YN-AAW-999
49924

Development and Application of Decentralised Energy Systems Utilizing Non-Conventional Energy Sources

- Salojipally Project -

SECOND CONFERENCE REPORT

February 20, 1982

JPL Task Plan No. 70-980

BHEL Project No. YN-80-240-83

Implementing Agencies

Bharat Heavy Electricals Limited, Hyderabad, India

Central Electronics Limited, Sahibabad, India

Collaborating Agency

Jet Propulsion Laboratory, Pasadena, California, USA

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SECTION I

GENERAL

A. INTRODUCTION

The Department of Science and Technology (DST), Government of India and the United States Agency for International Development (USAID) have co-sponsored a project for the development of a solar energy system in India. The date of initiation of the project was November 26, 1980. The implementing agencies, Bharat Heavy Electricals Limited (BHEL), Hyderabad, India; Central Electronics Limited (CEL), Sahibabad, India and the collaborating agency, Jet Propulsion Laboratory (JPL), Pasadena, California, USA had their first conference at JPL between May 16 to May 30, 1981.

During this conference, the scope of activities, information exchange procedure, base line configuration of the solar thermal and solar photovoltaic systems were discussed and systems and components design activities were initiated. Concurrently, the schedules and milestones of activities, division of responsibilities, manpower exchange schedule and other details were discussed.

The deliberations of the first conference were documented and the report was submitted to the sponsoring agencies.

Subsequent to the first conference, several tasks, as detailed hereafter, have been accomplished. As defined in the 'Project Proposal', a conference between the participating teams was proposed from February 2 to February 20, 1982 in India with the following objectives;

- review of the status of the tasks and of the overall project,
- detailed discussions on the design of the sub-systems and components,
- refinement of time schedules and milestones,
- identification of hardware and preparation of a procurement plan,
- future manpower exchange schedule.

This report deals with the deliberations of the second conference including the progress of design activities, future work schedule, load distribution, load management concepts, manpower exchange schedule and the list of hardware to be procured from the USA.

B. SUMMARY OF TASKS ACCOMPLISHED

During the intervening period between the first conference at JPL and second conference in India, the following tasks have been performed.

- finalisation of the configuration of the solar thermal system, *
- detailed thermodynamic analysis of the solar thermal system, *
- preliminary design concept of the concentrator and receiver,
- preliminary design of the control, instrumentation and measurement scheme,
- selection and procurement of the candidate prime mover for the solar thermal system,
- hydrological survey of the selected village to assess the water table,
- modification of a diesel engine to make it suitable for operation with bio-gas,
- actions for obtaining quotations for procurement of photovoltaic modules from the USA,
- construction of community centre in the village,
- construction of a bio-gas plant at site as a back-up for the solar thermal system,
- site activities such as construction of stores and office space.

C. PARTICIPATING TEAMS

The participating teams in the main conference were the following:

INDIA

Dr TK Bhattacharya	CEL
Dr BMS Bist	CEL
Dr NK Giri	BHEL
Dr A Gopalakrishnan	BHEL
Mr SP Joshi	CEL
Mr SK Kaila	BHEL
Mr TK Mukherjee	BHEL

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* Solar Thermal Power Plant - System Design, Dr. N.K. GIRI. Report submitted to Sponsorers.

Mr GP Reddy	BHEL
Mr UB Sahay	BHEL
Mr SK Sangal	CEL
Mr LM Siddique Ahmed	BHEL
Mr K Thirumalai	BHEL

UNITED STATES

Mr Royal G. Harrison	JPL
Mr W Owen	JPL
Mr W Carley	JPL
Mr J Newnham	JPL
Mr H Bank	JPL

The proceedings of the conference consisted of the following basic activities:

a) General meeting and briefing by the US team with CEL and BHEL at Delhi and Hyderabad.

b) Visit to CEL facilities at Sahibabad and BHEL facilities at Hyderabad.

c) Visit to the selected village and, on the spot discussions on load distribution, load management and alignment of concentrator reflector facets.

d) Meeting of the US and Indian teams with DST for detailed briefing.

e) Meeting of the US Project Manager and Indian Project Manager with USAID, New Delhi for general briefing and discussions on economic analysis.

The remainder of the conference activities were devoted to detailed discussions on design of sub-systems and components.

The names of participants in the general meetings are given in Appendix I of this report.

D. CONFERENCE DISCUSSIONS

Detailed reports of the conference discussions on the solar photovoltaic (PV) and the solar thermal systems are provided in Section II and Section III respectively of this document. The salient features of discussions were:

- Decision on source of procurement of PV modules.

- Decision on centralised installation of 7 kW PV modules.

- Loads to be connected to the PV system.

- Quality of electricity from the PV system.

- Decisions on concentrator configuration, receiver design, control and measurement scheme of the solar thermal system.

- Quality of electricity from solar thermal system and bio-gas operated engine-generator.

E. DISCUSSIONS AT DST

The main points of discussion were as under:

1. The Indian Project Manager, Mr TK Mukherjee and the JPL Project Manager, Mr Royal Harrison briefed DST and USAID regarding the status of the project, tasks completed so far and indicated that as per the worked out milestones, commissioning tests on the solar thermal power generation system should start sometime around October, 1983.

2. Mr Maheshwar Dayal desired that the date of the commissioning should be advanced sometime in September, 1983 and the project teams should endeavour to achieve the target.

3. Mr Maheshwar Dayal also wanted to know whether it would be feasible to utilise a higher efficiency prime mover for the system. The Project Managers informed that considering the reliability and time available, best options have been chosen, and the system efficiency from steam to electricity will be of the order of 13%.

4. Both DST and USAID verbally cleared the visit of Mr K Thirumalai and Mr SP Joshi to JPL, USA for prime mover adaptation and for participating in testing of photovoltaic modules respectively.

SECTION II

SOLAR PHOTOVOLTAIC SYSTEM

A. SYSTEM DETAILS

The capacity of the solar photovoltaic system will be 7 kW (peak). Photovoltaic modules for a capacity of about 5 kW (peak) will be obtained from US sources through JPL, and CEL will provide the balance from its own batch production. For appropriate control, load management and acquisiton of data, the photovoltaic arrays will be installed at one place, alongside the Solar Thermal Power Generation System. The generated power will be distributed to the load points from a central control room.

The system will be provided with adequate "balance of systems" such as power conditioner, storage batteries etc. The quality of electricity will be DC which will drive DC motor-pump sets for irrigation.

B. LOAD DISTRIBUTION

The generated power from the solar photovoltaic system is proposed to be used for irrigation of about 3-4 hectares of land which are presently dry. From the survey carried out, it appears that the water table varies from 7 meters (in rainy season) to 25 metres (in summer). The actual level of water table will be confirmed by drilling borewells in three different locations. Considering the water table variation, centrigufal pumps can not be used. It is proposed to utilise high efficiency turbine pumps for lifting water. The power from the photovoltaic system is proposed to feed several motor-pump sets installed near three borewells. Smaller sizes of pump-motors, say 1 kW each will be preferable from load management point of view.

C. ACTION POINTS

C1.	Clearance for drilling of borewells to be provided to BHEL by 10.3.82	Dr BMS Bist/ Dr TK Bhattacharya
C2.	Drilling of Borewells by 30.4.82	Dr NK Giri
C3.	Provide BOS specifications to JPL and BHEL by 30.5.1982	Dr BMS Bist
C4.	Formulation of test procedure of modules for Salojipally Project by 20.3.82 - information to CEL	Dr KM Koliwad
C5.	Decision on PV module procurement, source to be communicated to CEL by 20.3.1982	Mr Royal G. Harrison Dr KM Koliwad

C6.	Shipping Indian modules to JPL for testing by 1.6.82	Dr BMS Bist
C7.	Availability of US modules at JPL by 15.6.1982	Dr KM Koliwad
C8.	Shipping US modules to India by 15.7.1982	Mr Royal G. Harrison/ Dr KM Koliwad
C9.	Delivery of Indian modules to BHEL (3 kW approx.) by 15.7.1982	Dr BMS Bist
C10.	Shipping of BOS to India	Dr TK Bhattacharya/ Mr Royal C. Harrison
C11.	Assistance to CEL in identifying sources of supply for DC motor pump sets suitable for heads upto 40 metres, in 1-3 HP ranges (Procurement will be CEL's responsibility)	Mr Royal G. Harrison

D. TIME SCHEDULES AND MILESTONES

The time schedules for the project and the important milestones have been provided in the enclosed 'Bar Chart'.

E. MANPOWER EXCHANGE

In order to participate in the 'Testing Programme' of the photovoltaic modules, one engineer from CEL will be visiting JPL from 10th June, 1982 to 10th July, 1982.

Future visits by members of the CEL team will be decided by the respective Project Manager of CEL and JPL. Similarly, the visit of specialists from JPL will be decided by Project Manager of JPL and CEL.

F. PRELIMINARY LIST OF MATERIAL AND EQUIPMENT TO BE IMPORTED

F1. Photovoltaic modules of about 5 kW capacity

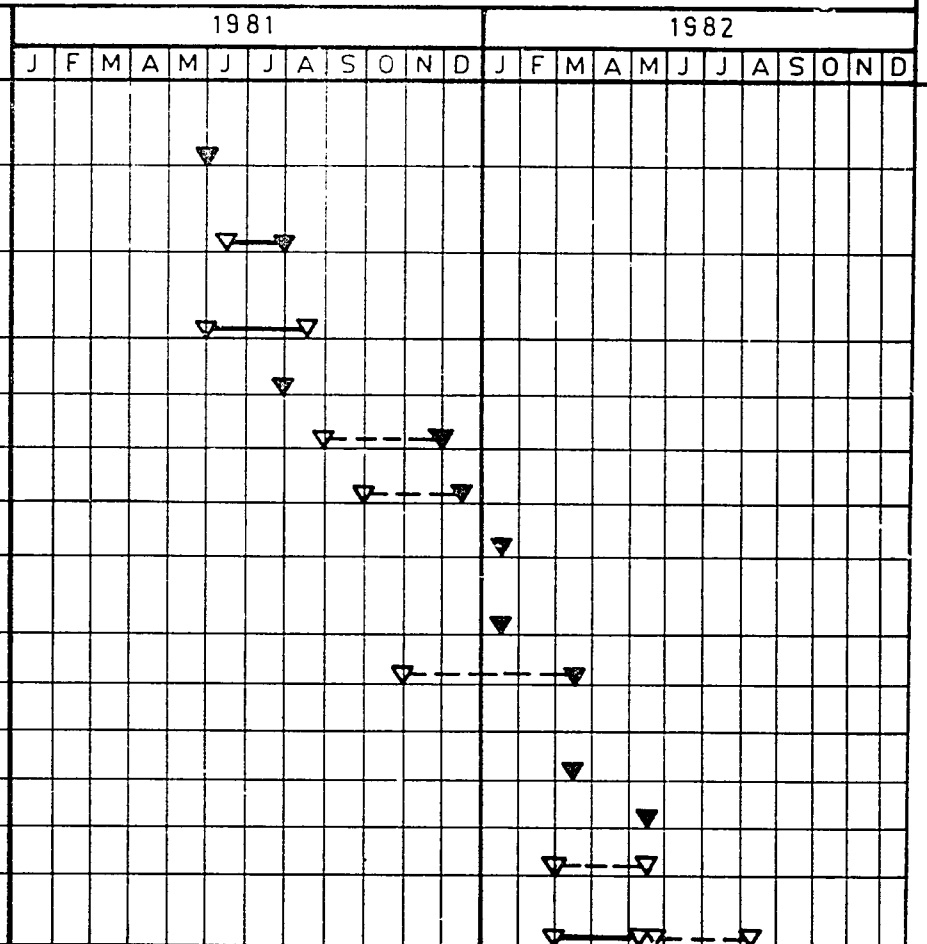
F2. DC pump - motor sets

F3. Radiometer

F4. Reference solar cells.

SALOJIPALLY PROJECT P.V. MODULE PROCUREMENT PROGRAM PLAN

SL. NO.	MILESTONES
1	DELIVER PRELIMINARY PV MODULE SPECS TO CEL
2	DELIVER SURVEY OF U.S. COMMERCIAL MODULES TO CEL
3	RECEIVE FINAL PV MODULE SPECS FROM CEL
4	RFQ PREPARED
5	RFQ RELEASED
6	BIDS RECEIVED
7	PRELIMINARY TECHNICAL EVALUATION
8	RANK ORDER AND REQUEST FOR ADDITIONAL TECH. INFORMATION
9	BIDDER SELECTION
10	DELIVERY SCHEDULE:
	a) INSPECTION SYSTEM PLAN
	b) UNCALIBRATED REFERENCE CELLS
	c) P.V. MODULES
11	COMPLETE MODULE TESTING AND SHIPMENT TO INDIA



▽——▽ PLANNED ▽- - -▽ REVISED ▼ COMPLETED

SECTION III

SOLAR THERMAL POWER GENERATION

A. SYSTEM CONFIGURATION

Considering the factors such as the status of technology, reliability, environmental requirement and maintenance, a "Rankine Cycle" based system with steam as the working fluid was chosen. The system comprises six concentrators of 9m diameter (approx) with direct steam generating receiver at the focal point of each concentrator. The generated steam is transported to a central point and expanded in a steam engine, especially adapted for the envisaged system. The shaft output is converted to electricity through an AC generator and supplied to loads after necessary regulation. A schematic layout of the collector field configuration is shown in Figure 1.

The six concentrators are laid out in a circle of approximately 28m diameter to ensure minimum thermal inertia, thermal losses and to ensure no blockage during operating hours, thereby improving its period of availability and overall efficiency. The main parameters of the system are:

Steam temperature at Receiver	:	$95^{o}C$ (inlet) $500^{o}C$ (outlet)
Steam Pressure at Receiver Outlet	:	70 kgf/cm^2
Steam Pressure at Engine Inlet	:	60 kgf/cm^2
Steam Temperature at Engine Inlet	:	$400^{o}C$
Mass flow rate, peak	:	180 kg/hour
Overall System Efficiency:	:	13% (Steam to electrical power)
Minimum Insolation for Operation (Direct), normal to the concentrator	:	0.55 kW/m^2
Insolation value for Design Point (Direct), normal to the concentrator	:	0.80 kW/m^2
Maximum Insolation Value (Direct), normal to the concentrator	:	1.0 kW/m^2

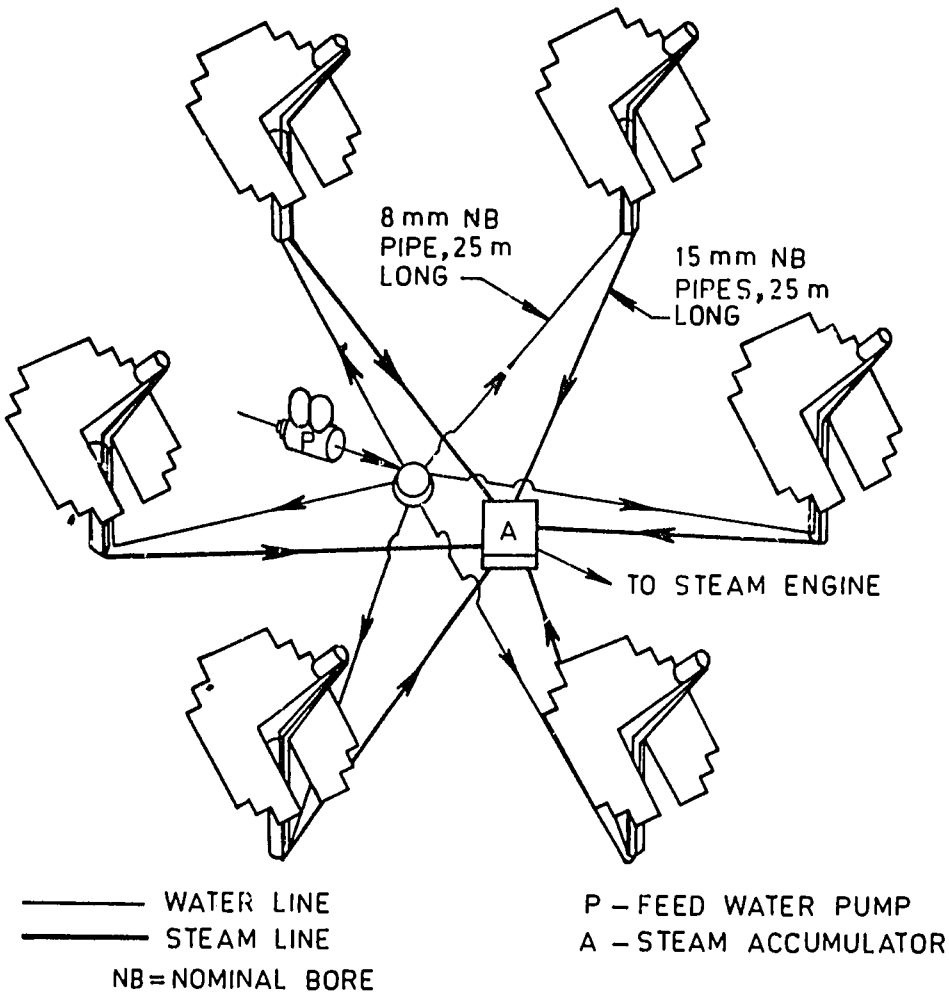


Fig.1 COLLECTOR FIELD CONFIGURATION

B. ANALYSIS OF INSOLATION DATA

The insolation data for Hyderabad, situated 104 km from the village have been considered as being representative insolation levels in the village. These data have been analysed to find out the total availability of the Solar Thermal Power Generation during a year. These results are given in Figs 2-13 and Tables 1-5.

C. SUB-SYSTEMS AND COMPONENTS

The essential sub-systems of the solar thermal system are:

- concentrators to collect solar energy,
- receivers to convert solar energy to thermal energy and generate steam,
- steam transport loop and buffer storage,
- steam engine to convert thermal energy to mechanical energy,
- electrical generator to convert mechanical energy to electrical energy,
- control loops and measurement sub-system to provide controls, both under quasi-steady and transient conditions and to acquire necessary data for evaluation of the system performance,
- bio-gas operated power generation system to provide auxiliary power for the solar thermal system and to act as a back-up sub-system during non-sunny periods.

Brief design considerations of the chosen sub-systems are provided in the following sections.

C1. Concentrator

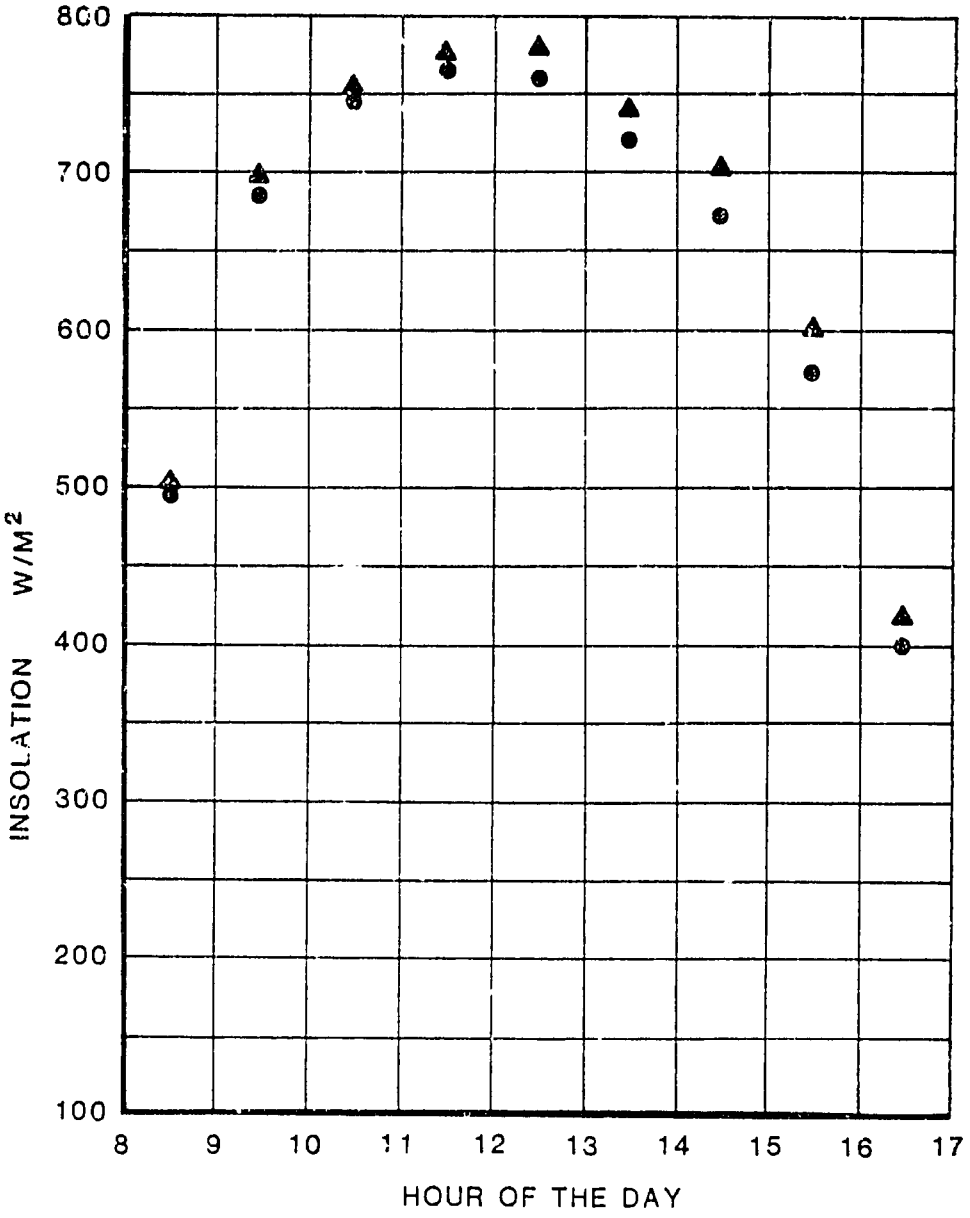
For the concentrator, three configurations were considered. They are:

* Parabolic concentrator with faceted mirrors similar to the "Test Bed Concentrator" at JPL, USA.
* Flat heliodish with mirrors having one or three radii of curvature.
* Conical heliodish with mirrors having one or three radii of curvature.

Comparative features of the three configurations are provided in Table 6.

