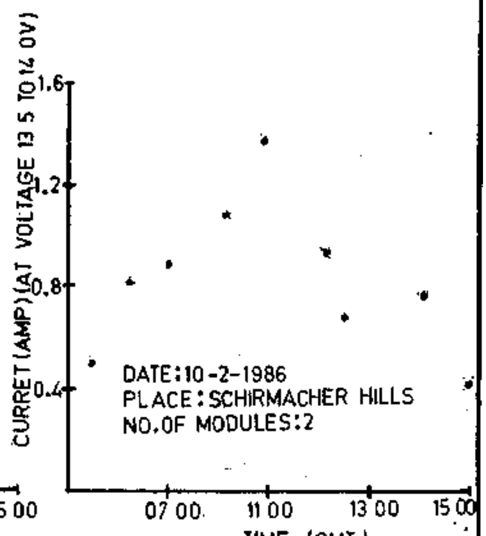


Fig. 9. Time Vs Current on a Cloudy Day

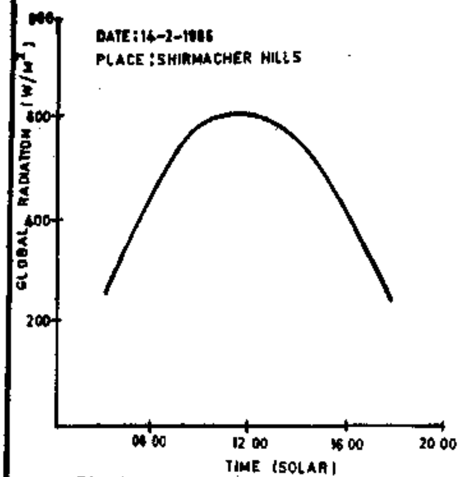


Fig. 10. Global Radiation on Earths Surface

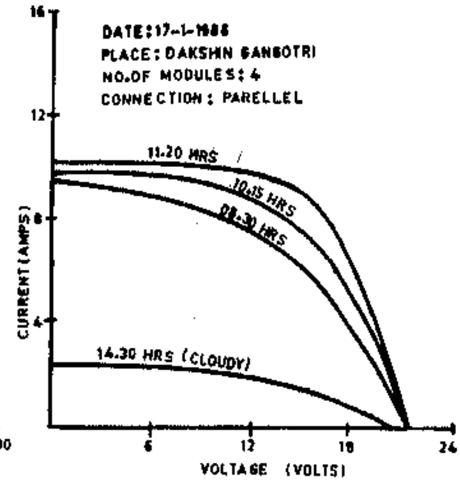


Fig. 12. I-V Characteristics

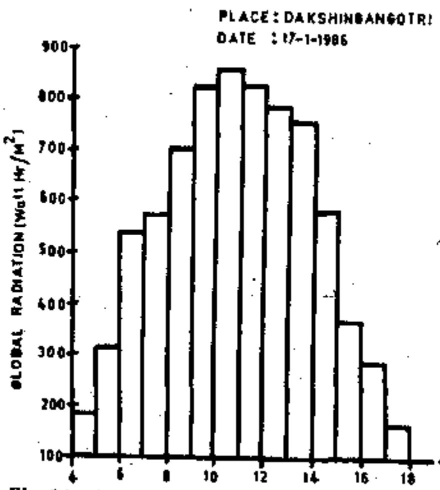


Fig. 11. Global Radiation at hour ending on Horizontal Surface

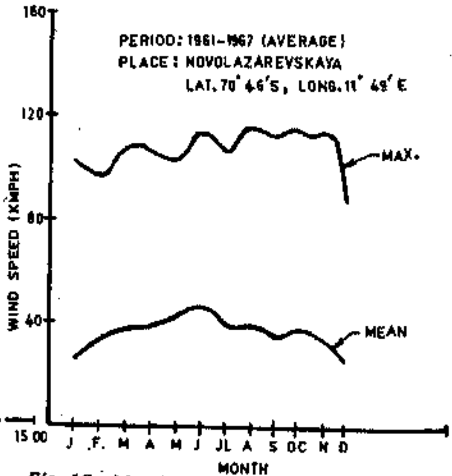


Fig. 13. Maximum and mean Wind Speed Curves

Conclusion

The performance of SPV system in Antarctica was found to be better than that in India. The main factors for this fact are the very low ambient temperature and very high albedo values among many other favourable atmospheric and meteorological parameters. With our own experience and interaction with other stations in Antarctica, it is found that wind energy conversion systems could be effectively used for space heating. SPV system could be used in summer for lighting and battery charging applications, thus saving a lot of fuel and reducing maintenance of conventional energy systems.

Acknowledgements

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Reference

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