FIG. 2 DIRECT SOLAR INSOLATION NORMAL TO DISH
MONTHLY AVERAGE

JANUARY, 80
HYDERABAD



● – FOR ALL DAYS

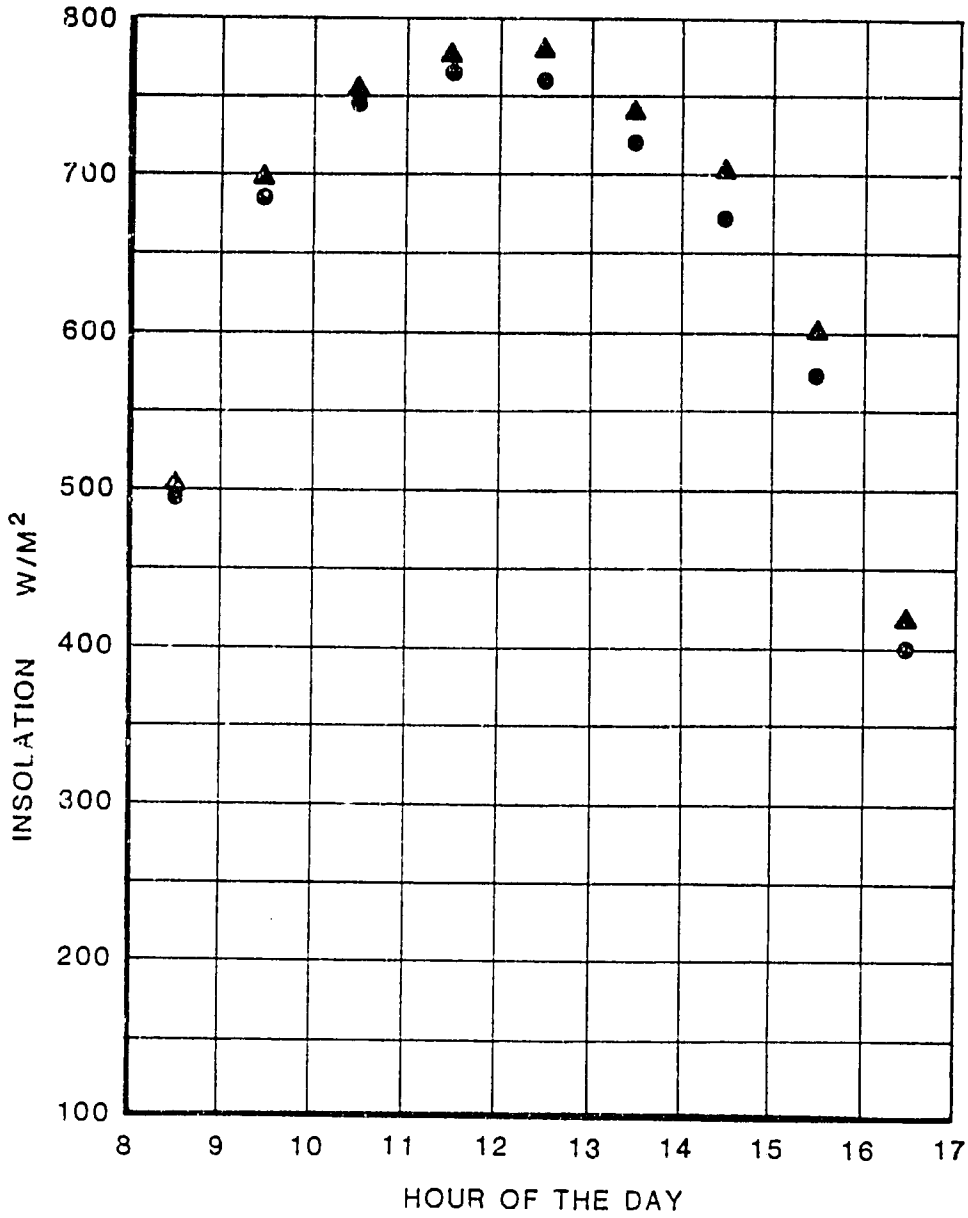
▲ – FOR DAYS WITH 0.5 KW/M² INSOLATION FOR MINIMUM 5 HRS

11 X

21

FIG. 2 DIRECT SOLAR INSOLATION NORMAL TO DISH
MONTHLY AVERAGE

JANUARY,80
HYDERABAD

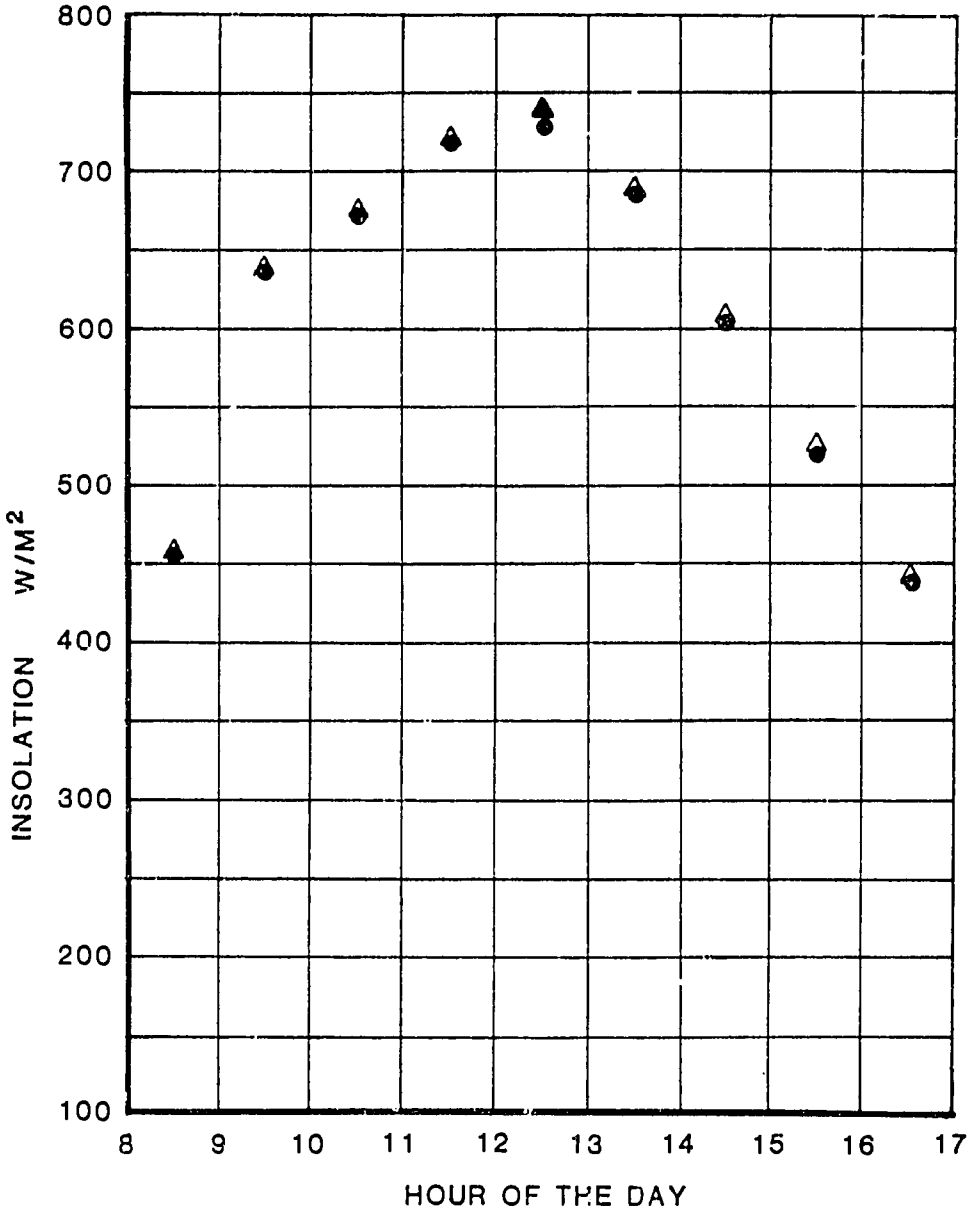


● – FOR ALL DAYS

▲ – FOR DAYS WITH 0.5 KW/M^2 INSOLATION FOR MINIMUM 5 HRS

FIG. 3 DIRECT SOLAR INSOLATION NORMAL TO DISH
MONTHLY AVERAGE

FEBRUARY,80
HYDERABAD

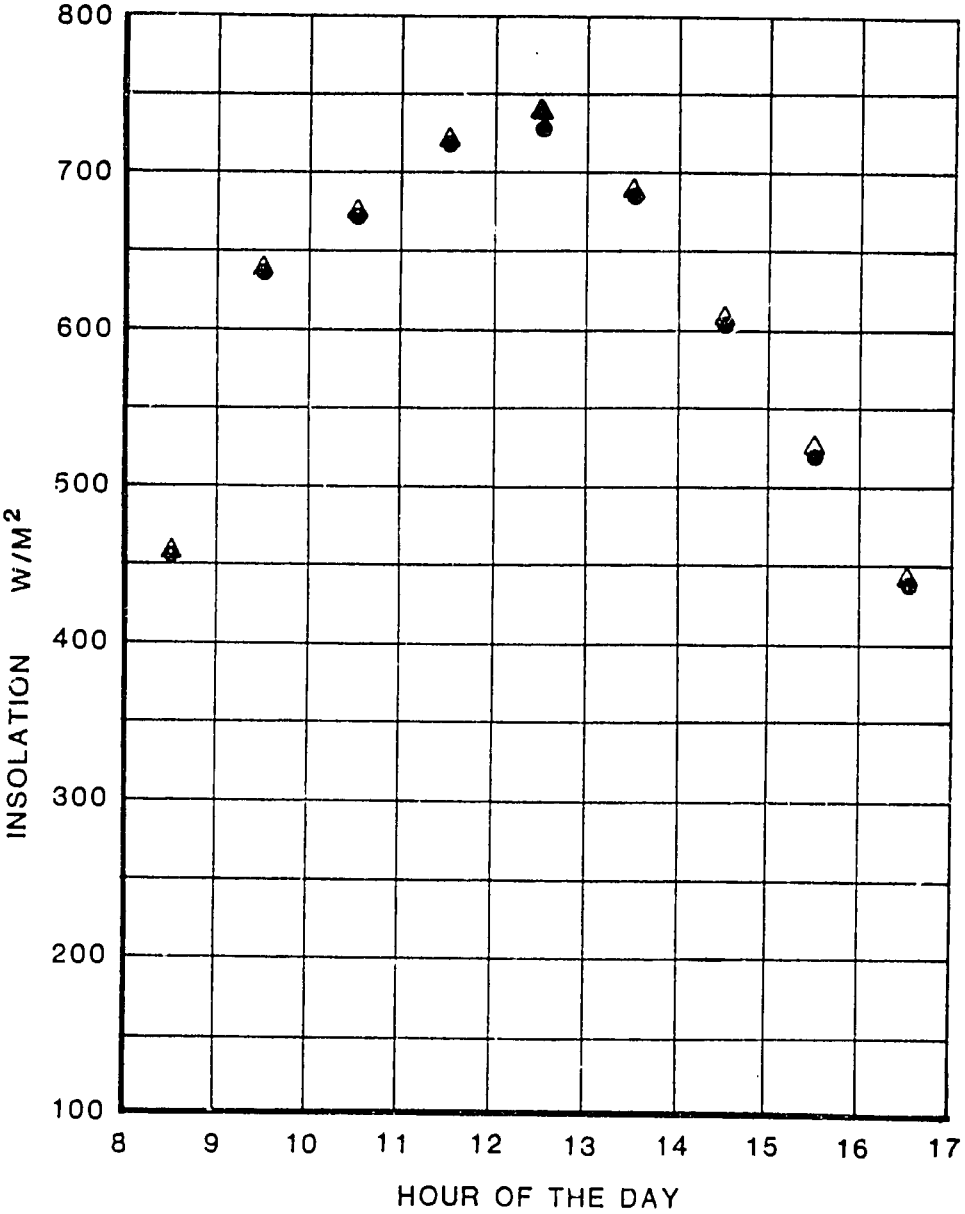


● – FOR ALL DAYS

▲ – FOR DAYS WITH 0.5 KW/M² INSOLATION FOR MINIMUM 5 HRS

FIG. 3 DIRECT SOLAR INSOLATION NORMAL TO DISH
MONTHLY AVERAGE

FEBRUARY,80
HYDERABAD

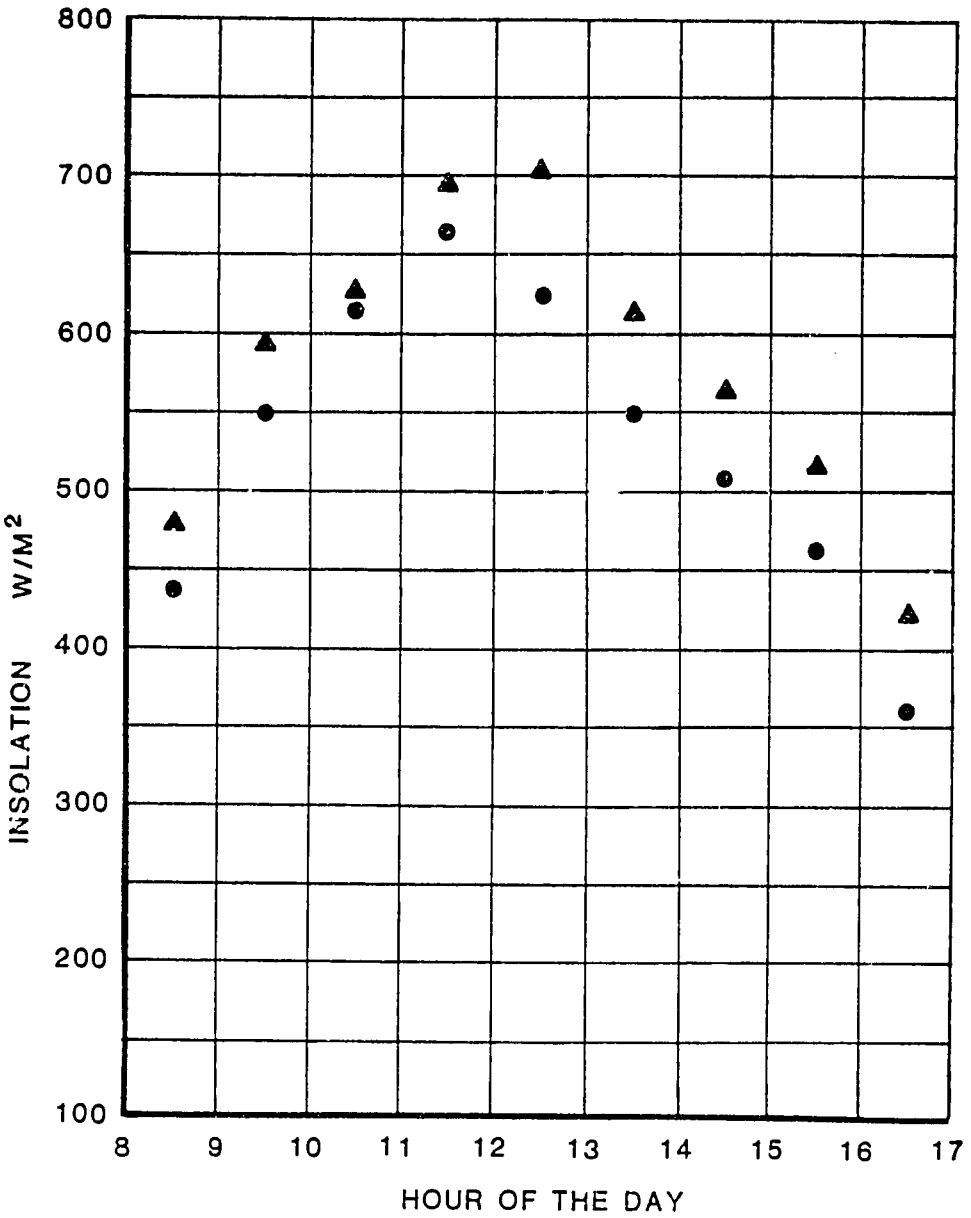


● – FOR ALL DAYS

▲ – FOR DAYS WITH 0.5 KW/M^2 INSOLATION FOR MINIMUM 5 HRS

FIG. 4 DIRECT SOLAR INSOLATION NORMAL TO DISH
MONTHLY AVERAGE

MARCH,80
HYDERABAD

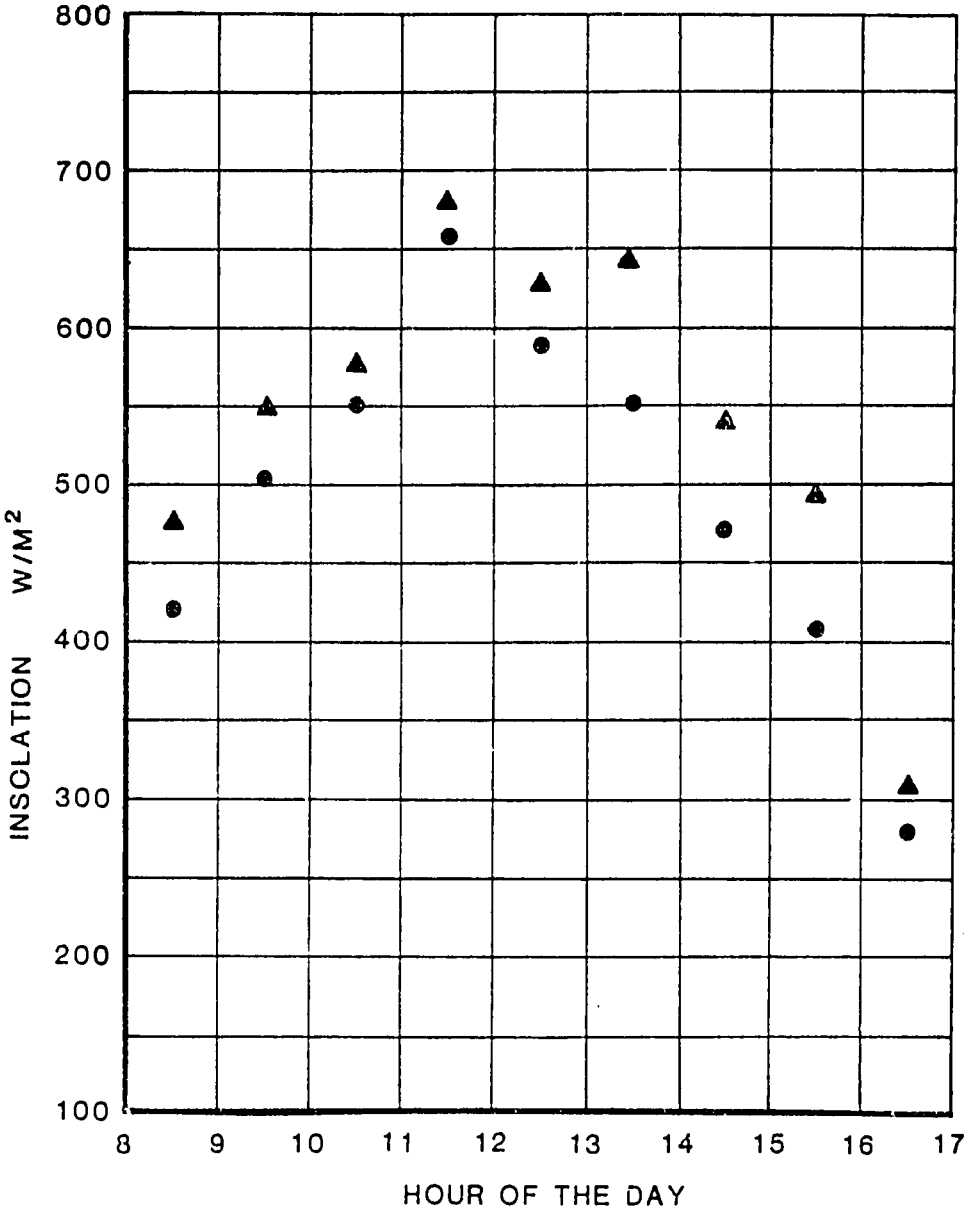


● – FOR ALL DAYS

▲ – FOR DAYS WITH 0.5 KW/M^2 INSOLATION FOR MINIMUM 5 HRS

FIG. 5 DIRECT SOLAR INSOLATION NORMAL TO DISH
MONTHLY AVERAGE

APRIL,80
HYDERABAD

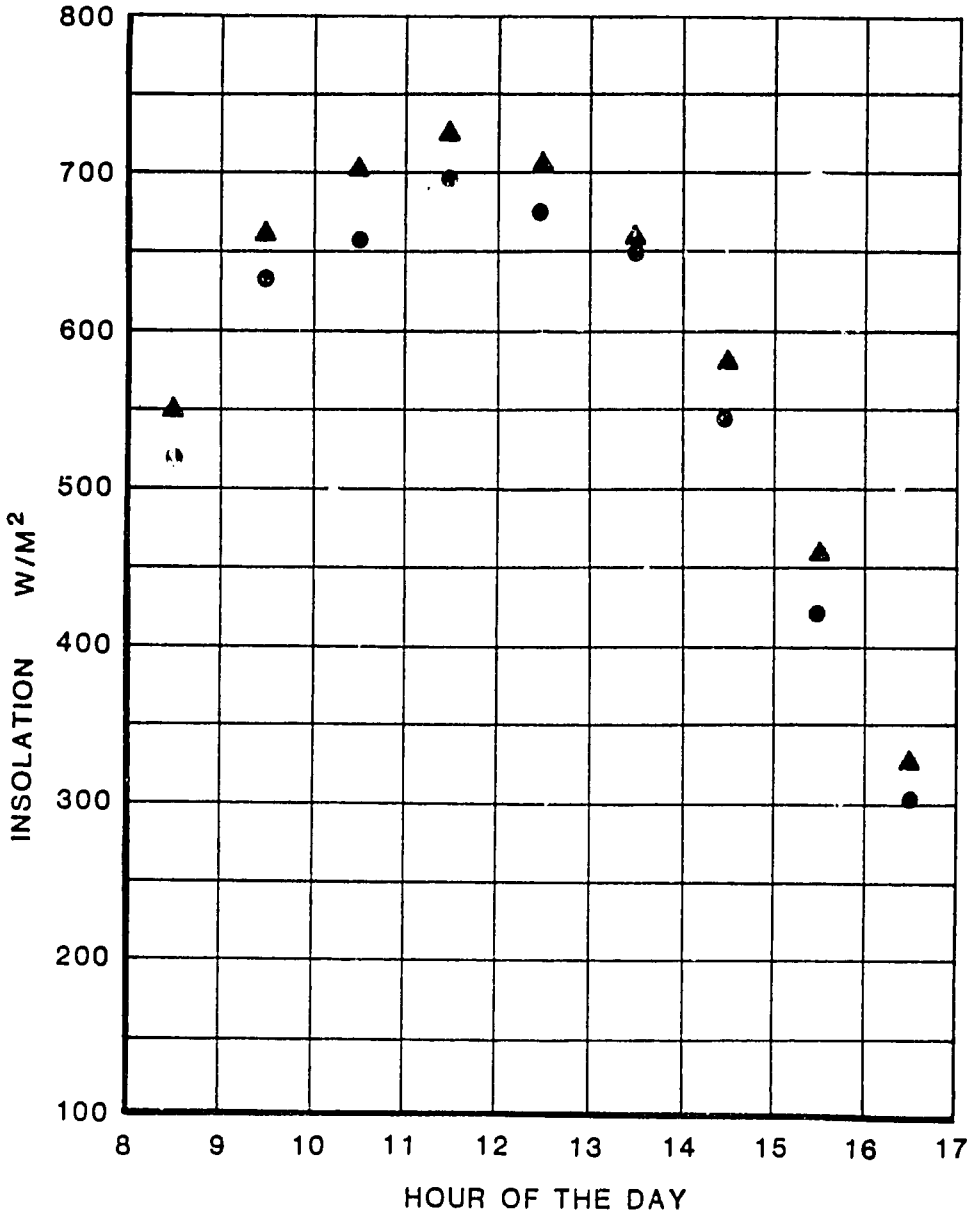


● – FOR ALL DAYS

▲ – FOR DAYS WITH 0.5 KW/M^2 INSOLATION FOR MINIMUM 5 HRS

FIG. 6 DIRECT SOLAR INSOLATION NORMAL TO DISH
MONTHLY AVERAGE

MAY,80
HYDERABAD

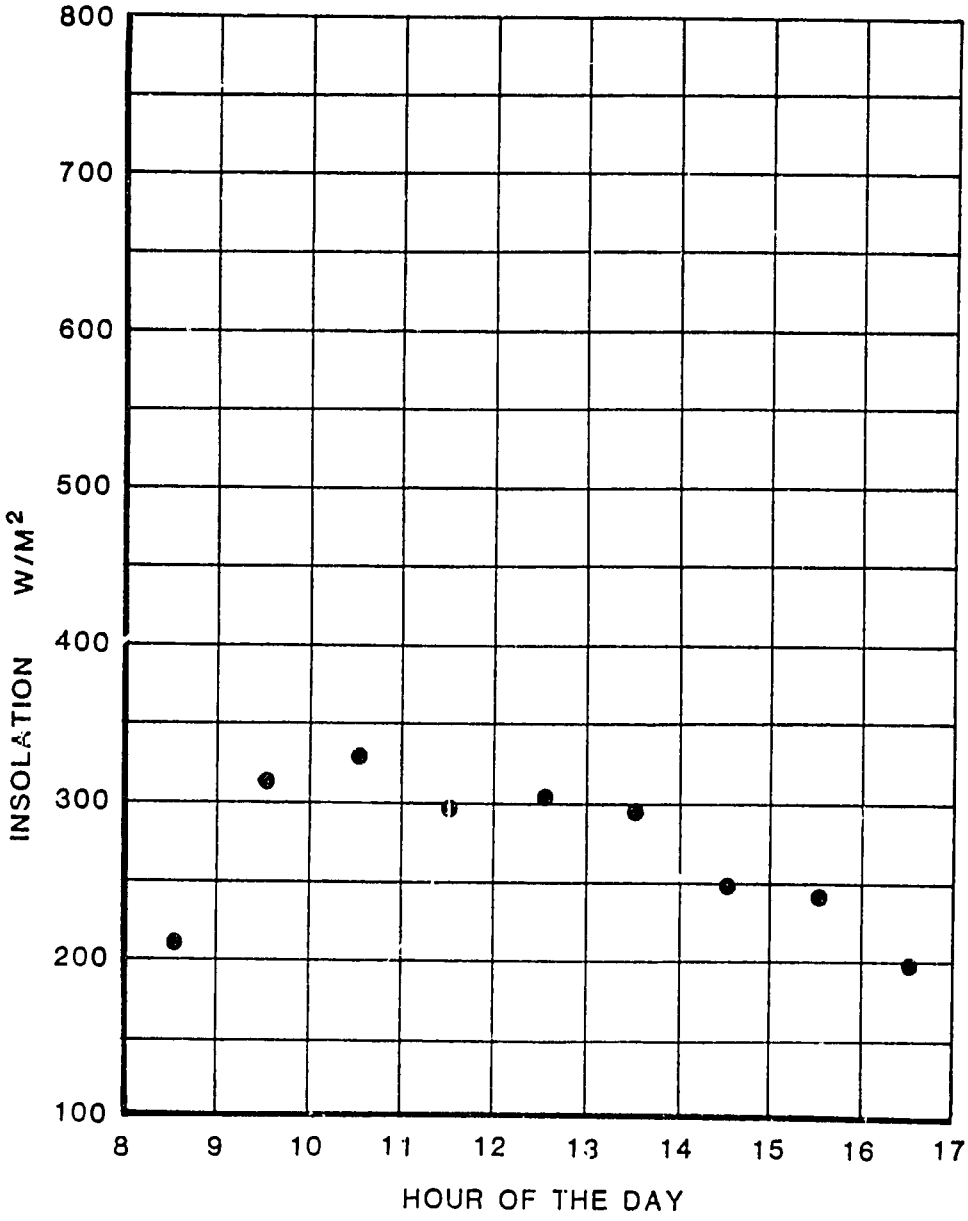


●–FOR ALL DAYS

▲–FOR DAYS WITH 0.5 KW/M^2 INSOLATION FOR MINIMUM 5 HRS

FIG. 7 DIRECT SOLAR INSOLATION NORMAL TO DISH
MONTHLY AVERAGE

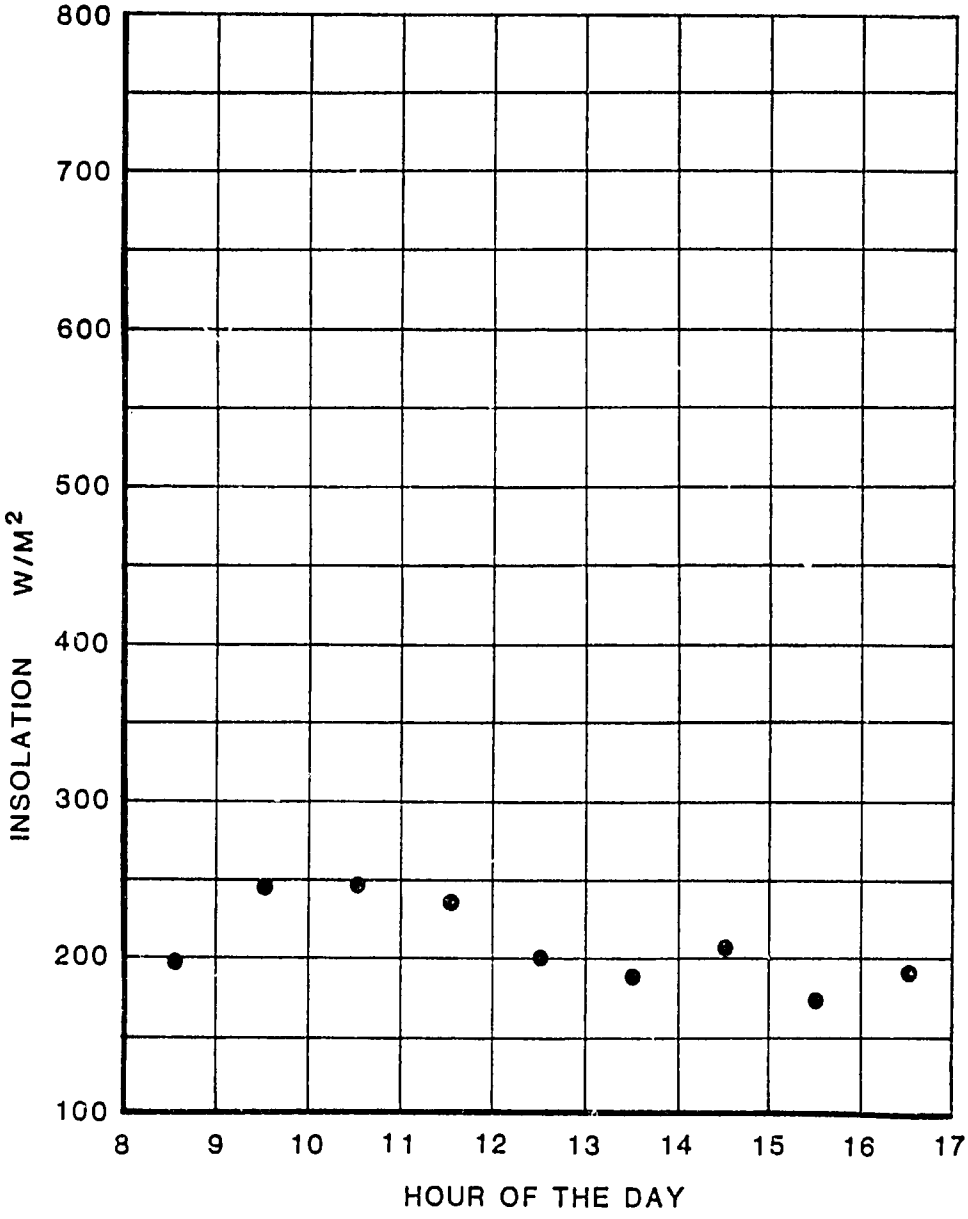
JUNE,80
HYDERABAD



● – FOR ALL DAYS

FIG. 8 DIRECT SOLAR INSOLATION NORMAL TO DISH
MONTHLY AVERAGE

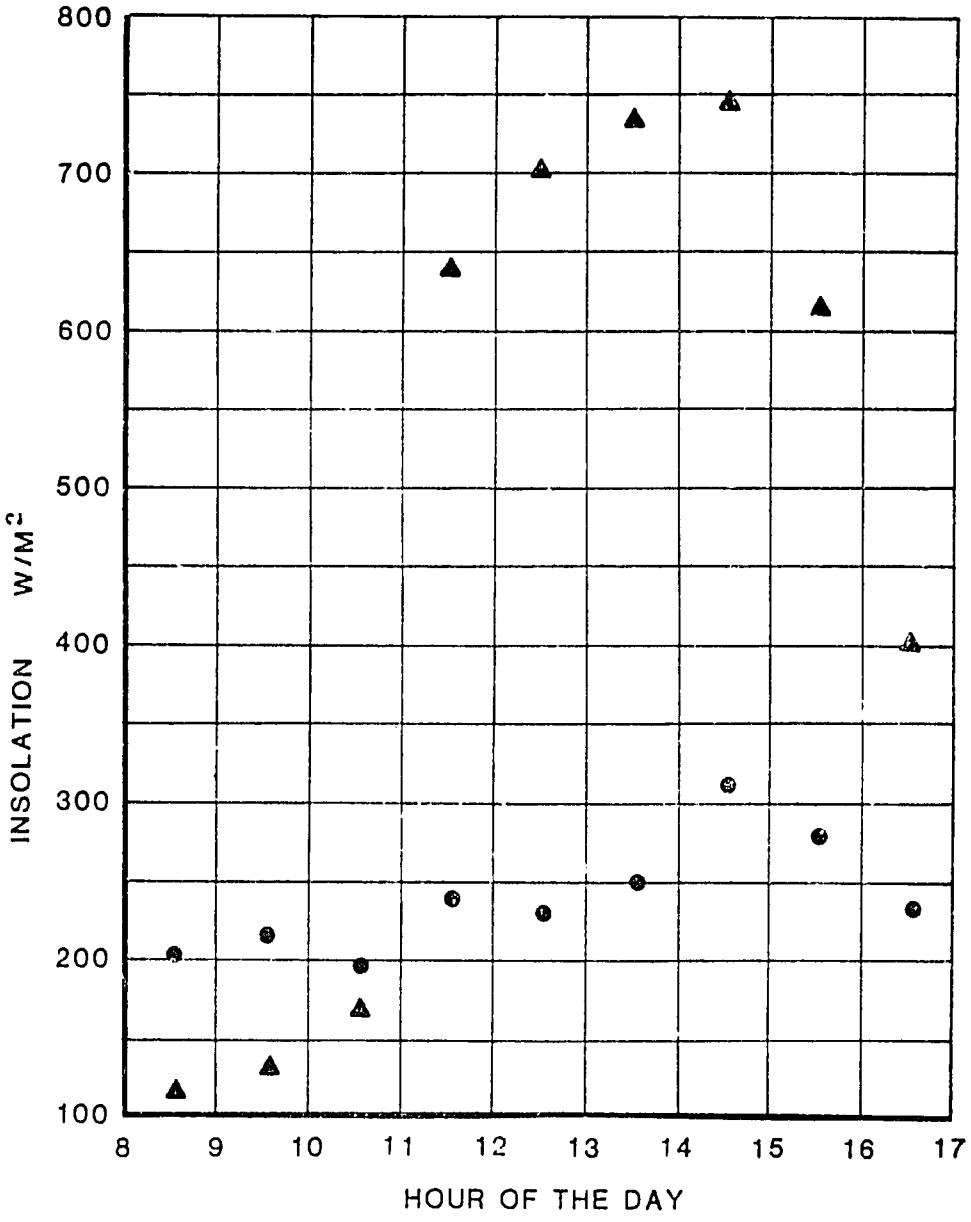
JULY,80
HYDERABAD



● – FOR ALL DAYS

FIG. 9 DIRECT SOLAR INSOLATION NORMAL TO DISH
MONTHLY AVERAGE

AUGUST,80
HYDERABAD

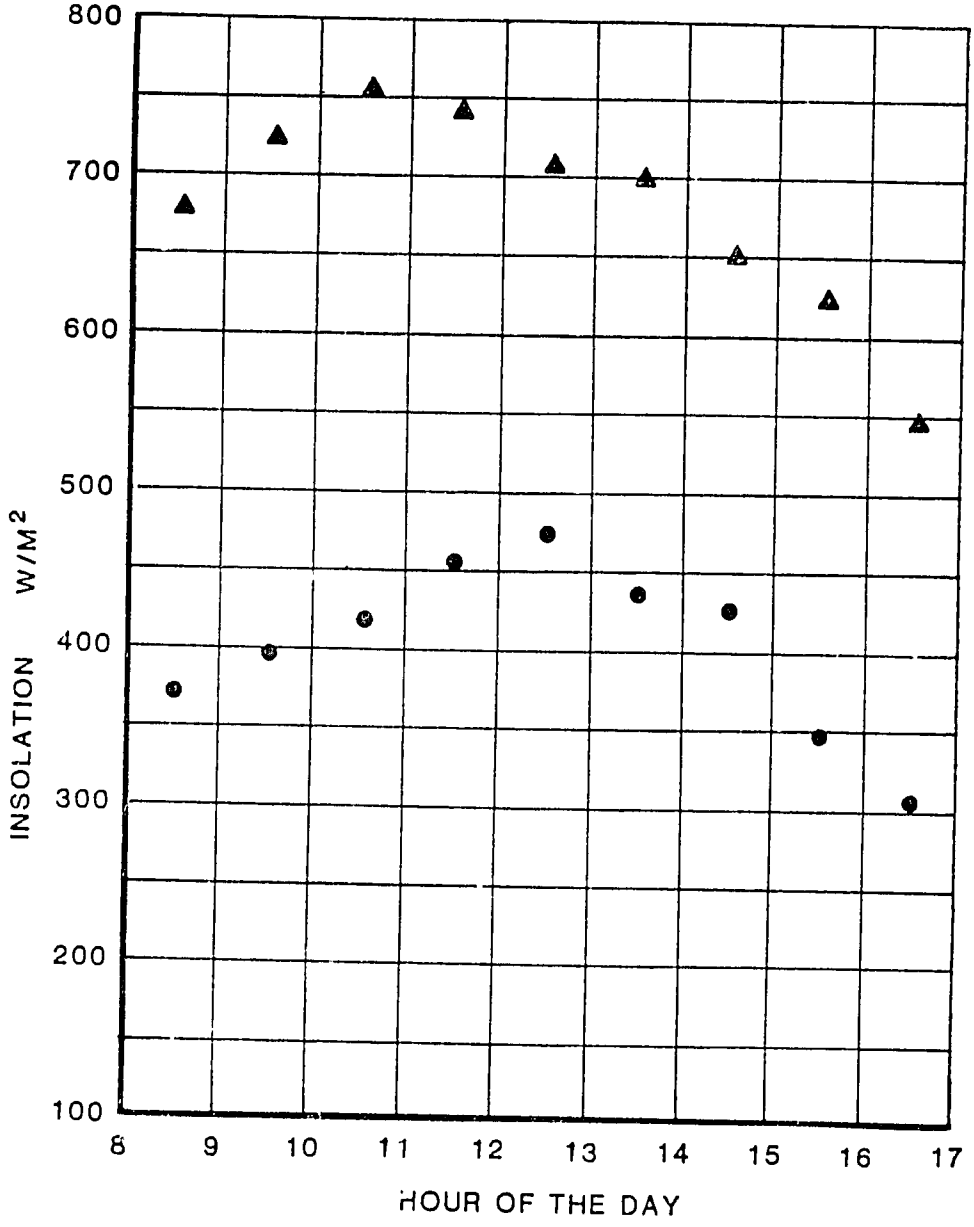


● – FOR ALL DAYS

▲ – FOR DAYS WITH 0.5 KW/M² INSOLATION FOR MINIMUM 5 HRS

FIG. 10 DIRECT SOLAR INSOLATION NORMAL TO DISH
MONTHLY AVERAGE

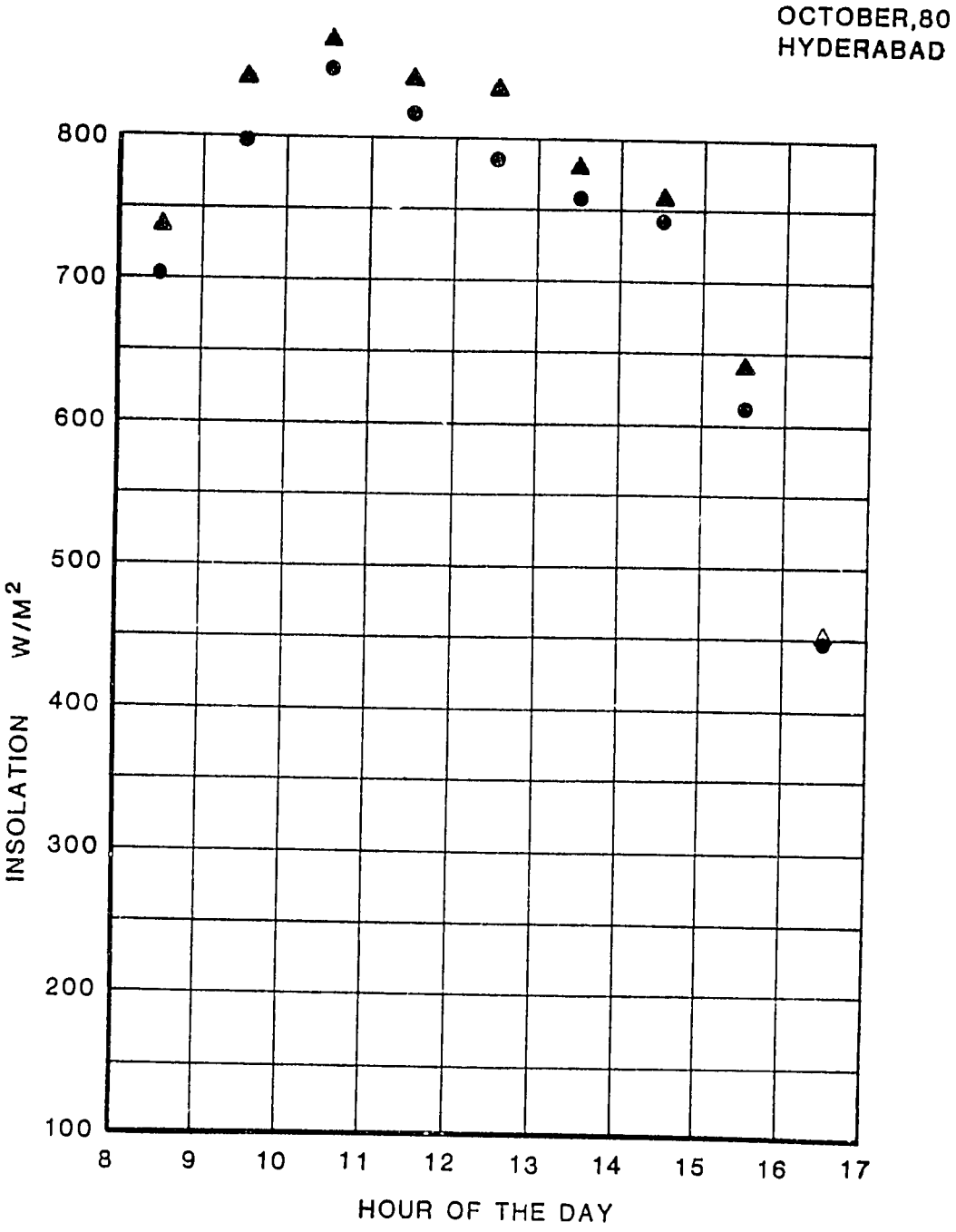
SEPTEMBER,80
HYDERABAD



●–FOR ALL DAYS

▲–FOR DAYS WITH 0.5 KW/M^2 INSOLATION FOR MINIMUM 5 HRS

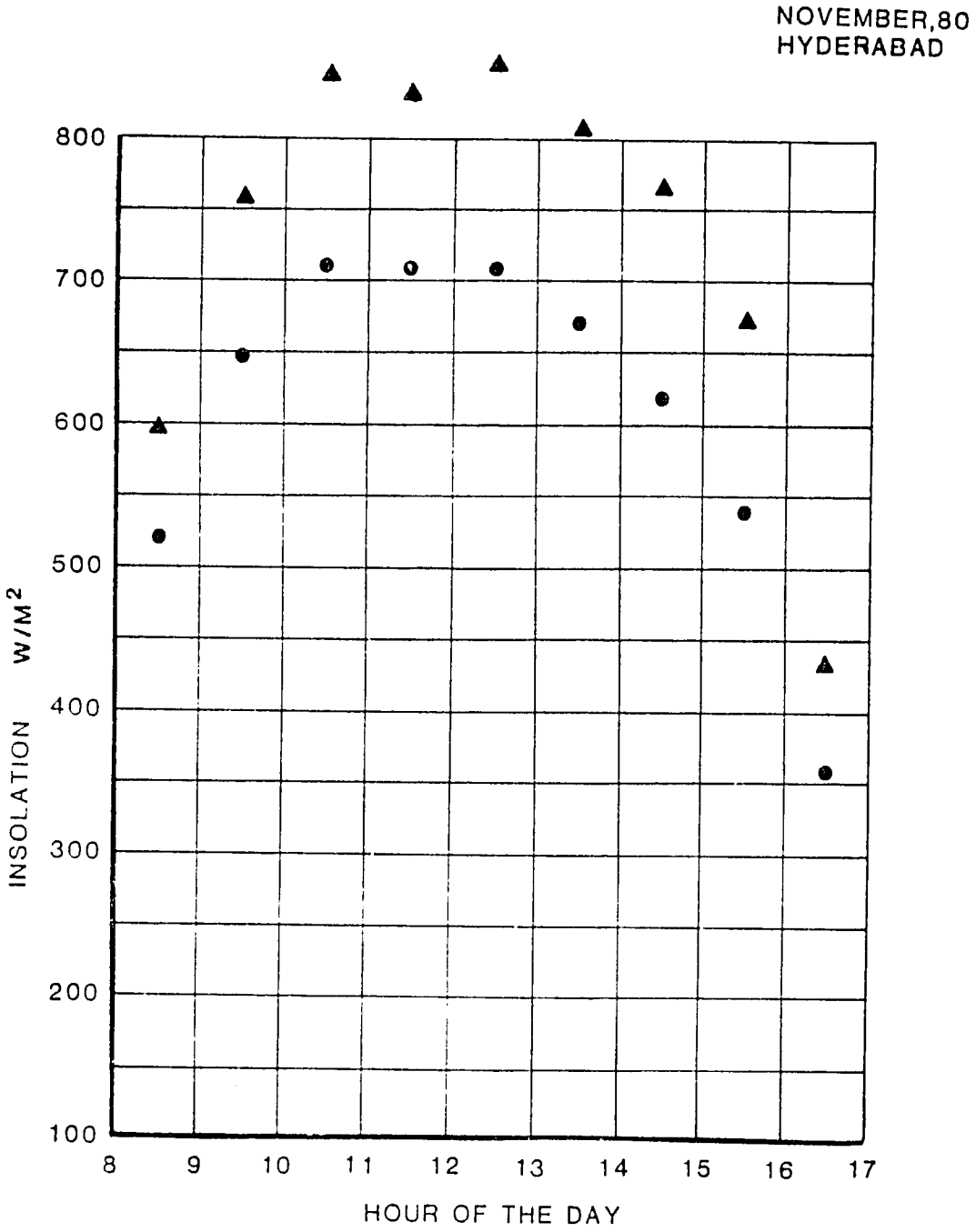
FIG. 11 DIRECT SOLAR INSOLATION NORMAL TO DISH
MONTHLY AVERAGE



●–FOR ALL DAYS

▲–FOR DAYS WITH 0.5 KW/M^2 INSOLATION FOR MINIMUM 5 HRS

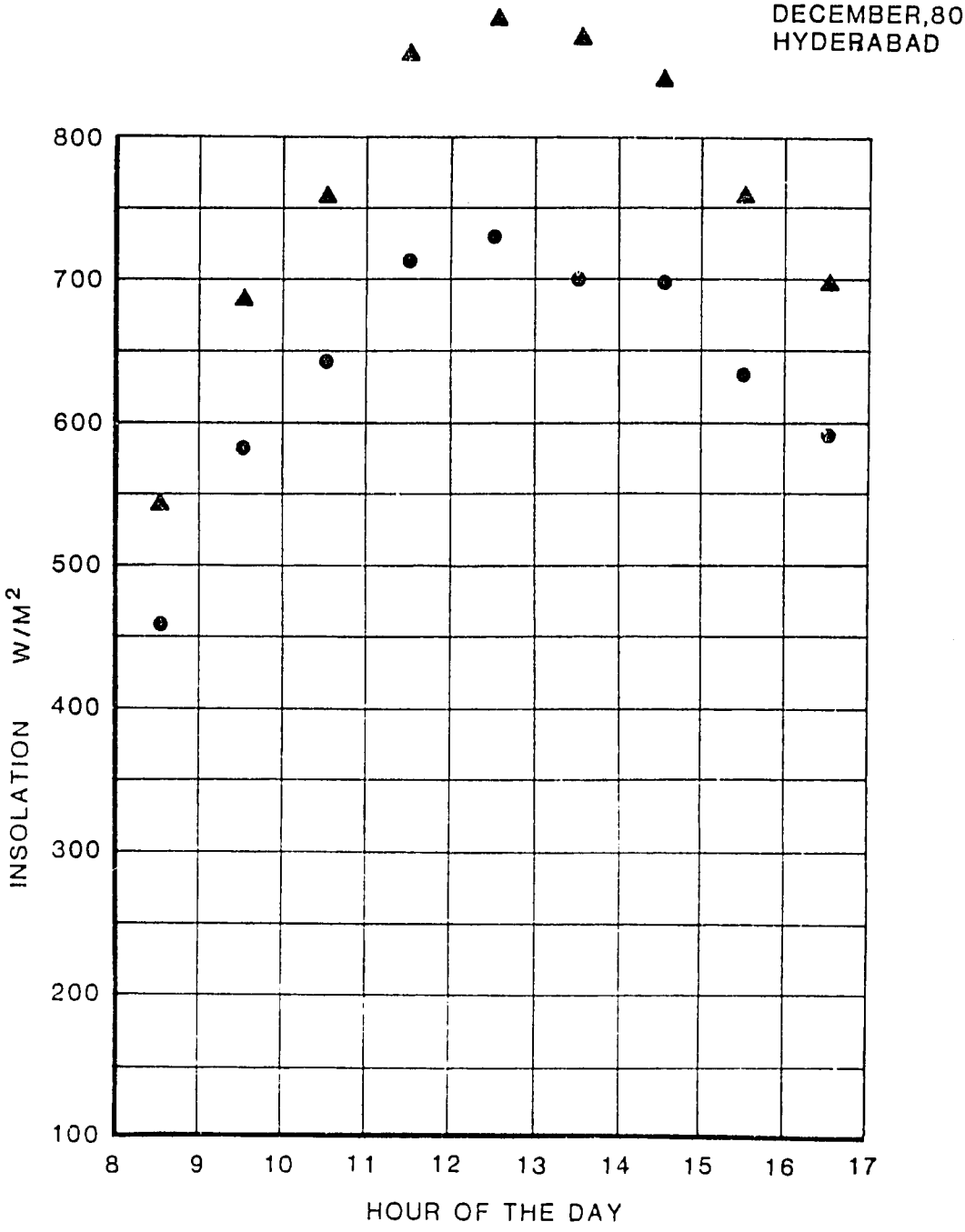
FIG. 12 DIRECT SOLAR INSOLATION NORMAL TO DISH
MONTHLY AVERAGE



●–FOR ALL DAYS

▲–FOR DAYS WITH 0.5 KW/M^2 INSOLATION FOR MINIMUM 5 HRS

FIG. 13 DIRECT SOLAR INSOLATION NORMAL TO DISH
MONTHLY AVERAGE



● – FOR ALL DAYS

▲ – FOR DAYS WITH 0.5 KW/M^2 INSOLATION FOR MINIMUM 5 HRS

Table 1. DIRECT SOLAR RADIATION ON HORIZONTAL SURFACE

(Monthly Average Value, Watts/M^2)

Year 1980

HOURS / MONTHS	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
January	172.0	362.7	497.3	578.6	595.7	541.7	444.2	295.5	132.4
February	180.8	374.3	495.1	595.6	525.6	567.5	445.2	306.3	173.5
March	213.6	373.[illegible]	505.3	608.7	586.0	491.9	406.7	296.1	157.9
April	241.8	382.3	492.0	639.9	582.9	520.9	375.9	272.1	129.9
May	315.2	493.5	615.5	685.4	671.3	594.7	458.7	288.2	147.6
June	126.8	242.1	296.4	288.8	302.7	281.1	210.3	169.5	111.3
July	114.7	184.9	221.1	230.0	199.2	180.3	180.7	123.2	111.2
August	115.1	162.3	175.8	232.2	230.1	240.6	264.5	192.7	114.2
September	202.5	291.9	363.6	431.8	452.2	377.1	322.8	216.4	126.1
October	361.9	546.8	688.5	715.9	705.4	625.5	515.1	319.0	137.8
November	231.3	396.0	519.0	560.5	563.2	494.7	384.9	246.5	90.7
December	196.8	341.8	449.0	539.1	549.8	481.3	398.7	257.0	121.2
YEARLY AVERAGE	206.1	346.0	443.2	508.9	497.0	449.8	367.3	248.5	129.5

Table 2. DIRECT SOLAR RADIATION NORMAL TO DISH

(Monthly Average Value, Watts/M^2)

Year 1980

HOURS / MONTHS	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
January	496.2	684.2	742.5	764.5	759.4	720.7	672.3	570.9	399.5
February	456.8	638.3	673.3	719.8	728.3	685.7	605.0	520.9	439.2
March	437.2	548.6	610.9	665.3	623.6	546.5	509.3	461.7	358.5
April	421.8	504.7	550.9	658.5	589.9	554.3	452.3	407.0	280.0
May	519.7	631.3	676.2	696.9	673.7	627.2	544.9	420.8	302.4
June	212.5	314.1	329.3	295.8	304.6	259.3	246.6	240.8	216.1
July	198.4	244.0	247.7	236.1	199.7	188.0	209.3	172.3	211.6
August	203.8	215.9	197.6	238.7	231.8	253.1	312.0	278.6	232.3
September	367.6	397.5	419.5	458.3	474.8	420.5	412.4	352.2	310.2
October	704.8	759.2	848.8	818.2	805.5	769.2	744.1	613.4	449.0
November	521.9	648.1	711.1	707.3	709.2	672.5	620.8	541.4	358.7
December	459.6	582.0	642.7	715.0	733.2	700.8	700.8	635.5	594.1
YEARLY AVERAGE	416.7	514.0	554.2	581.2	569.5	533.2	502.5	434.6	346.0

Table 3. DIRECT SOLAR RADIATION NORMAL TO DISH

(Monthly Average Value with 0.5 kW/M^2 for at Least 5 Hrs. a Day)

Year 1980

HOURS / MONTHS	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
January	505.2	697.0	752.8	774.2	778.9	739.6	701.2	599.4	416.3
February	458.4	640.9	676.0	722.4	739.4	667.7	610.1	526.9	442.5
March	479.6	593.1	646.0	695.8	684.2	610.5	563.5	516.3	399.2
April	458.3	548.0	578.3	680.4	626.8	643.5	540.1	494.1	309.3
May	546.5	661.2	701.7	722.5	703.1	658.2	578.7	455.1	324.4
June	-	-	-	-	-	-	-	-	-
July	-	-	-	-	-	-	-	-	-
August	113.0	131.2	169.8	642.9	705.3	734.3	746.9	617.2	403.2
September	679.6	725.0	754.6	742.7	707.8	701.2	653.9	625.2	516.8
October	737.2	819.5	868.2	839.6	833.6	790.5	758.5	639.9	452.3
November	595.7	758.6	845.7	831.7	851.5	806.3	761.4	673.2	428.6
December	543.8	686.4	757.3	854.5	883.4	869.7	835.2	758.3	696.2
YEARLY AVERAGE	511.7	626.0	675.0	750.7	751.4	722.2	675.0	590.6	438.9

INSOLATION / MONTHS	0.50 kW/M^2	0.55 kW/M^2	0.60 kW/M^2
January	29	28	26
February	28	27	23
March	25	20	14
April	21	12	8
May	28	22	18
June	Nil	Nil	Nil
July	Nil	Nil	Nil
August	1	1	1
September	9	9	8
October	29	29	29
November	23	22	20
December	24	22	19
YEARLY	207	192	166

Table 4. NUMBER OF DAYS DIRECT SOLAR RADIATION NORMAL TO DISH With 0.50, 0.55, and 0.60 kW/M^2 for at Least 5 Hrs. a Day

INSOLATION / MONTHS	0.75 kW/M^2	0.80 kW/M^2	0.85 kW/M^2	0.90 kW/M^2
January	27	16	7	1
February	12	1	Nil	Nil
March	3	Nil	Nil	Nil
April	3	Nil	Nil	Nil
May	13	10	5	2
June	Nil	Nil	Nil	Nil
July	Nil	Nil	Nil	Nil
August	Nil	Nil	Nil	Nil
September	9	6	4	Nil
October	30	29	27	15
November	20	18	15	12
December	24	24	22	15
YEARLY	141	104	80	45

Table 5. NUMBER OF DAYS DIRECT SOLAR RADIATION NORMAL TO DISH With 0.75, 0.80, 0.85, and 0.90 kW/M^2

TABLE 6

Item	Parabolic	Conical	Flat
Peak Flux	18,000 suns	15,000 suns (estimated)	14,000 suns
Slope error	1 m. rad	1 m. rad	1-1.5 m. rad
Total weight	11,400 Kg.	6,500 Kg.	6,500 Kg.
Total area utilisation	92-95 %	92-95 %	88 %
Fabrication complexity	Complex	Simple	Simplest

Considering the complexity of the parabolic configuration and the cost, the flat and conical configurations were chosen as the candidate concentrators. Optical and structural analysis of the flat configuration were carried out. The experience gained by the JPL team in their 'Test Bed Concentrator' revealed that although the peak flux value in the parabolic configuration is the highest, more emphasis has to be placed on the average value of the flux and, from this point of view, either the flat or the conical configuration would be appropriate. In fact, it may even be necessary to defocus the facets at the central portion of the concentrator to obtain a flatter flux distribution curve on the receiver aperture plate during sun acquisition and defocus. From the point of view of this project, the flat configuration with facets having one radius of curvature was chosen. The facets will be trapozoidal in shape with foam-glas base and glass mirror bonded on it.

From the theoretical point of view, it was considered necessary to carry out the detailed analysis, both optical and structural, of the conical heliodish so that within the duration of the project, the design of conical heloidish would also be available. Preliminary design drawings of the flat and conical heliodish are enclosed.

The concentrator will have 15° elevation offset to take care of zenith tracking of the sun at the latitude of installation. It will have two axes tracking sub-system with an accuracy of 0.1°. The drive mechanism will be a BHEL design using available information on components from similar systems used in USA. The design will be similar to the second generation heliostat.

C2. Receiver:

The Receiver will be of cavity type, For this project, the heat transfer coil will be of stainless steel 347, the aperture plate of CS Graphite

and the back plate of high temperature nickel alloy steel. The aperture diameter has been tentatively fixed to be 250 mm and it will be finalised after the detailed design of the concentrator is completed in all respects. A drawing of the receiver is enclosed.

C3. Prime Mover:

As per the system calculations, the capacity of the solar thermal system is expected to be of the order of 22 kWpeak (net). For such a capacity, steam turbines are not available, and even if available, they are highly inefficient. Steam screw expander technology is not fully established and, therefore, for this system it was decided to utilise a steam engine. Two steam engines have been procured. These will be adapted to suit the soalr thermal system. One engine has been tested at JPL and the other will be tested by BHEL and adapted for specific application. Base line parameters of the steam engines are given hereunder:

ENGINE I

Type	:	V-2 Double acting compound steam engine.
Bore	:	a) High Pressure cylinder 1.75" b) Low Pressure cylinder 3.00"
Stroke	:	2.0"
Max. Output	:	35 bhp at 2000 rpm
Inlet Temp	:	480°C (900°F)
Max. Inlet Pressure	:	1000 psi
Overall dimension	:	23" x 19" x 18.5"
Weight	:	168 lbs.

ENGINE II

Type	:	Two cylinder uni-flow type
Bore	:	2.5"
Stroke	:	3.0"
Max. Output	:	20 to 25 bhp at 3600 rpm
Inlet temperature	:	565°C (1050°F)
Inlet Pressure	:	1000 to 1500 psi.

C4. Control and Instrumentation:

It is recognised that the input energy is not only variable from morning to evening but also subject to transients due to sudden cloud covers. The control philosophy has been developed taking such factors into consideration. In the control system there are essentially three loops:

- Steam control loop
- Tracking control loop
- Power generation control loop

The steam control loop provides steam at constant temperature with variable mass flow rate. The tracking accuracy is 0.1° and will be performed with servomotors. The power generation control incorporates mass flow rate control and provides basically unregulated 3 phase, 440 volts AC power.

The measurement scheme provides avenues of acquisition of insolation data, temperatures, pressures and mass flow rates at various points of the system. The schemetic control and instrumentation diagrams are shown in Figs 14-17.

C4.1 Quality of Electricity:

Due to the variable nature of the input energy, the speed of the prime mover will be variable and the resultant electrical power will be of variable frequency. Several options were considered. They are:

- Field modulated generator,
- Permanent magnet generator,
- Induction generator,
- Conventional AC generator without frequency control,
- Conventional AC generator with AC-DC-AC conversion,

Field modulated generators are still under development and only one prototype is available and is expensive. Considering the status of technology and reliability, this option was deleted. Permanent magnet generator was deleted due to similar reasons. An induction generator could not be chosen for the system because of its motoring possibility in the 'Stand Alone' system and consequential hazards. The option of utilising a conventional AC generator with uncontrolled frequency was rejected because the loads require a 50 cycle, AC power supply. Therefore, the final option is to employ a conventional AC generator, rectify the power to DC and invert the same to a 3 phase, 50 cycle, 440 volt AC supply. A schematic layout is shown in Fig. 18.

C5. Bio-gas Based Power Generation:

A 9.8 hp diesel engine has been modified to operate solely with bio-gas as available from a bio-gas plant. The engine, when coupled to a generator, will provide 5 kW (approximately) of electrical power. This will be utilised to supply auxiliary power for the solar thermal power generation system. The

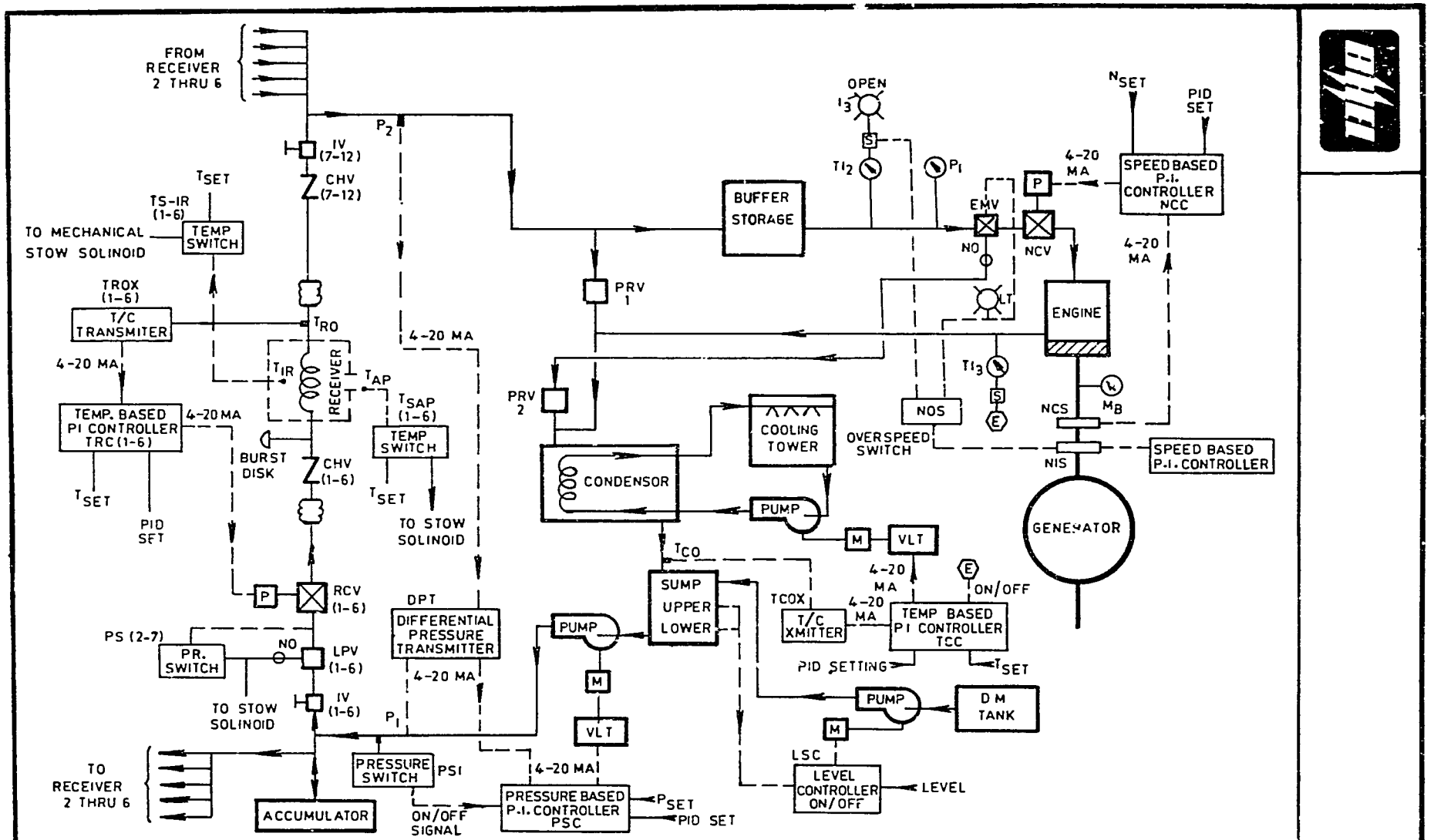


Fig. 14 STEAM TEMPERATURE CONTROL LOOP

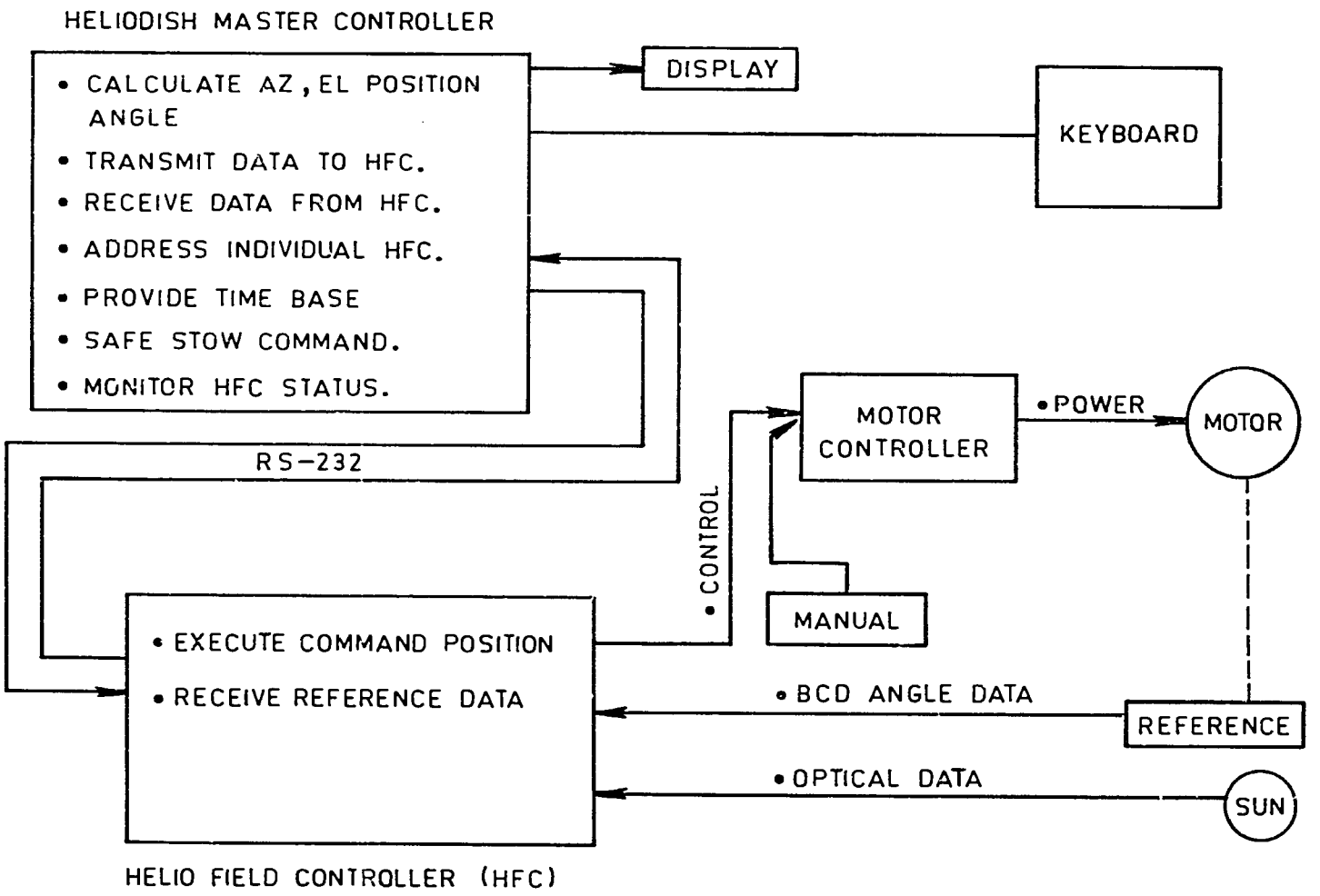


Fig. 15 TRACKING SYSTEM BLOCK DIAGRAM

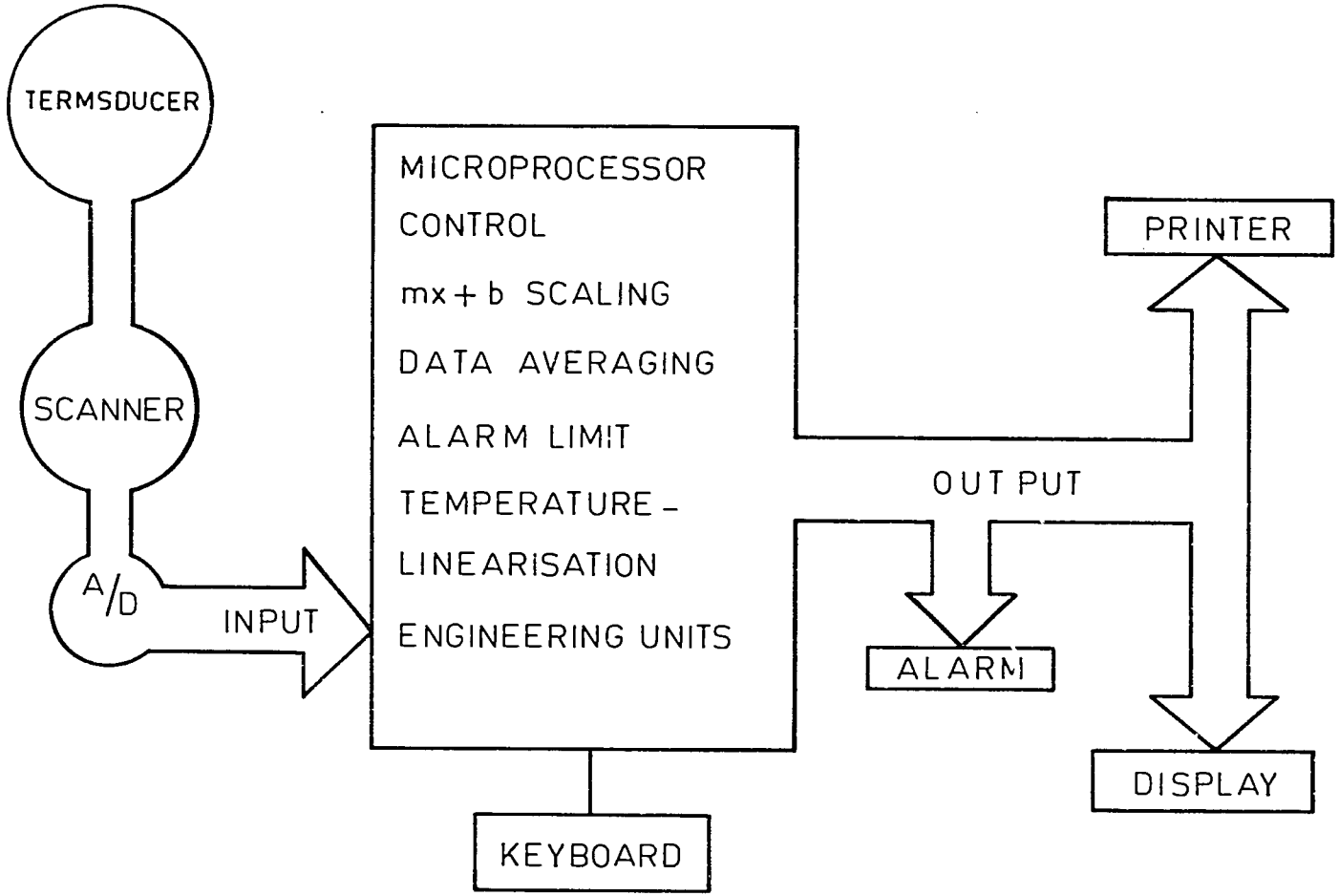


Fig. 16 MEASERMENT SYSTEM BLOCK DIAGRAM

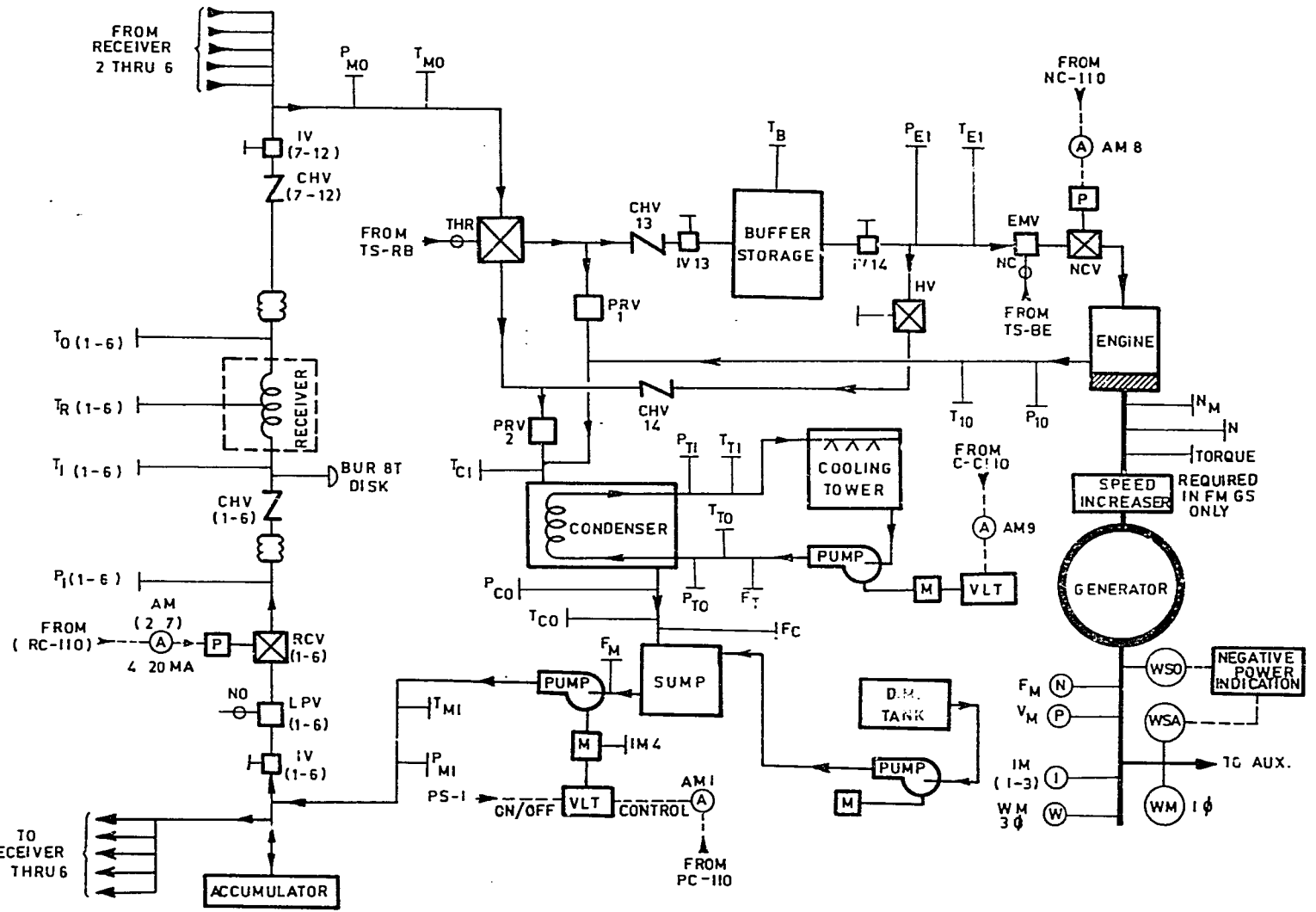


Fig. 17 MEASUREMENT SYSTEM

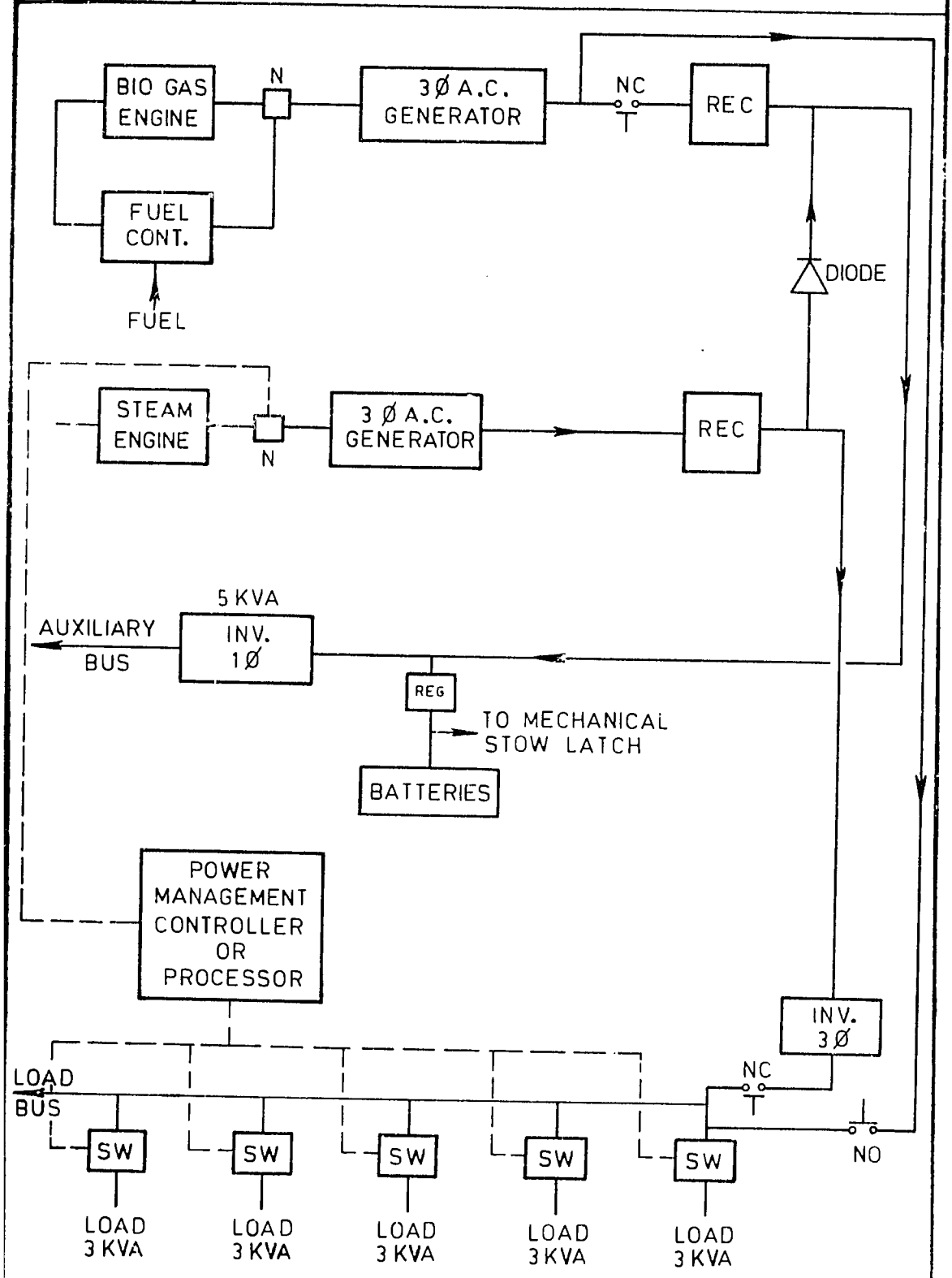


Fig. 18 AC–DC–AC GENERATION SYSTEM

output of the engine will be regulated through a rectifier-inverter system of suitable capacity to obtain regulated power.

Flexibility has been provided to transfer power between bio-gas based power and solar thermal power as shown in the schematic layout(Fig. 18).

D. LOAD DISTRIBUTION

The selected village has no access to electrical energy and, therefore, there does not exist any firm load. The envisaged system will undoubtedly permit provision of essential energy needs of the community. From the point of view of benefit to the community, irrigational requirements hold the highest priority.

The power generated by the solar thermal and bio-gas systems is expected to provide about 22 kW peak electrical power for irrigation. This power will be distributed in the form of about six irrigation pumps of 3 kW (approx.) capacity each.

Appropriate water management and irrigation concepts will be applied with the help of local administration.

E. LOAD MANAGEMENT

Due to the variable nature of the input energy, the power output from the solar thermal system will be variable. The load management concept will comprise stepped load variation to fulfill irrigational requirements. Closer load management will be performed through supply of power for drining water pumping and charging of batteries for the auxiliary start up.

F. ACTION POINTS

In order to enable the project activities to proceed as per schedule, the following actions will have to be taken.

	Item	Action By
F1.	Completion of detailed design of the concentrator structure and provision of load requirements for drives to Mr. H. Bank	Mr. GP. Reddy
F2.	Obtain details of available Heliostat Drive system and assessment of their load capability and provide the information to Mr. GP Reddy	Mr. H. Bank

	Item	Action By
F3.	Review of drive system design compatibility with load requirement of flat heliodish if F2 is not possible. Information to be provided to Mr. GP Reddy on special parts as available	Mr. H. Bank
F4.	Detailed aerodynamic load calculation of flat helio-mirror to Mr. GP. Reddy - Detail aerodynamic load analysis of parabolic dish to be supplied to GP. Reddy	Mr. H. Bank
F5.	Provision of information on drive systems to Mr. J. Newnham and Mr. UB. Sahay	Mr. GP. Reddy Mr. SK. Kaila
F6.	Information on size of facets, radius of curvature and availability of single piece Indian foamglas to Mr. W. Carley	Mr. SK. Kaila
F7.	Information regarding possibility of making a set of tools for facet curvature facing tools in India to Mr. W. Carley	Dr. NK. Giri
F8.	Requirement of materials for facet fabrication - specification and bill of quantities to Mr. W. Carley	Mr. SK. Kaila
F9.	Placement of order, assistance in identifying sources of supply for foamglas, mirrors, paint and other materials based on F6, F7 and F8.	Mr. W. Carley
F10.	Optical analysis of conical heliodish and despatch of results to Mr. TK. Mukherjee	Mr. Royal Harrison
F11.	Provide information on design and fabrication of calorimeter to Mr. LM. Siddique Ahmed	Mr. W. Carley
F12.	Fabrication of calorimeter	Mr. LMS. Ahmed
F13.	Determine availability of the JPL Flux mapper on temporary loan for the Salojipally project. Information to Mr. Harrison	Mr. W. Owen
F14.	Provide information on design and fabrication of facet slope mirror measurement, radius of curvature measurement instruments to Mr. SK. Kaila	Mr. W. Carley

F15.	Fabrication of facet slope mirror measurement, radius of curvature measurement instruments	Mr. SK. Kaila
F16.	Provide information on steam engine adaptation and testing to Mr. J. Newnham and Mr. UB. Sahay	Mr. K. Thirumalai
F17.	Drilling of borewells	Dr. NK. Giri
F18.	Provide water table information to JPL/CEL/Mr. UB. Sahay	Dr. NK. Giri
F19.	Develop understanding of mirror facet alignment procedure by performing procedure on TBC at JPL	Mr. K. Thirumalai
F20.	Shipment of steam engines to BHEL	Mr. Royal G. Harrison
F21.	Receiver material procurement	Mr. W. Owen
F22.	Identifying sources of supply in the USA for feed water pump, high pressure hoses with fittings, valves for various lines, pipe fittings etc.	Mr. W. Owen
F23.	Identifying sources of supply for high temperature insulation	Mr. H. Bank
F24.	Procurement/identification sources of supply for generator, rectifier, controls and instruments	Mr. J. Newnham.
F25.	Installation of bio-gas plant	Dr. NK. Giri
F26.	Final list of materials and equipment to be procured in the USA-to be provided to Mr. Royal G. Harrison	Mr. TK. Mukherjee
F27.	Obtaining customs duty exemption	Mr. TK. Mukherjee
F28.	Determination of materials and equipment to be imported through Indian Rupees or US Dollars	Mr. TK. Mukherjee Mr. Royal G. Harrison

G. TIME SCHEDULES AND MILESTONES

Time schedules and milestones for different activities have been worked out and are shown in the bar-charts.

SOLAR THERMAL POWER GENERATION
TIME SCHEDULES AND MILESTONES
DESIGN PHASE

SL. NO.	ACTIVITIES	4/82	5/82	6/82	7/82	8/82	9/82	10/82
1	DETAILED DESIGN OF CONCENTRATOR							
2	DESIGN OF DRIVE SYSTEM							
3	DESIGN OF RECEIVER							
4	ENGINE ADAPTATION AND TESTING							
5	DESIGN OF CONTROL AND INSTRUMENTATION							
6	DESIGN OF CONDENSER STORAGE AND OTHER ITEMS							
7	BIOGAS ENGINE ADAPTATION							
8	PREPARATION FOR SUB-SYSTEM PROCUREMENT/FABRICATION							

SOLAR THERMAL POWER GENERATION
TIME SCHEDULE AND MILESTONES
PROCUREMENT AND FABRICATION PHASE

SL. NO.	ACTIVITIES	6/82	7/82	8/82	9/82	10/82	11/82	12/82	1/83	2/83	3/83	4/83
1	CONCENTRATOR STRUCTURE FABRICATION											
2	FACET FABRICATION AND TESTING											
3	DRIVE SYSTEM FABRICATION											
4	RECEIVER FABRICATION											
5	ENGINE ADAPTATION											
6	CONDENSER, STORAGE COOLING TOWER											
7	BIO-GAS ENGINE WITH EXTRA ENGINE											
8	PIPE AND FITTINGS											
9	INSTRUMENTATION AND CONTROL											
10	PUMPS, MOTORS, GENERATOR, CABLES											

SOLAR THERMAL POWER GENERATION
TIME SCHEDULES AND MILESTONES
TESTING, SITE ACTIVITIES AND ERECTION PHASE

SL. NO:	ACTIVITIES	2/82	3/82	4/82	5/82	6/82	7/82	8/82	9/82	10/82
1	INSTALLATION OF BIO-GAS PLANT									
2	INSTALLATION OF BIO-GAS PUMP-SET									
3	INSTALLATION OF 5 KW BIO-GAS ENGINE AND GENERATOR									
4	CIVIL WORKS									

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SOLAR THERMAL POWER GENERATION
TIME SCHEDULES AND MILESTONES
TESTING, SITE ACTIVITIES AND ERECTION PHASE

SL. NO.	ACTIVITIES	12/82	2/83	4/83	6/83	8/83	10/83	12/83
1	TESTING OF CONCENTRATOR RECEIVER AT R & D DIVISION BHEL							
2	INSTALLATION OF CONCENTRATORS AT SITE							
3	INSTALLATION OF CONDENSER, STORAGE COOLING TOWER & ENGINES							
4	INSTALLATION OF PIPING, VALVES, PUMPS AND BALANCE OF SYSTEM							
5	CONTROLS INSTRUMENTATION & DATA ACQUISITION							
6	INSTALLATION OF LOADS							
7	COMMISSIONING & TRIAL RUNS							
8	FINAL REPORT							

H. MANPOWER EXCHANGE

BHEL TEAM

It is envisaged that one engineer from BHEL will be visiting JPL for adapting the steam engine for the project by the first week of April. Another engineer and Indian Project Manager will be visiting JPL by the middle of June for finalising the overall system design, drives system for concentrators, for optical analysis of conical heliodish etc. An additional engineer may have to visit JPL for discussions and finalisation of procurement and other activities.

JPL TEAM

One engineer from JPL is required to visit India by the second week of August 1982 for assisting in facet fabrication. Another engineer has to visit BHEL, India for demonstrating facet alignment procedure by the first week of February 1983. One engineer and the US Project Manager will visit BHEL to participate in the testing programme as required.

BHEL/JPL

As the need for manpower exchange arises, each case will be discussed by the Project Managers before the travel is authorised.

I. PRELIMINARY LIST OF MATERIALS TO BE IMPORTED:

1. Steam engines - Two versions
2. Foamglas
3. Mirrors for facets
4. Paints and adhesives for facet fabrication
5. Tooling for facets fabrication (2 nos.)
6. Fixtures for fabrication of facets
7. Search light and its accessories for mirron alignment
8. Drives and Head components for the concentrator (7 nos.)
9. Heat exchanger coils for the receiver
10. Aperture plate for the receiver
11. Back and front reflector for the receiver
12. Heliodish Master controller
13. Sunsensor

14. Encoder (optical)

15. Field controller, Motor interface and servomotor or programmable servo system

16. Card cage

17. Data Logger

18. Extender Unit.

19. Temperature transducers and transmitters

20. Extension cables

21. Pressure transducers

22. Flow meters

23. Voltage, current and power transducers

24. Specific tools for instrumentation:

    a) Thermocouple wire stripper
    b) Thermocouple welding machine
    c) Multipurpose plier
    d) Crimping tool

25. Rectifier - Invertor 5 KVA and 20 KVA capacity

26. Power management controller

27. 3 mode PID controller

28. Analog Actuator

29. Control valves

30. Differential pressure transmitters

31. Temperature switches

32. Pressure switches

33. Speed transducer

34. Overspeed switch

35. Other components for steam control loop (temperature, pressure gauges etc.)

36. Feed water pump

37. High pressure hoses and fittings

38. High temperature insulation material

39. Valves for various lines and special pipe fittings

40. Water pumps of high efficiency for high head operation.

APPENDIX I

LIST OF PARTICIPANTS

A. MEETING AT CEL, SAHIBABAD ON 4.2.1982

1.	Lt. General KS Garewal	CEL
2.	Mr. UV. Warlu	CEL
3.	Dr. TK. Bhattacharya	CEL
4.	Mr. Royal Harrison	JPL
5.	Mr. W. Carley	JPL
6.	Mr. H. Owen	JPL
7.	Mr. H. Bank	JPL
8.	Mr. J. Newnham	JPL
9.	Dr. NK. Giri	BHEL
10.	Mr. TK. Mukherjee	BHEL

B. MEETING AT BHEL, NEW DELHI ON 5.2.1982

1.	Mr. Royal G. Harrison	JPL
2.	Mr. W. Carley	JPL
3.	Mr. W. Owen	JPL
4.	Mr. H. Bank	JPL
5.	Mr. J. Newnham	JPL
6.	Mr. PN. Arumugam	BHEL
7.	Mr. AS. Padmanabhan	BHEL
8.	Dr. YP. Abbi	BHEL
9.	Mr. Suresh Chandra	BHEL
10.	Dr. NK. Giri	BHEL
11.	Mr. TK. Mukherjee	BHEL

C. MEETING AT BHEL, HYDERABAD ON 8.2.1982

1.	Mr. Royal Harrison	JPL
2.	Mr. J. Newnham	JPL
3.	Mr. W. Carley	JPL
4.	Mr. A. Owen	JPL
5.	Mr. H. Bank	JPL
6.	Dr. A. Gopalakrishnan	BHEL
7.	Mr. TK. Mukherjee	BHEL
8.	Mr. AK. Tiwari	BHEL
9.	Mr. Syed Basheer Ahmed	BHEL
10.	Dr. RK. Khogra	BHEL
11.	Mr. SRC. Sathyanarayan	BHEL
12.	Mr. RK. Jain	BHEL
13.	Mr. Shashi Mantrawadi	BHEL
14.	Mr. VC. Santhanam	BHEL
15.	Mr. K. Thirumalai.	BHEL
16.	Dr. Ashok Chandrupatla	BHEL
17.	Mr. UB. Sahay	BHEL

C.

18.	Mr. LM. Siddique Ahmed	BHEL
19.	Mr. SK. Kaila	BHEL
20.	Dr. NK. Giri	BHEL
21.	Mr. GP. Reddy	BHEL

D. MEETING AT DST ON 18.2.1982

1.	Mr. Maheshwar Dayal	DST
2.	Mr. AK. Gupta	DST
3.	Mr. SK. Mehndiratta	DST
4.	Mr. DK. Rakshit	DST
5.	Mr. JR. Meena	DST
6.	Dr. GD. Sootha	DST
7.	Dr. (Mrs) P. Boughton	USAID
8.	Mr. J. Malick	USAID
9.	Mr. RK. Berry	USAID
10.	Mr. Royal G. Harrison	JPL
11.	Mr. W. Carley	JPL
12.	Mr. W. Owen	JPL
13.	Mr. H. Bank	JPL
14.	Mr. J. Newnham	JPL
15.	Mr. UV. Warlu	CEL
16.	Dr. BMS. Bist	CEL
17.	Mr. SP. Joshi	CEL
18.	Mr. SK. Sangal	CEL
19.	Dr. A. Gopalakrishnan	BHEL
20.	Mr. TK. Mukherjee	BHEL
21.	Mr. Suresh Chandra	BHEL
22.	Dr. NK. Giri	BHEL
23.	Mr. K. Thirumalai	BHEL
24.	Mr. SK. Kaila	BHEL
25.	Mr. LM. Siddique Ahmed	BHEL
26.	Mr. UB. Sahay	BHEL
27.	Mr. GP. Reddy	BHEL

APPENDIX II

PRELIMINARY TECHNO-SOCIO-ECONOMIC ANALYSIS OF SOLAR THERMAL AND SOLAR PHOTOVOLTAIC POWER GENERATION

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B. 1 Details of Salojipally Project System

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B. 1. 2 Cost of the First Plant

B. 2 Future Projections

B. 3 Analysis of the Specific System

B. 4 Benefit from Similar Systems Based on Target Cost Per kW_e

C. SOLAR PHOTOVOLTAIC POWER GENERATION

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C. 2 Future Projections

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C. 4 Benefit from Similar Systems Based on Target Cost Per kW_e

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E. METHODOLOGY FOR ECONOMIC ANALYSIS FOR SALOJIPALLY PROJECT AND PRELIMINARY SOCIO-ECONOMIC BENEFIT

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E. 2 Preliminary Economic Analysis

E. 3 Expected Benefit Through Additional Irrigation

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G. BIBILIOGRAPHY

A. INTRODUCTION

Activities towards development of Solar Power Generation, through photovoltaic and thermal routes have been going on in many countries for the last few years. Due to advantages of geographical location, and consequent abundant availability of solar energy, developing countries like India have placed concentrated emphasis on these developments. In such countries, 'Decentralised Energy Systems' are of significance because of lower availability of fossil fuel based central power plants, long transmission and distribution lines leading to high losses and poor load factor in the rural communities. Considering these factors, 'Decentralised Solar Power Generation Systems' offer attractive options for countries like India.

It is, therefore, worthwhile to analyse the present and future "Techno-Socio-Economic" position of such developments in the light of investments towards developmental costs. In the following paragraphs the preliminary "Techno-Socio-Economics" of solar photovoltaic and solar thermal power generation have been provided which clarify the following:

- Rationale for the cost of the first prototype system.
- First plant cost versus future projections.
- Whether cheaper alternative energy systems could be considered in future.
- The impact of similar systems on the economic status of the rural communities in future.

This preliminary report is based on published information, discussions with various Indian engineers conversant with the energy situation and inhabitants of a village in Andhra Pradesh.

B. SOLAR THERMAL POWER GENERATION

B. 1 Details of Salojipally Project System

B. 1. 1 System Description

The Solar Thermal Power Generation System being designed for Salojipally village is based on 'Steam Rankine Cycle' with concentrating collectors. The system has been chosen to ensure reliability and employs proven technology. The theoretical design values of the system are:

No. of Dishes (Concentrators) of 8 m diameter each	:	6
Total Collection area @ 64 m^2/dish	:	384 m^2
Max^m Power at 800 W/m^2 of solar energy	:	304 kW_{th}
Average Power at 550 W/m^2 of solar insolation	:	211 kW_{th}

Efficiencies:

-	Concentrator	90%
-	Receiver	85%
-	Transport	85%
-	Engine	15-20%
-	Generator	90%

Calculated Power Output:

-	Peak	27-36 kW
-	Average	19-25 kW

B. 1. 2 Cost of The First Plant:

Based on the costs of raw materials and components, the following will be the estimated cost of the various sub-systems and the total system.

		$
Concentrator @ $ 400/m^2 for 400 m^2	:	160,000
Receiver	:	20,000
Engine/Generator	:	25,000
Controls/Instruments	:	100,000
Balance of Plant	:	95,000
Total	:	400,000

Thus the installed cost of the present system will be of the order of $ 20,000/kW$_e$.

B. 2 Future Projections:

A large amount of work has been carried out by economists, scientists and engineers to predict the future costs of "Solar Thermal Power Generation Systems" based on Scale of manufacture, status of technology, labour content and other related factors. Figure 1 shows the cost projections for concentrators/m^2 of surface against annual production levels. It may be noted that at a production level of 1000 concentrators per year, the cost is of the order of $ 150/m^2 as against the present cost of $400/m^2. Similarly, Figures 2 and 3 indicate the projected costs of receiver and energy conversion sub-systems in $/kW$_e$, the respective figures being of the order of $ 40 and $ 300 respectively. The projected costs of different sub-systems indicate that the installed cost of a solar thermal power generation system, depending on its capacity and the level of production can be of the order of $ 2000/kW$_e$.

B. 3 Analysis of The Specific System:

The hardware involved in a solar power generation system are such that the cost of materials is about 30-35% of the total cost, while the labour content is to the extent of 65-70%. Figure 4 illustrates the influence of labour content in relative cost of the system. In India, the labour cost is considerably cheaper and, therefore, at lower levels of production, the installed cost/kW$_e$ will be much lower in India than in developed countries like the USA, West Germany etc. At higher levels of production, due to automation and related factors, the influence of labour cost gets diluted and the cost of production becomes identical.

The system selected for implementation includes concentrators, receivers, a steam engine, a generator and required controls. All the components are reliable and compatible with the available technology. The cost of the power sub-system is presently of the order of $ 400/kW$_e$, while for higher level of production at 1000 nos. per year, the cost is expected to be of the order of $ 150/kW$_e$ (Fig. 5). Finally, Figure 6 shows the corelation between the plant cost and production volume. The present cost of the proposed system is $ 20,000/kW$_e$ (first plant cost) while for a level of production of 1000/year, it would be $ 5000/kW$_e$, the figure for 90,000/year production level being $2000/kW$_e$.

Following Table shows the projected cost of systems similar to the present one at a production level of 1000/year.

		$
Concentrator @ $ 150/m^2 for 400 m^2	=	60,000
Receivers @ $ 35 for 400 m^2 collector area	=	13,500

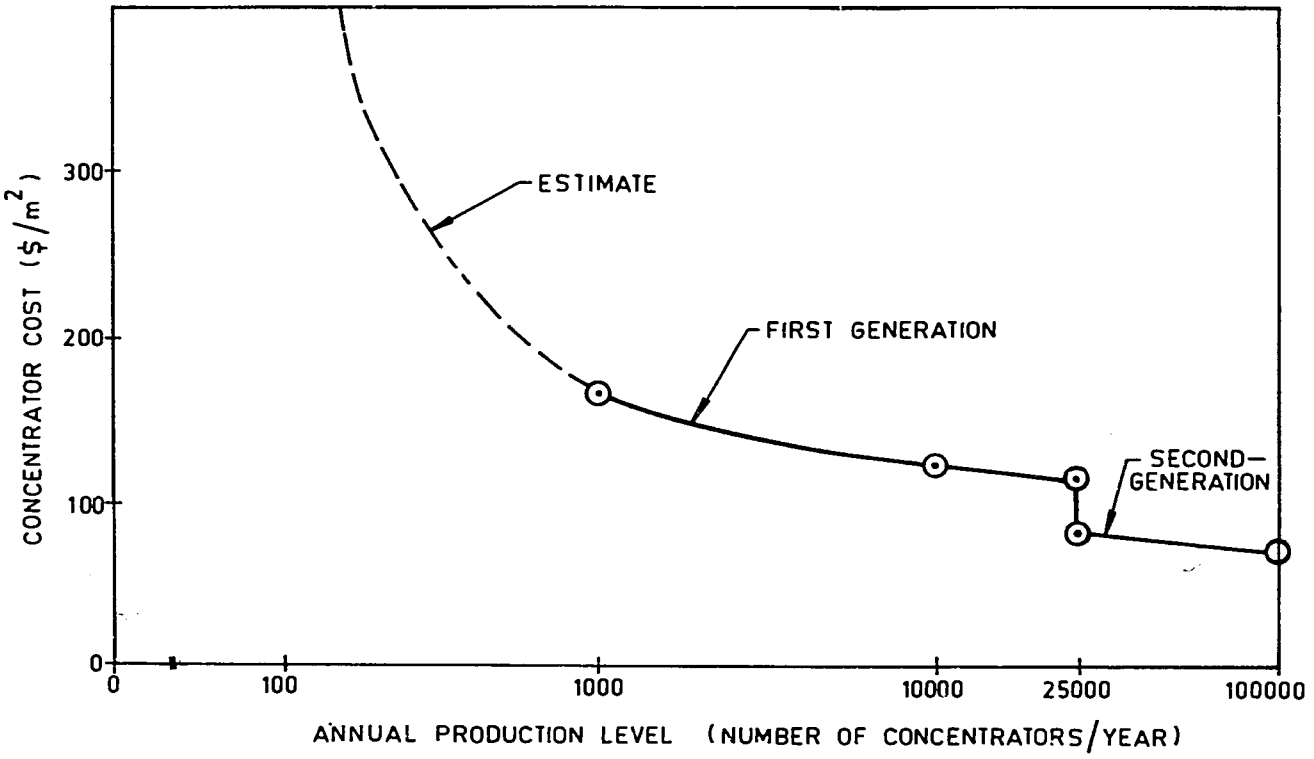


Fig. 1 FIRST AND SECOND GENERATION CONCENTRATOR COST ESTIMATES – VERSUS PRODUCTION LEVEL

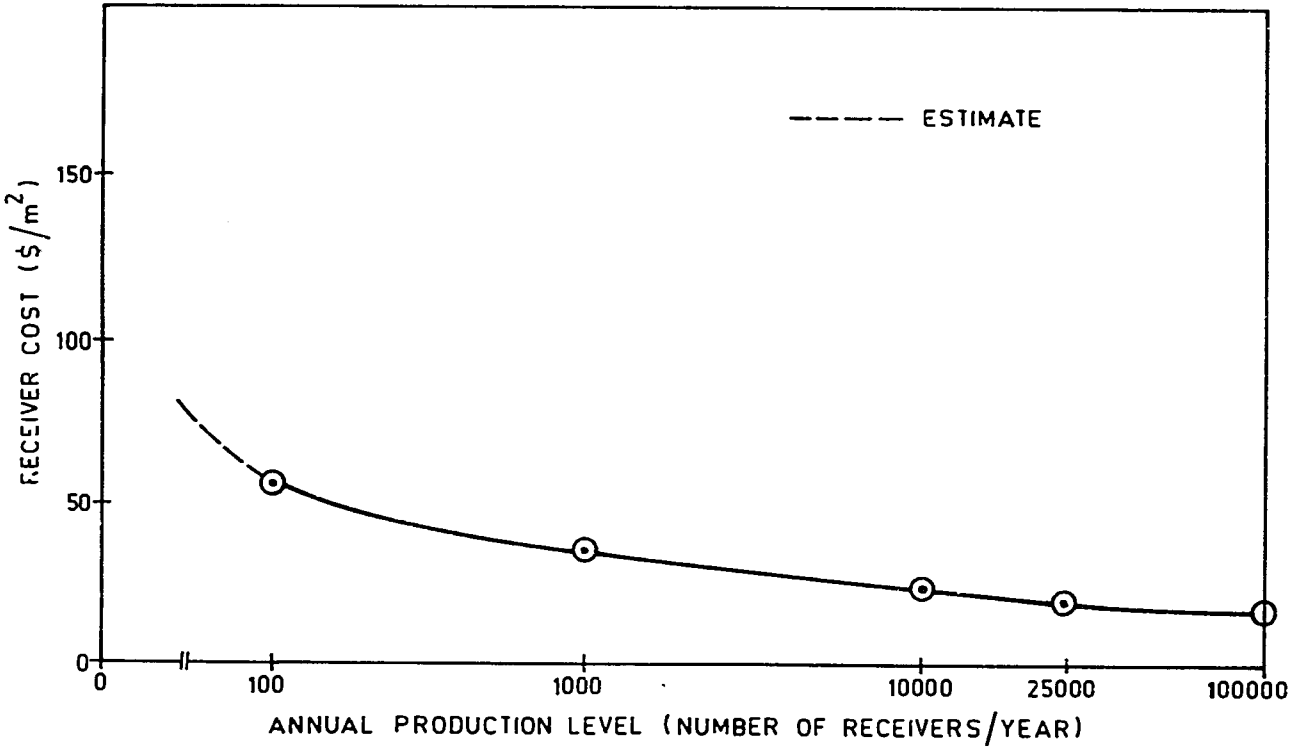


Fig. 2 RECEIVER COST ESTIMATES VERSUS PRODUCTION LEVEL

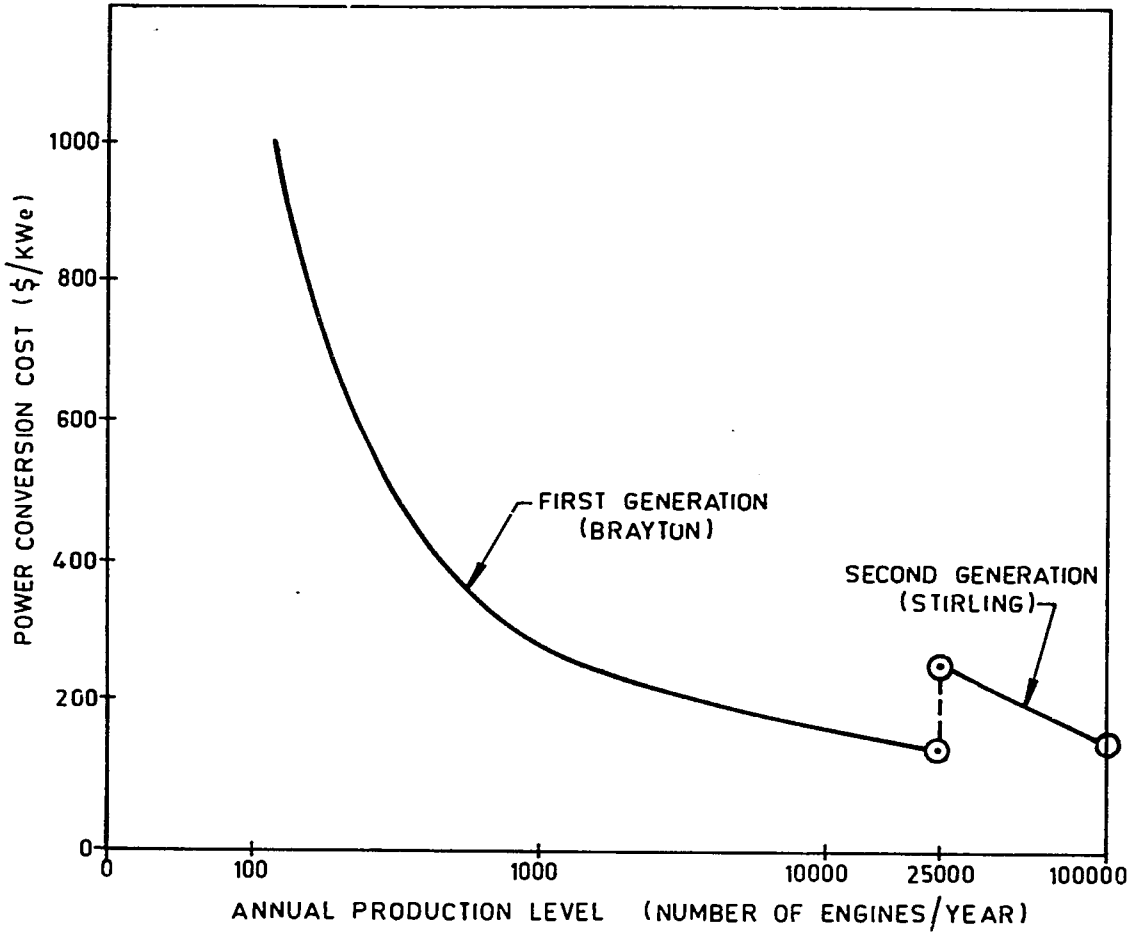


Fig. 3 SUBATMOSPHERIC BRAYTON ENGINE & STIRLING ENGINE POWER CONVERSION—COST ESTIMATES

MATERIAL COSTS EQUAL

LABOUR BASIS: \$ 8/HR X 8 = \$ 64/DAY U.S.

Rs. 20/DAY X $\frac{1}{9}$ = \$ 2.20/DAY U.S.

$\frac{64}{2.2} \cong 30$ USE 10 TO ACCOUNT FOR INDIRECTS

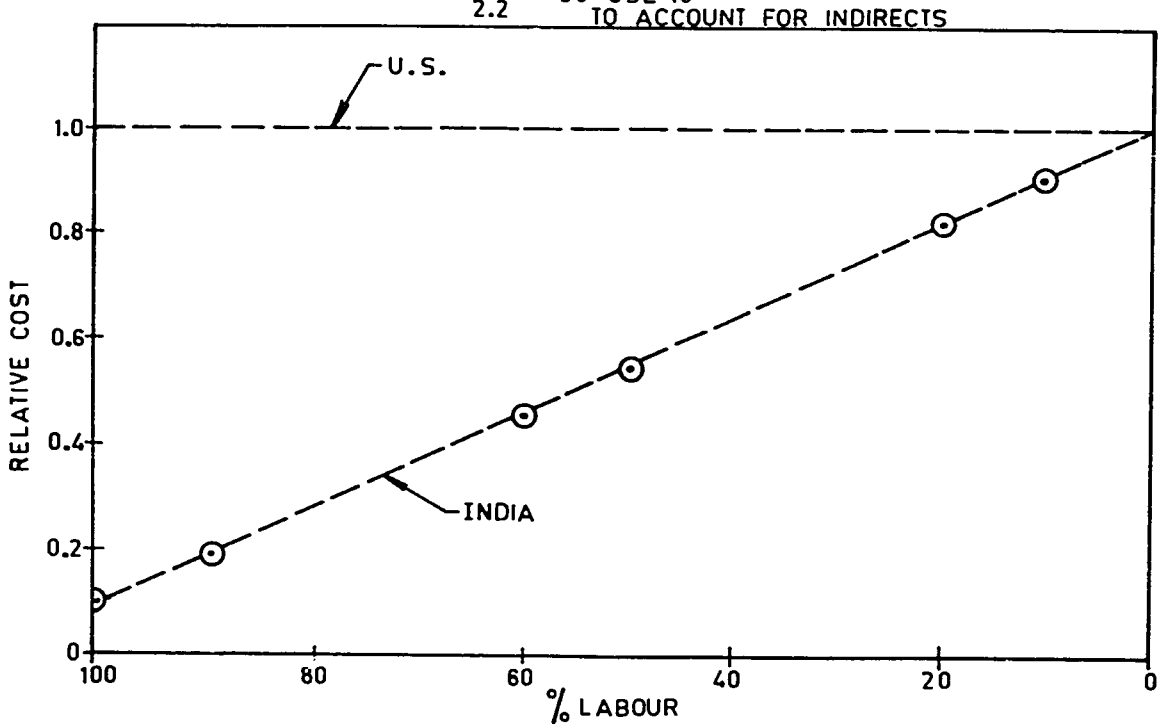


Fig. 4 RELATIVE PROJECT COSTS

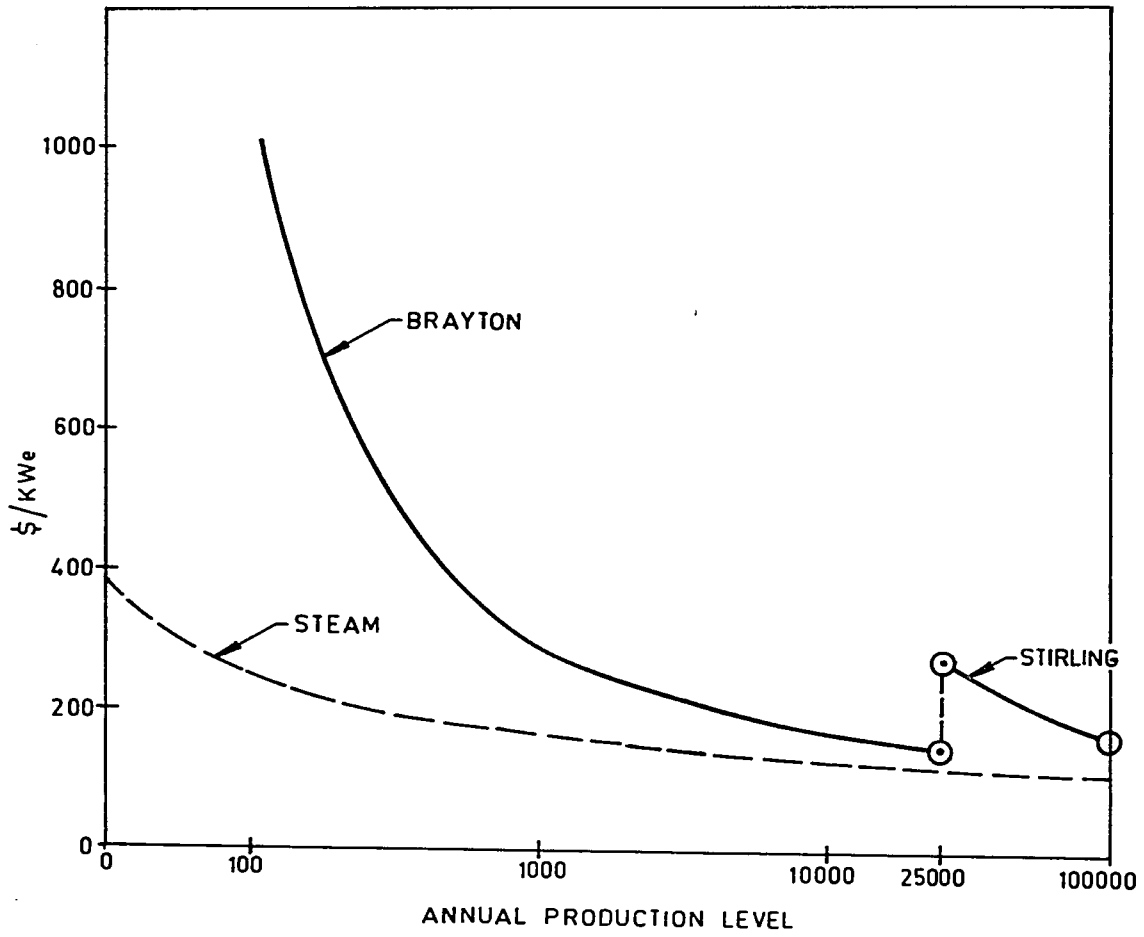


Fig. 5 POWER CONVERSION COSTS

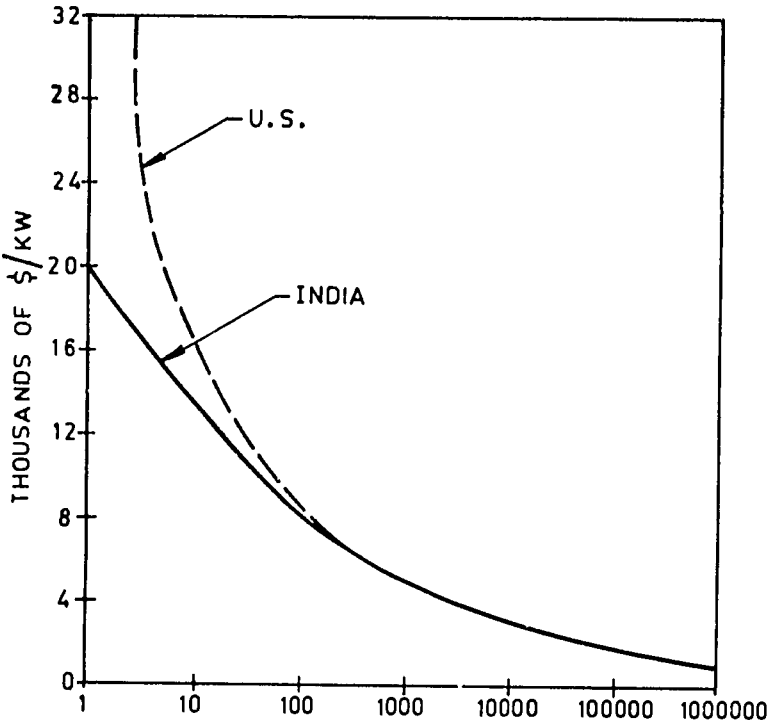


Fig. 6 PLANT COST Vs PRODUCTION VOLUME

		$
Engine @ $ 15 to convert energy from 400 m^2 collector area	=	6,000
Controls	=	20,000
Others	=	10,000
Total	=	109,500 for 20 kW_e

Installed cost/kW_e = $\frac{109,500}{20}$ = 5000/kW_e

As shown in Fig. 6 this cost will reduce further with increased level of production, approaching $ 2000/kW_e at a production level of 90,000 - 100,000 per year.

B. 4 Benefit from Similar Systems Based On Target Cost Per kW_e.

The priority energy need for most of the rural areas is for irrigation. It has, therefore, been considered worthwhile to make a preliminary assessment of the impact of such systems on the rural communities taking irrigational needs into account. Brief calculations follow:

Water required for raising 2 crops a year = 50,000 lit/hect/day (plus rainfall)

Output from a good pump (under a head of 7m approx) = 40,000 lit/HP

Total acreage covered by a 25 HP system = $\frac{25 \times 40000}{50,000}$ hectares

= 20 hectare = 50 acres

In India there are thousands of marginal and small farmers whose average holding is of the order of 1.2 hectares. Therefore a 25 HP system will be able to fulfill the irrigational requirements of 16-17 farmers (average), who do not presently have any access to energy systems.

Based on the information available from villagers, the cost of land is of the following order:

Dry Land	:	$ 250 per acre
Wet Land	:	$ 1000 per acre

The irrigation facilities available through installation of solar thermal power generation systems will thus improve the property value of the poor community by about \$ 750/acre of land. Based on the target cost of \$ 2000/kW_e for a 20 kW_e system, the investment per kW_e is equivalent to the increase in property value/acre of land.

Additionally, due to irrigation, the productivity per acre/year will be of the order of \$ 400,, the net increase in productivity being \$ 20,000/year from a total area of 50 acres. The system would thus contribute to elevate the economic status of the poorer community through increase in land value as well as productivity.

C. SOLAR PHOTOVOLTAIC POWER GENERATION

C.1 Details of System for Salojipally Village:

Solar Cells are used to convert solar energy directly to electric power. At present, the commercially available photovoltaic devices are silicon solar cells and arrays. The solar photovoltaic power generation system for Salojipally Village will be of $7kW_e$ (peak) capacity, about 5 kW to be supplied by JPL and the balance to be provided by CEL from its batch production at Sahibabad. The photovoltaic arrays will have balance of system such as storage, power conditioner, instrumentation, controls and loads such as motor-pump sets to permit evaluation of performance and to supply power to the selected load points.

C.2 Future Projections:

Before touching upon the future projections on solar photovoltaic power generation it is worthwhile to mention here the sub-systems that comprise the generation system. They are:

- Photovoltaic arrays
- Power conditioning equipment
- Storage Equipment

Solar energy prices are normally quoted in dollars per peak watt. The peak wattage is the maximum power generating capacity of a solar energy system under standard (Air Mass 1) sunlight conditions of 100 mW/cm^2 incident radiation at 28^oC. Figure 7 shows the levels of price of photovoltaic panels on this basis and a projection of future costs. The high rate of reduction in solar module prices have got moderated during the last 3-4 years primarily because the envisaged levels of production could not be achieved. It is foreseen that steady progress in cost reduction will now be possible based on increased volume of production and continued technological improvements. Module costs under $ 1 per watt are projected in 1990.

Solar array support and batteries represent a reasonable proportion of system costs, but this is increasing with reduced module prices. Significant reduction in costs for these are not anticipated until the fall in module prices puts pressure on the battery element. Thereafter steady progress is predicated and improving meteorological and field data may safely reduce the amount of battery storage built into systems. Consequently, the total solar photovoltaic system costs are expected to reduce by about one order of magnitude by 1990; in round numbers from 20 (in 1978) to 2 dollar per peak watt. The system cost is thus projected to 2000 dollars per peak kW by 1990.

Before making price comparison with other power generation systems it is necessary to exchange the dollars per peak watt unit for dollars per continuous watt. The continuous output is the output which the solar/battery system can deliver continuously for a full 24 hours/day. Since the sun does

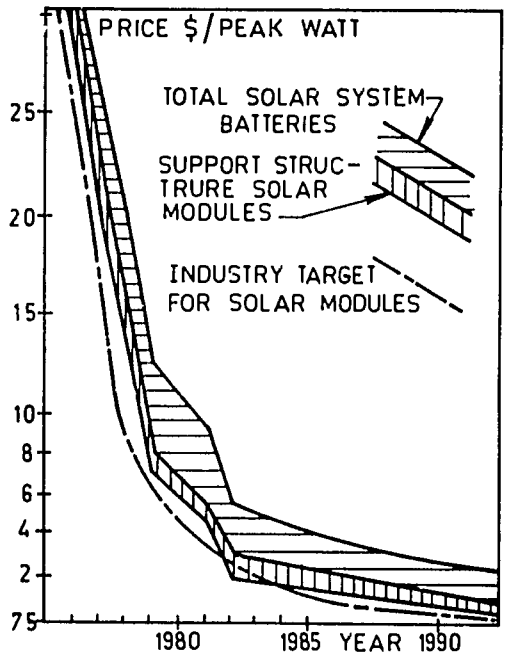


Fig. 7 SOLAR SYSTEM PRICE PROJECTION

not shine all day, the size of solar array required to deliver 1 continuous watt is of the order of 3.1/2 peak watts and varies depending on location. For this note a peak capacity of 3.1/2 watts has been considered for 1 watt continuous output. The price comparison for power generation will have to take into account both the initial cost of installation and the annual cost of operation. For comparison purposes the site has been assumed 50 Km from the nearest grid. Fuel, labour rates have been taken from local sources and the material cost, maintenance etc. from published catalogues. Comparison has been made between diesel generator, thermo-electric generators and solar systems.

Figure 8 displays the results of these comparisons presented in two ways. Firstly, the total cash outlay is shown for a typical installation of 200 watts. This illustrates that the initial cost is about twice as high for solar installations. The cost of operating the system is then added on annually as is the cost of batteries and eventually the generator also. It can be seen that in this instance, a solar installation would breakeven in about 3 years, after which it would provide increasing savings over other generators. The effects of inflation are excluded but would tend to favour solar systems where the major outlay is the initial cost, and annual costs are small.

C.3 Analysis of The Specific System:

The present system will have a capacity of 7kW (peak) sufficient to operate several pumps upto a total power output of 6 kW_e. The estimated cost of this system will be of the following order:

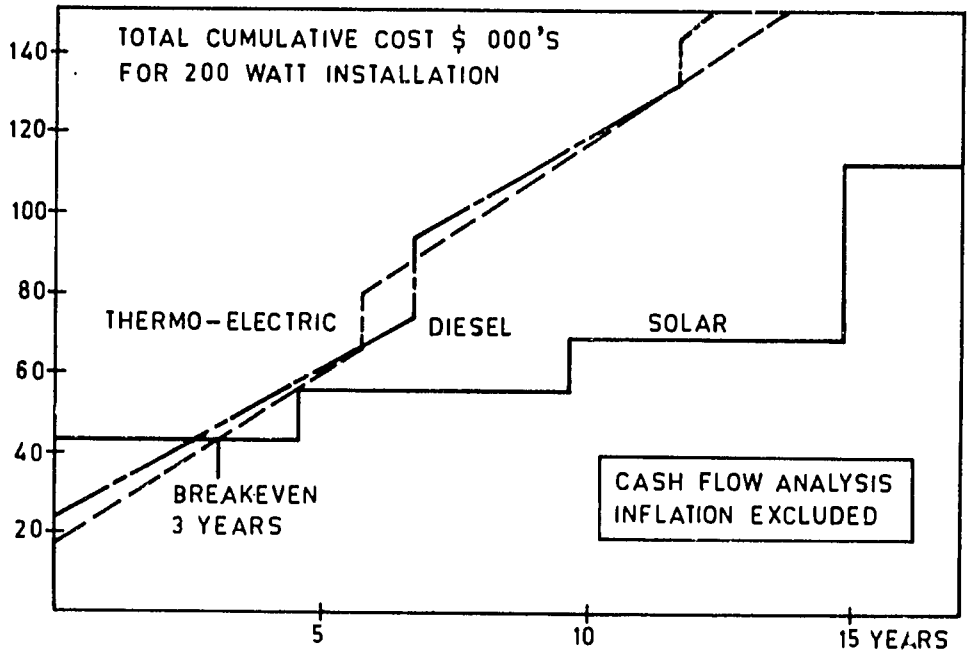
		$
Photovoltaic arrays @ $ 12 per peak watt	:	84,000
Balance of systems	:	33,600
Instruments, Controls	:	8,400
Others	:	14,000
Total	:	140,000

Cost per kW_e peak : $ 20,000

With the predicted cost of 2 dollar/peak watt including balance of systems, the cost is expected to be of the order of 2000 dollars per kW which is similar to the projected costs of solar thermal power generation systems.

C.4 Benefits From Similar Systems Based On Target Cost Per kW_e:

As indicated under C.2, based on the target cost of 1990, solar photovoltaic systems are expected to be more cost-effective than both diesel and thermo-electric generators. As far as electric power from central power generation



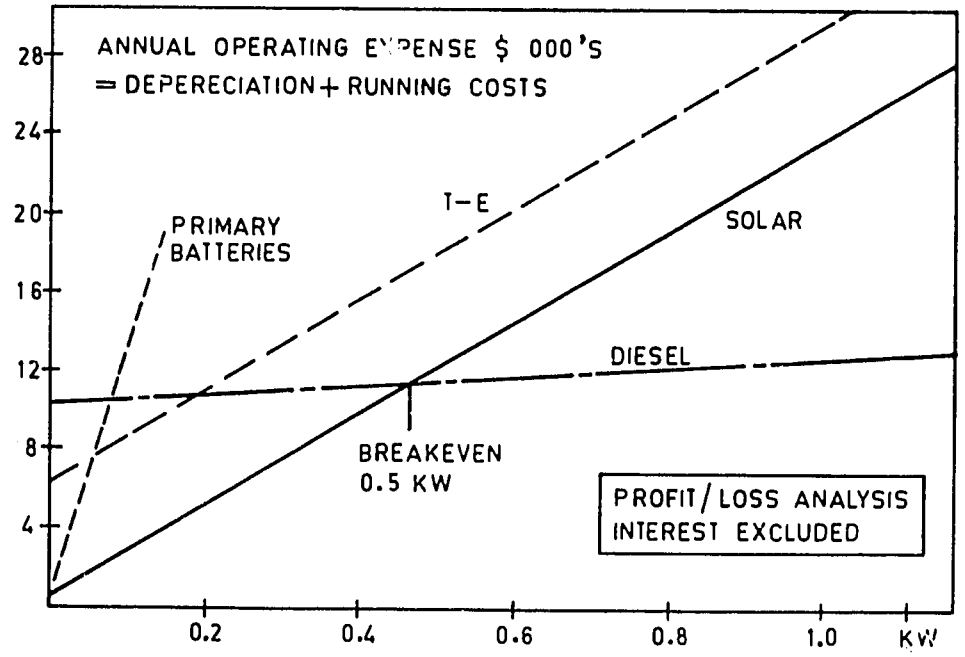


Fig. 8 COMPARATIVE ANALYSIS OF DIFFERENT GENERATOR - TYPES FOR EXAMPLE LOCATION RIYADH

plants are concerned, the cost-effectiveness will depend primarily on the distance of transmission, distribution and load factors. The monetary benefits from this specific project has been delat with under Chapter E of this report.

D. AVAILABLE ALTERNATIVES

The alternative energy systems for performing similar duties are:

- Coal Based Central Power Plants
- Oil Based Central Power Plants or Decentralised Energy Systems such as Diesel Engines.
- Nuclear Power Plants

The proven and inferred reserves of coal in India is sufficient to last for about 50 years. The deposits, however, have high ash content and the lower availability of central power plants can be attributed to this factor to a large extent. Additionally, the cost of transmitting and distributing small blocks of power is very high and according to an estimate the cost per kilometer is of the order of $ 11,000. Assuming a distance of 15 km, the cost of reaching 1 kW_e power is of the order of $165,000.

As far as oil is concerned, India imports 70% of its requirements which is affecting its 'Balance of Payments' position adversely. The Government of India has decided to encourage reduction in oil consumption to the maximum extent and, therefore, utilisation of oil based centralised or decentralised systems have no future potential. Similarly, nuclear plants are cost intensive and the high cost of transmission and distribution will continue to be a limiting factor in reaching small blocks of power with a degree of reliability to a large number of villages.

From these points of view, decentralised 'Solar Power Generation Systems' either photovoltaic or solar thermal, have a high degree of promise considering the target cpsts and also due to the fact that the materials, technology and appropriate labour will be available indigenously.

E. METHODOLOGY FOR ECONOMIC ANALYSIS FOR SALOJIPALLY PROJECT AND PRELIMINARY SOCIO-ECONOMIC BENEFIT

E.1 Methodology For Economic Analysis:

The analysis to assess the impact of the envisaged system on the economic status of the selected community is being carried out in two steps.

I. Acquisition of Present-Day Base Line Data For The Following:

i) Total cultivable land in the village
ii) Total area under cultivation at present
iii) Total quantity and types of crops raised in a year
iv) Area of dry land, cultivable but cultivation not done due to lack of irrigation facility.
v) Total productivity of the village
vi) Per capita income
vii) Distribution of village wealth among the population
viii) Present health problems due to use of water from open wells
ix) Present level of education and occupation pattern.

The aforementioned study will be carried out jointly with the local Administration (District Collector) and by involving local agricultural officer and social scientist who have intimate knowledge of the methods of local cultivation, irrigation and social behavioural pattern. These base line data will be analysed to assess the present economic status of the community.

II. After the system is installed in the village, each of the factors considered earlier will be looked into again to obtain data to establish the post-project implementation economic status.

Comparison of the former and later analysis is expected to provide information on the impact of the system on the community.

E.2 Preliminary Economic Analysis:

a) Land Under Irrigation at Present:

Presently, only a portion of the cultivable land in the selected village is cultivated. Irrigation for these lands is carried out from monsoon fed tanks and varies substantially from year to year depending on the rainfall.

During rainy season, about 50 acres (20 hectares) of land is irrigated utilising the water from the tank. Water from the same tank is also used to irrigate the land in closer proximity during other periods of the year. An indication of the land under irrigation beyond rainy season is given hereunder:

Year	Acreage Irrigated
1979	8
1980	10
1981	nil (drought year)
1982	20 (excellent monsoon)

All other cultivable land available in the village are dry, the output from them being practically zero.

b) Area Proposed To Be Irrigated Through The Envisaged System:

Under the present project, it is proposed to fulfill the irrigational energy needs for irrigating the dry land in closer proximity to the village. The system capacity will be adequate to provide about 25 kW - 27 kW (peak) power for irrigation purposes, which will drive atleast 8 nos of 3 kW motor-pump sets. Based on the hydrological survey carried out, each pump will be capable of irrigating about 4 acres of dry land, the total acreage being 32 acres. This will help improve the agricultural productivity and occupation of more than 40% of the families in the village.

E. 3. Expected Benefit Through Additional Irrigation:

With the availability of irrigational facility, the farmers are expected to raise cash crops like paddy, sugar cane etc. The income from such crop is of the order of Rs. 4000 per acre per year, the total income from 32 acres being of the order of Rs. 128,00 per year. The envisaged system will thus elevate the productivity and economic status of more than 40% of the community which is presently not producing anything because of the non-availability of energy resources.

E. 4. Additional Benefits:

Additionally, the system will provide safe drinking water facility and street lighting and a 'Community Centre' in the village. These are expected to help improve the health condition, education and awareness level of the community. It is indeed not possible to quantify such benefits in terms of Rupees, but an attempt will be made to estimate the quantum of improvement during Step II of 'Economic Analysis' activity.

F. CONCLUSIONS

From the foregoing it may be concluded that the cost of the presently envisaged first prototype is reasonable and consistent with the future cost goals. The target costs of \$ 5000/kW_e and \$ 2000/kW_e for a level of production of 1000 and 90,000-100,000 respectively per year for solar thermal system are realistic. The same applies to solar photovoltaic. The systems similar to the envisaged one and the upgraded ones are also consistent with the present and future energy situations in terms of cost and availability. Finally implementation of such decentralised energy systems will help improve the economic status of a large number of small and marginal farmers through improvement of their land value and increasing the productivity two fold.

Finally it will not be out of place to quote from a seminar proceedings on 'Industrial Applications for Solar Energy'. 'As for irrigation by Solar Pumps; from the present trends of development, it appears that by 1985, solar pump will become competitive and be able to provide pumping requirements for irrigation and village water supply. Thus 150×10^9 units of energy required (Table-4, P. 312) by 1990 for pump sets by the entire rural India, could be also met by solar energy. This costs the conventional methods about Rs. 150,000 crores for distribution of 30,000 MW power required to run about 560,000 pumpsets (@ 10 pumpsets/village) in rural India. It is going to cost definitely much less amount for solar pump by 1990, and no running cost.

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7) Wolfe, PR, The Developing Role of Photovoltaic Generation, International Conference on Future Energy Concepts, 30 January-1 February, 1979, PP 26-29.

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APPENDIX III

SUMMARY OF ACTIVITIES CARRIED OUT BY ENGINEERS OF BHEL AT JPL

1. Mr SK Kaila

Mr SK Kaila stayed at JPL from 3.12.1981 to 27.1.1982 with the objective of designing a concentrator for the solar power generation project to be installed at Salojipally village. The following activities were carried out:

- Discussions on the design details of the 8.5 M diameter concentrator designed in India.
- Development of a concept of the concentrator suitable to Indian fabrication and latitude conditions.
- Optical design of the concentrator (facet characteristics, radius of curvature of facets, flux distribution)
- Facet design
- Experience in the facet fabrication
- Study of facet testing set up
- Study of mirror alignment set up

The following are the specifications of the concentrator design (preliminary)

Insolation level	:	Design point - 0.800 kw/m^2 Minimum- 0.550 kw/m^2
Projected area of the reflective surface	:	45-50 M^2
Focal length to Aperture Ratio (F/D)	:	0.6
Diameter	:	9.0 M
Reflectivity of mirrors	:	0.92 - 0.94 (Initial)
Thermal output of the concentrator (Ref; system design)	:	32.0 kW
Azimuth travel range	:	$\pm 110^o$
Elevation travel range	:	-15° to 105°

Mirror surface slope	:	0.5 m.rad
Structure slope error	:	3 m.rad
Tracking error	:	1.76 m.rad

2. Mr LM Siddique Ahmed

The objective of visit of the concerned engineer to JPL, USA from 3.12.1981 to 27.1.1982 was:

(a) To design a low cost steam 'Rankine' solar receiver to be manufactured in India by scaling down the large JPL receiver

(b) Using the analytical method developed by Garrett Airesearch Corporation, USA and JPL

(c) Using the materials and manufacturing technology already experimented with at JPL

The design conditions for the receiver were:

Solar Input	=	32 KW(TH)
Steam Flow Rate	=	32.6 kg/hr
Steam Outlet Temp.	=	$500^{o}C$
Water Inlet Temp.	=	$95^{o}C$
Water Inlet Pressure	=	70 kgf/cm^2
Pressure Drop	=	7 kgf/cm^2

During the stay at JPL, the concerned engineer completed the preliminary design analysis of the receiver using Garrett Airesearch Corporation/JPL, Computer Programme. The preliminary drawing of the receiver was also completed. Further, with the objective of carrying out detailed design analysis in future, the basic computer programme of receiver design was also obtained. This basic computer programme will be developed further and will be used for receiver design. The preliminary design dimensions arrived at JPL are the following:

. Cavity diameter	=	305 mm
. Cavity length	=	445 mm
. Overall dimension		
diameter	=	485 mm
length	=	580 mm
. Weight	=	60 kg

.	Aperture diameter	=	225 - 250 mm
.	Pressure drop	=	3 kgf/cm^2
.	Tube size	=	9.5 mm OD x 16 Gauge
.	Tube material	=	Stainless steel - 347
.	Back Reflector plate	=	RA 330 Nickel Steel alloy
.	Aperture plate	=	C.S. Graphite

3. Mr UB Sahay

Mr UB Sahay visited Jet Propulsion Laboratory, USA and worked with Mr Joe Newnham, Group Supervisor (Instrumentation Section) from 6.12.81 to 27.1.1982 on the pre-assigned task of Instrumentation and Control system. Based on the drive requirement, tracking accuracy and simple software control, the microprocessor based d.c. servo-tracking system has been designed. The block diagram illustrating the function of various components in the tracking system is included in this report.

The various electric generator classes have been considered and system configuration corresponding to each generator class have been studied. Performance of various systems using these configurations, with and without battery back up, have been analysed. Transient conditions, due to step changes in solar insolation and electric load demand have also been considered. Based on all factors, an AC-DC-AC generation system is selected and designed. A block diagram of the system is included in this report.

The complete steam temperature control loop has been designed to control and ensure that steam required for the engine is delivered at a prescribed temperature. The designed loop is shown in the report. The measurement scheme of the plant has been designed to measure various parameters to evaluate the system efficiency. The 'Data Logger' with microprocessor control has been selected. Special instrumentation has been provided for the receiver. The measurement scheme and the block diagram of the data logging system is included in the report.

Complete specification of various components,of each loop has been worked out. The list of materials required for each loop has been prepared for procurement.

4. Mr GP Reddy

The concerned engineer was at JPL, Pasadena, California USA from 3.12.1981 to 27.1.1982 and following tasks were accomplished.

a) Indian Base Line Design:

Detailed design carried out in India for 8.5 M diameter parabolic solar concentrator was discussed with JPL engineers. This design was similar to the JPL test bed collector with few modifications. It was agreed that the Indian design is having a very rigid structure and, for commercial concentrators, a lighter structure is sufficient.

It was decided to study the alternative design concepts of conical and flat type solar concentrators. JPL was in possession of design data for heliostats that were developed earlier. Since the flat configuration is more conservative than the conical, the preliminary design for the flat configuration was taken up.

b) Preliminary Design

Preliminary collector concept consists of 14 radial beams connected to the central main beam and 9 concentric rings mounted on the radial beams with small spacers. The receiver is mounted on the collector with tripod, 120° apart. The collector is mounted on a cylindrical steel column of 500 mm diameter with a slot in the structure for clearing the pedestal during operation.

c) Loads

Loads that are acting on the structure due to self weight, facet weight, receiver weight and wind have been calculated for the various positions of the collector i.e., when the collector is vertical, horizontal and at an inclination of 30° to the horizontal.

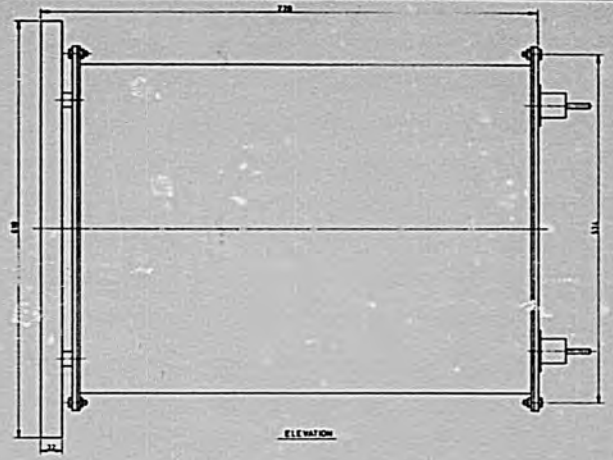
d) Analysis

NASTRAN program, available with JPL, was run for the structural analysis of the collector and the analysis results were obtained for the three positions of the collector.

e) Drives

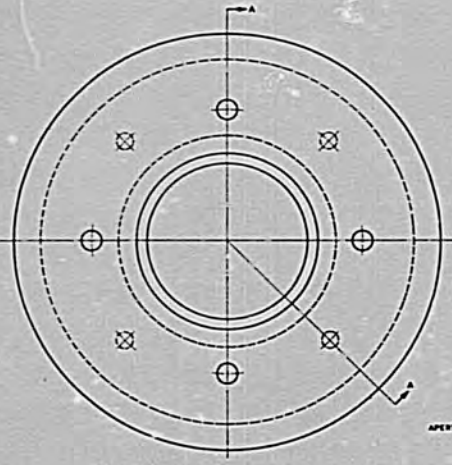
Limited information available on the drive systems, adopted for various heliostats developed in the USA were studied and one particular drive system concept with screw jack for the elevation travel and harmonic drive for azimuth travel was selected for the Indian design.

THIRD ANGLE PROJECTION | ALL DIMENSIONS ARE IN mm

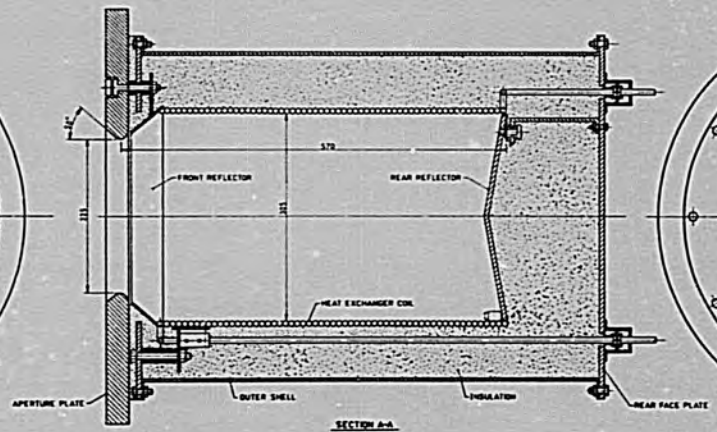


ELEVATION

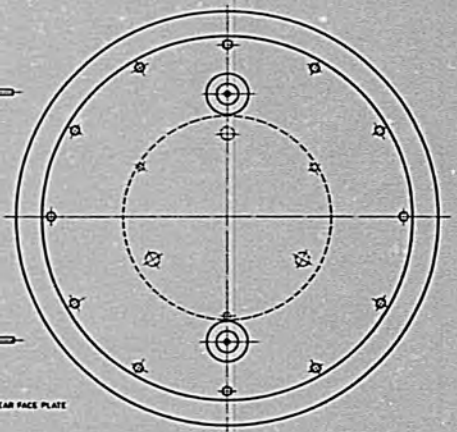
NO.	ITEM	SIZE	MATERIAL
1	HEAT EXCHANGER COIL LENGTH DIAMETER TUBE SIZE	4.00 305 9.5 X 1.6	347 STAINLESS STEEL
2	APERTURE PLATE	32 THK. X 610 Φ	C S GRAPHITE
3	FRONT REFLECTOR	50 X 230	RA 33 NICKLE ALLOY STEEL
4	REAR REFLECTOR	9.5 THK. X 300 Φ	RA 330NICKLE ALLOY STEEL
5	RAMOOL INSULATION	75 TO 150 THK.	
6	OUTER CONTAINMENT SHELL CYLINDRICAL PORTION END PLATES	16 THK. X 605 LG. 6 THK. X 534 Φ	MILD STEEL



END VIEW
APERTURE



SECTION A-A



END VIEW
REAR

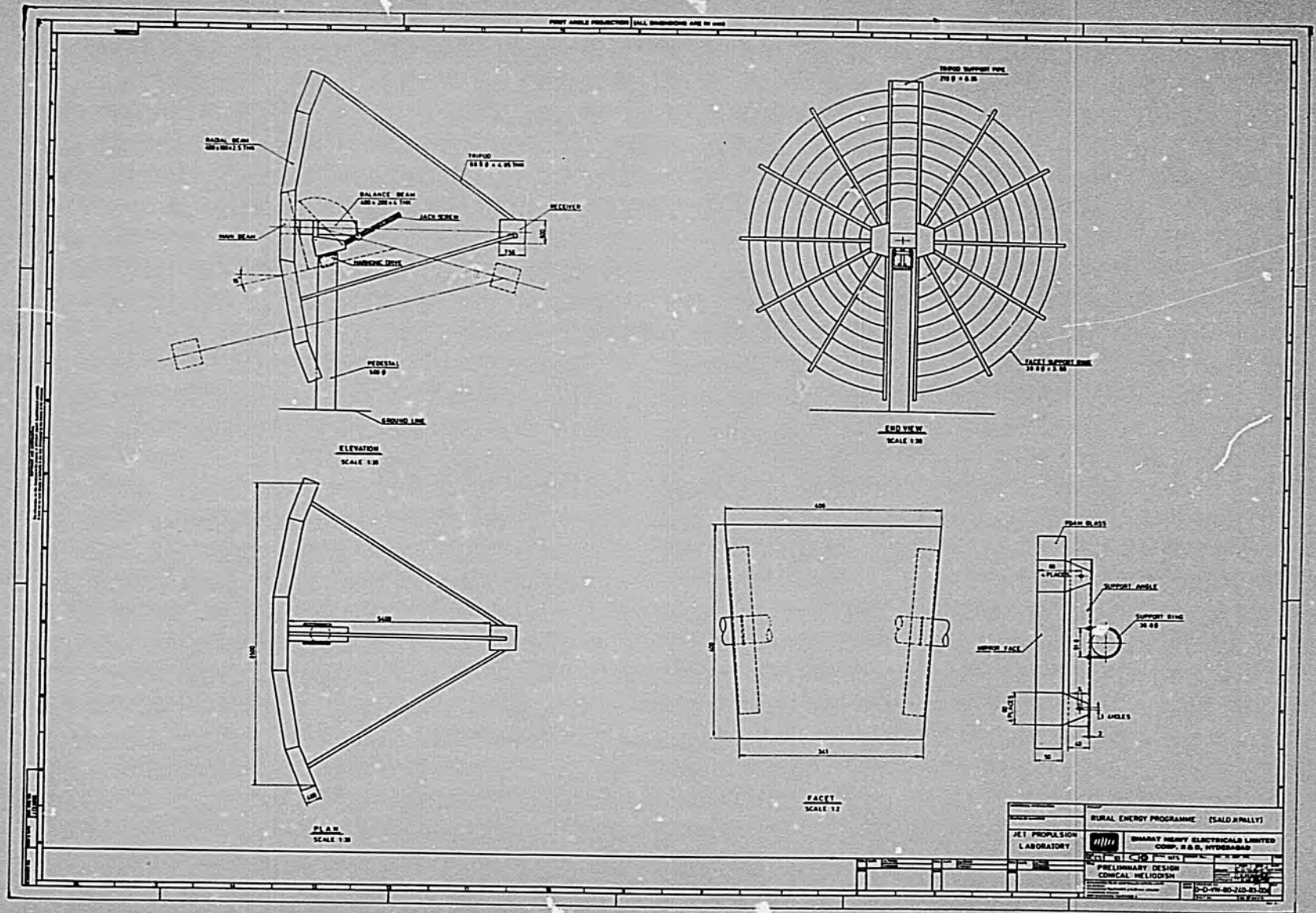
JET PROPULSION LABORATORY

RURAL ENERGY PROGRAMME
(SALLBA PALLY)

BHARAT HEAVY ELECTRICALS LIMITED
CORP. R & D, HYDERABAD

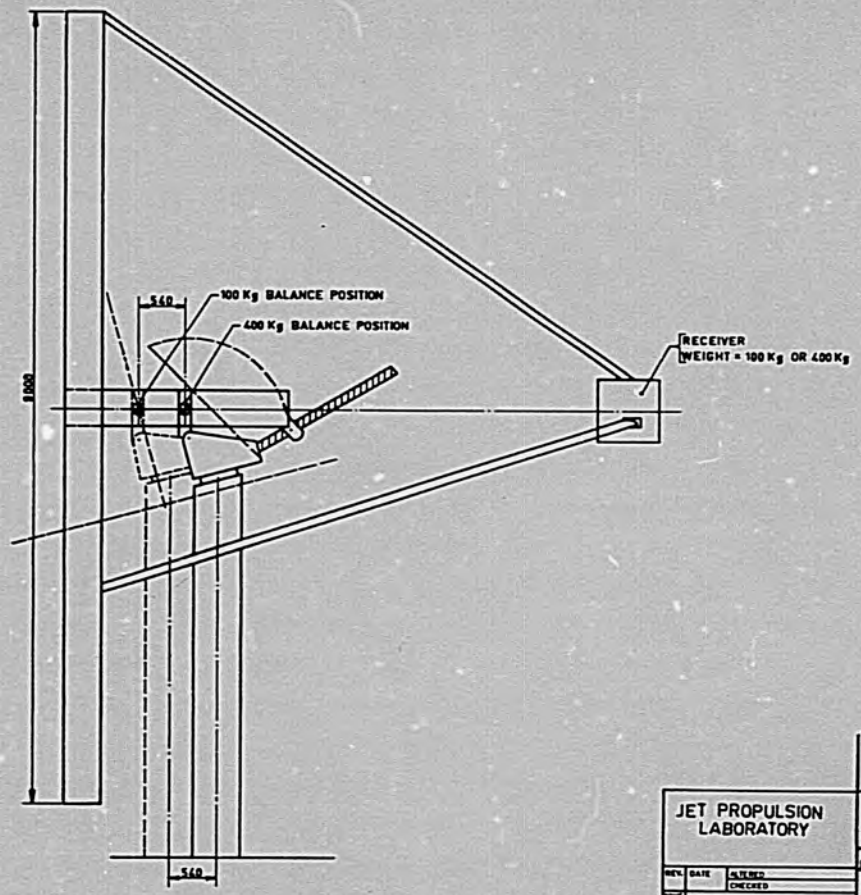
PRELIMINARY DESIGN
STEEM RECEIVER

D-D-TH-80-240-80-02


FIRST ANGLE PROJECTION
ALL DIMENSIONS ARE IN mm
RADIAL BEAM
TRIPOD
BALANCE BEAM
JACK SCREW
RECEIVER
MAIN BEAM
HARMONIC DRIVE
PEDESTAL
GROUND LINE
ELEVATION
SCALE 1:30
TRIPOD SUPPORT PIPE
FACET SUPPORT RING
END VIEW
SCALE 1:30
PLAN
SCALE 1:30
FOAM GLASS
4 PLACES
SUPPORT ANGLE
SUPPORT RING
MIRROR FACE
ANGLES
FACET
SCALE 1:2
RURAL ENERGY PROGRAMME (SALD JPALLY)
JET PROPULSION LABORATORY
BHARAT HEAVY ELECTRICALS LIMITED
CORP. R & D, HYDERABAD
PRELIMINARY DESIGN
CONICAL HELIOSTAT
D-D-PN-80-210-83-001

76

FIRST ANGLE PROJECTION (ALL DIMENSIONS ARE IN mm)



JET PROPULSION LABORATORY

PROJECT: RURAL ENERGY PROGRAMME (SALOJI PALLY)

BHARAT HEAVY ELECTRICALS LIMITED
CORP. R&D, HYDERABAD

DEPT: NCES | CODE: 83 | SCALE: NTS | WEIGHT (Kg) | REF TO ASSY. DWG | ITEM

TITLE: HELIODISH BALANCING FOR ALTERNATE FOCAL POINT EQUIPMENT

DRAWN: S.R.H | CHECKED: T.K.H | APPROVED: T.K.H | DATE: 2-3-81

DIMENSIONS TO BE COMPLETED WITHIN LIMITS.
AS DRAWN
MACHINING TOLERANCE 0.25 mm UNLESS OTHERWISE SHOWN
NON MACHINING TOLERANCE

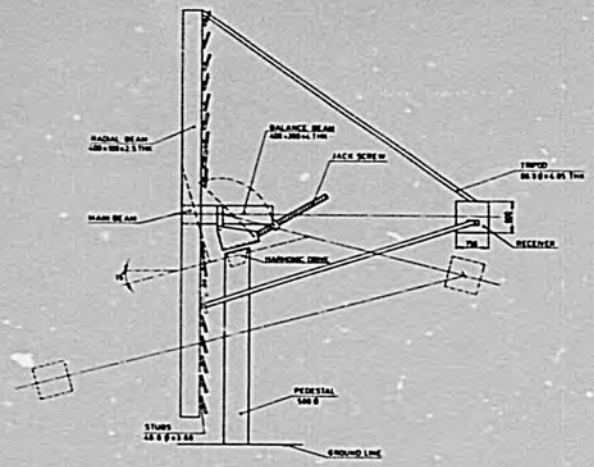
CODE NO.: 2-D-YN-80-240-83-009 | REV.

SHEET NO. | NO. OF SHEETS

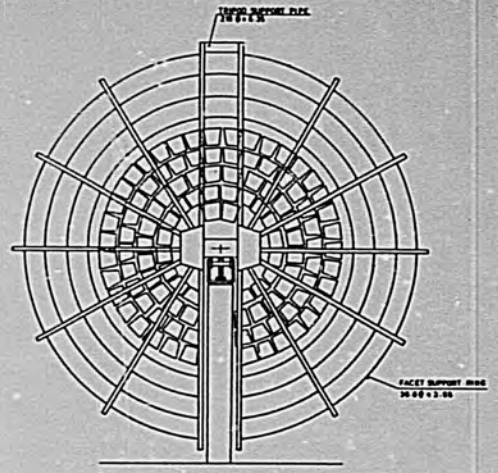
REV | DATE | ALTERED | CHECKED | SIGN

77

FIRST ANGLE PROJECTION (ALL DIMENSIONS ARE IN mm)



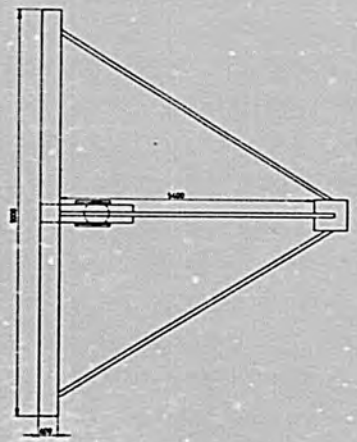
ELEVATION
SCALE 1:30



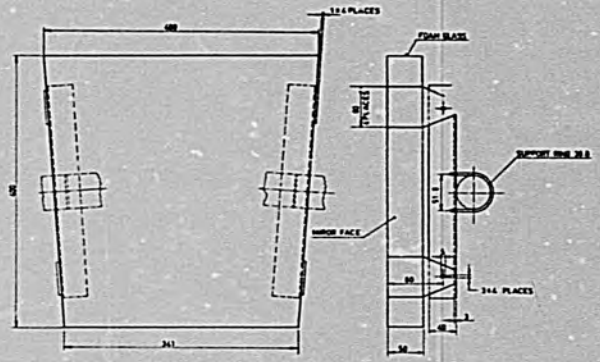
END VIEW
SCALE 1:30

RING NO	RADIUS
I	544
II	1283
III	1913
IV	2629
V	2612
VI	2900
VII	3334
VIII	3900
IX	4200

NUMBER OF FACETS :337



PLAN
SCALE 1:30



FACET
SCALE 1:2

JET PROPULSION LABORATORY	RURAL ENERGY PROGRAMME (SALD.INALLY)	
	BHARAT HEAVY ELECTRICALS LIMITED GOVP, R & D, HYDERABAD	
	PRELIMINARY DESIGN FLAT HELIODISH	D-0-PN-80-210-03-006